The budget approach: A framework for a global transformation toward a low-carbon economy

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(Received 12 October 2009; accepted 22 January 2010; published online 30 June 2010)

Latest research shows that there is only a realistic chance of restricting global warming to 2 °C if a limit is set to the total amount of CO_2 emitted globally between now and 2050 (global carbon dioxide budget). We move this global budget to the forefront of our considerations regarding a new global climate treaty in the post-Copenhagen process. [The authors are members of the "German Advisory Council on Global Change" (WBGU). The WBGU recently published a study on "Solving the climate dilemma: The budget approach." This paper builds on the fundamental ideas and findings of the WBGU study and demonstrates that the budget approach could serve as a cornerstone for an institutional design for a global low-carbon economy.] Combining findings from climate science and economics with fundamental concepts of equity, the "budget approach" provides concrete figures for the emission allowances that are still available to countries, assuming they want to prevent the destabilization of the planet's climate system. Our calculations demonstrate that the time pressure for acting is almost overwhelming—in industrialized countries and also in emerging economies and many developing nations. We suggest several institutional innovations and rules to manage the global and the national CO_2 budgets in a transparent, fair, and flexible way. A sober analysis of the state of the art of climate change science and of the state of multilateral attempts to create an effective climate protection accord so far reveals that the budget approach can provide crucial orientation for the negotiations toward a comprehensive post-Copenhagen climate regime. The approach facilitates at the same time an institutional design for a low-carbon global economy, setting the necessary incentives for decoupling economic growth from the burning of fossil fuels. © *2010 American Institute of Physics.* [doi:10.1063/1.3318695]

I. THE 2 °C-guardrail requires immediate action

In 1995, the German Advisory Council on Global Change (WBGU) suggested that global warming should be limited to a maximum of 2 °C above the preindustrial level in order to prevent dangerous anthropogenic interference with the climate system.[1] However, in the light of more recent research, even a warming of 2 °C cannot be regarded as "safe" but is likely to generate already serious consequences—such as sea-level rise that could render certain island states and densely populated coastal regions uninhabitable. In the "Copenhagen Accord" from December 2009, the importance of limiting global warming to 2 °C or less has been accepted. Many countries have already made the 2 °C-guardrail an official goal of their climate policy. Scientists broadly support this climate protection target.[2,3] A growing number of studies indicate that in a world that has overshot the 2 °C-limit, our civilization—which has developed in the amazingly stable climatic conditions of the Holocene—would face unprecedented challenges.[4–7]

In estimating the level of emission reductions necessary for compliance with the 2 °C-guardrail, various important factors must be considered: These include not only the emitted quantities of CO_2 but also the emissions of other greenhouse gases, the cooling effect of air

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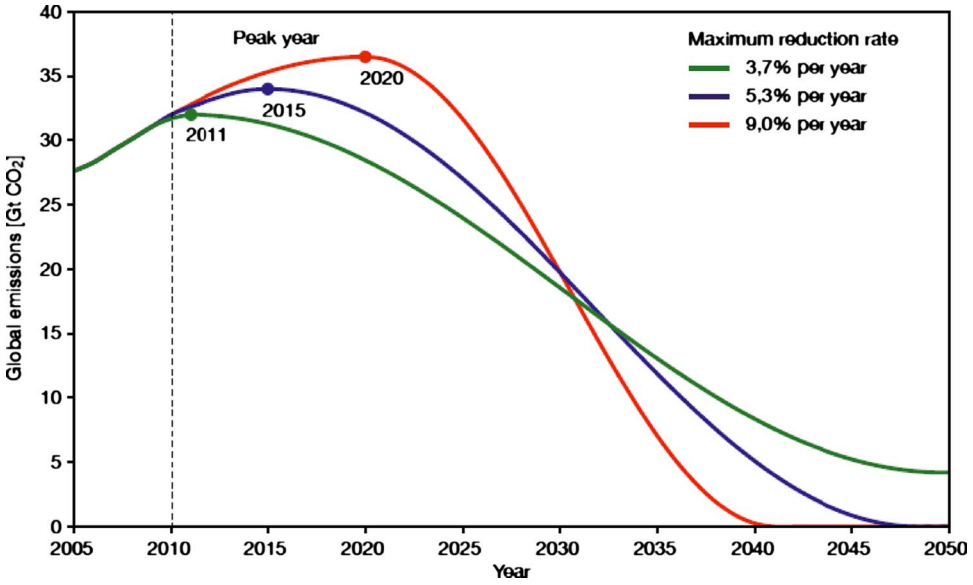

FIG. 1. Examples of global emission pathways for the period of 2010–2050 with global CO_2 emissions capped at 750 Gt during this period. At this level, there is a 67% probability of achieving compliance with the 2 °C-guardrail. The figure shows variants of a global emission trend with different peak years: 2011 (green), 2015 (blue), and 2020 (red). In order to achieve compliance with these curves, annual reduction rates of 3.7% (green), 5.3% (blue), or 9.0% (red) would be required in the early 2030s (relative to 2008) (source: Ref. 10).

pollution (especially sulfur particles), the warming effect of soot particles, the inertia of the climate system (most notably of the oceans), and all the other uncertainties that make a probability analysis the only appropriate assessment. Recent studies show, however, that this complexity can be substantially reduced.[8,9] Due to the remarkable longevity of CO_2 in the atmosphere, this particular substance will become increasingly dominant in the long term in comparison with rather short-lived greenhouse gases and aerosols. For that reason, the trend of atmospheric warming over the course of this century will mainly depend on how much more CO_2 is emitted in total. Specifically, cumulative CO_2 emissions till 2050 will largely determine the extent to which global temperature rise can be kept within the 2 °C-guardrail. In order to achieve this with a probability of 67%, fossil CO_2 emissions till 2050 must be capped at around 750 Gt, with only a small residual amount being emitted post-2050. At current emission rates, however, this CO_2 budget will be exhausted within around 25 years—and even sooner if emissions continue to rise (after a short dip in the wake of the recent economic downturn).

The reversal of the global emission trend must therefore start as soon as possible; in view of the very limited CO_2 budget, any delay will result in almost unachievable reduction requirements. With a reversal of the trend (and the emission peak being passed) by 2010, global emissions would need to fall to 50%–80% below the 1990 baseline by 2050, with further reductions toward zero emissions being achieved thereafter. Even a slight delay in the reversal of the trend, i.e., postponement of the peak year to 2015, would trigger annual global emission reduction requirements of up to 5% (as a fraction of 2008 emissions) (Fig. 1). In other words, the world would then have to meet *annual* emission reduction targets equivalent to those established by the Kyoto Protocol for two full decades! Moreover, this would apply not only to the group of Annex-I countries but the global economy as a whole. Delaying the peak year even further to 2020 could necessitate global emission reduction rates of up to 9% per year—i.e., reductions on an almost inconceivable scale, entailing technological feats and social sacrifices comparable to those of the Allied mobilization during the Second World War. Whatever the details, there is no option but to halt the hitherto unabated rise in CO_2 emissions as quickly as possible and to immediately switch to emission reductions on a global scale thereafter.[11,12]

II. THE INTERNATIONAL CLIMATE POLICY CONTEXT

The current international climate policy context is far from favorable. After the Copenhagen summit and based on the Copenhagen Accord, there is a real risk that the UN Climate Change Conference in Mexico at the end of 2010 will only produce a weak compromise, which cannot prevent dangerous climate change. According to recent analyses, the various national emission reduction pledges submitted so far would almost certainly result in warming the planet by significantly more than 2 °C.[13] The major actors are moving in the right direction but far too slowly.

In the climate-negotiations-as-usual process, the world's countries cling to their usual long-winded approach in which complex interests are weighed up in minute detail. The major polluters lay the responsibility at each other's doors: China and other newly industrializing economies, supported by the least developed countries, point to the high per-capita emissions produced by the industrialized countries and their emission-based economic growth since the Industrial Revolution. By way of contrast, the industrialized countries maintain that China is now the largest emitter of greenhouse gases and that those emissions in the developing regions, especially Asia, will increase substantially in the future. Finally, the EU stresses that the USA's per-capita emissions are twice as high as its own. The Copenhagen climate conference reflected these beggar-my-neighbor strategies, translating into results at the lowest common denominator. The negotiations appear to have all but stalled now. Therefore a transparent and fair concept for international burden sharing is needed.

III. THE BUDGET APPROACH—SOLVING THE CLIMATE DILEMMA

In support of the international climate negotiations, the German Advisory Council on Global Change developed a new approach that derives national emission budgets by determining the total ecologically tolerable quantity of global CO_2 emissions up to the year 2050 and apportioning this in line with fundamental principles of equity (see similar concepts in Refs. 14–16). Based on a simple, transparent, and equitable "climate formula," all countries' reduction commitments and the requisite financial transfers between industrialized and developing countries are established and calculated on a clear and comprehensible basis.

A. Basic principles

We start with the scientific knowledge that in order to keep atmospheric warming below 2 °C, the total amount of anthropogenic CO_2 emitted to the atmosphere must be limited.[8] Therefore, the budget approach rests on a binding cap on the total amount of CO_2 that can be emitted from fossil sources up to 2050 (or an alternative meaningful deadline). This ceiling is an essential prerequisite for ensuring, with a certain level of probability, that the 2 °C-guardrail will not be crossed. In this way, humankind would have a specific and defined amount of emissions available. The allocation of this amount would be subject to negotiations; in particular, it can be broken down into national emission budgets based on equal-per-capita entitlements worldwide.

Proposals for the allocation of emission rights have particularly good prospects of being accepted by the international community if they are viewed as fundamentally equitable by as many stakeholders and affected parties as possible. In this context, we propose that the allocation should be based on three "first principles," namely, the polluter-pays principle, the precautionary principle, and the principle of equality.

In accordance with the *polluter-pays principle*, the industrialized countries have a particular responsibility to cut their greenhouse gas emissions due to their high cumulative emissions in the past. Unless the industrialized countries act according to this responsibility, hardly any global climate treaty will ever be achieved.

In line with the principle of sustainability[17] and based on the 2 °C-guardrail, the *precautionary principle*[18] must be respected; this means that timely action is required to prevent irreversible

damage to present and future generations. The global emission budget as induced by the 2 °C guardrail requires not only the industrialized countries but also the emerging economies and developing countries to adopt a course toward a low-carbon future. "Catch-up" development in Africa, Asia, and Latin America during the 21st century that is based primarily on fossil fuels would gamble with many of humankind's natural life-support systems.

Conversely, the populations of the industrialized countries do not have a natural right to per-capita emissions many times greater than those of the developing countries. The *principle of equality*—which postulates individuals' equal rights, without distinction, to the benefits of the global commons—is recognized by many countries but is not yet enshrined in law. The UN General Assembly (Resolution 43/53, 1989) and the UNFCCC (Ref. 19) acknowledge "that change in the Earth's climate and its adverse effects are a common concern of humankind." From a theory-of-justice perspective, this concern does not permit any differentiation based on national or individual interests.[20] It requires emissions to be allocated in a manner that reflects the interests of the global community and humankind as a whole. The principle of equality does imply that equity in per-capita emissions should be the basis for the allocation of national emission budgets.

Due to the socioeconomic conditions, the global budget allocated on a country-by-country level cannot be utilized entirely without time constraints, as the 2 °C-line can only be held if realistic decarbonization dynamics are taken into full account. First, it takes decades to restructure emission-intensive infrastructures and production processes and to transform consumer behavior, so there is no easy way to reduce global emissions at high speed. Second, global decarbonization must commence as soon as possible, as the best of our current knowledge indicates that any postponement now would necessitate emission reductions at an unattainable rate in the future. Third, at the end of the budget period, i.e., around 2050, a virtually zero-emission economy must have emerged, as the remaining environmental space for the subsequent decades is likely to be very limited: The accumulation of CO_2 in the Earth system by the middle of this century would be just about tolerable, yet the high carbon load would persist for a long time due to the geophysical and biochemical processes and peculiarities involved.

In order to accommodate these constraints, the budget approach must therefore be fleshed out with specific rules.

(1) *Global interim targets.* As an important milestone, it should be stipulated that the global CO_2 emission curve must peak between 2015 and 2020 and decline thereafter (see Fig. 1). As a further milestone it should be stipulated that by 2050 full decarbonization is to be widely accomplished.

(2) *National decarbonization road maps and interim targets.* All countries should pledge to develop and present national strategies to manage their own CO_2 budgets ("decarbonization road maps"). These should be based on realistic evaluations of the national emission reduction potentials as a function of time; their plausibility and operability should be verified by an independent international institution. This would reduce the risk that certain governments would postpone the necessary action indefinitely and leave all burdens to future generations. By allowing high flexibility in the choice of transformation pathways, the strengthening of countries' individual responsibility is coupled with accountability to the international community.

(3) *Interregional flexibility.* The unrestricted and efficient management of national budgets via a global CO_2-emission trading system is highly recommended. As a prerequisite, the national budgets must be declared to be tradable quota. International emission trading allows and encourages a very wide range of bilateral and multilateral transactions. For example, trading not only permits industrialized countries, who have used up almost all of their CO_2 budget, to purchase allowances but also enhances the incentives for countries to reduce their own emissions. Substantial capital flows are generated for the developing countries, and here too incentives are created for emission reductions, as CO_2 budget surpluses can be traded and monetized.

B. Calculating national emission budgets

For the proposed budget approach, the total available global emission budget of CO_2 from fossil sources that allows compliance with the 2 °C-guardrail is calculated for a specific period. This amount is then allocated among the individual countries based on equal cumulative per-capita emissions over a fixed period.

It is then very easy to determine the national budgets because the model only contains *four*—political, i.e., negotiable—parameters: The period for the total budgeting as defined by a *start* year and an *end* year; the *probability* of achieving compliance with the 2 °C-guardrail; and finally, a *demographic reference year* for the national population strengths that form the basis for the concrete allocation figures. We propose that the year 2050 be selected as the end point for the budget period, as there is no doubt that most of the requisite emission reductions will need to have been achieved by that date.

The other three parameters determine the overall budget amount and its relative distribution. They are therefore parameters of the utmost political relevance.

- The *start year* determines the point at which global equitable emission management—in other words, the proposed distribution formula—should come into effect. If the start year is backdated (i.e., a year in the past is defined as the commencement point), the budget to be distributed will include emissions that have already taken place. This inevitably means that countries with high historical per-capita emissions will have a proportionately smaller emission budget available in the future.
- Due to the complexity of the climate system, it is not possible to calculate *precisely* what additional amount of CO_2 can still be absorbed by the Earth's atmosphere without breaching the 2 °C-guardrail. However, with the help of so-called ensemble calculations and using the best simulation models available worldwide as well as sophisticated statistical methodologies, climate science can compute the *probabilities* that a specific total amount of emissions will remain "subcritical" and will thus be compatible with restricting warming to 2 °C. The global budget that is available for distribution can thus be calculated directly on the basis of a political global risk assessment: The higher the probability of compliance with the 2 °C-guardrail that is chosen, the smaller the budget to be spent worldwide over the chosen period must be. It is crucial to note at this point that probabilities of averting damage that fall within the 50%–90%-range—i.e., the range generally discussed in relation to the climate problem—would be considered completely unacceptable in everyday contexts (e.g., with respect to traffic safety, prevention of infectious diseases, etc.)! Unfortunately, global environmental change has progressed too far already for a genuine precautionary policy that satisfies the criteria of common sense.
- The demographic reference year determines the national share of the global budget based on the country's relative demographic weight for the given year. The later the reference year that is chosen, the higher the benefit for countries with rapidly growing populations as their relative demographic weight is steadily increasing and, concomitantly, their relative cumulative-emission share. Instead of accounting for the population figures in a single year, allocation could also be based on the (mean) population weight over a longer period involving projections of trends. The argument in favor of using a fixed reference year is that in countries with high population growth rates, it could serve as an incentive for demographic change since unabated population growth after the reference year would stretch the allocated budget, effectively reducing emissions per capita. This reflects the fact that the absolute amount of cumulative emissions worldwide is limited, so per-capita allowances shrink with a growing global population.

In a broader perspective, the outlined budget approach serves to analyze the low-carbon transformation challenge from the following four angles.

- taking stock with respect to national emission budgets—defining the magnitude of the transformation challenge;
- developing the foundations for a new global climate architecture—simplifying the negotiation process and focusing on environmental integrity;

Mathematical formula describing the budget approach

The key parameter is the global CO_2 emissions budget from fossil sources $C_{glob}(p)$, i.e. the maximum emissions from fossil sources which may be released/produced within a specific period T_1 to T_2 if the 2°C guard rail is to be obeyed with probability p. Once p has been defined (based on precautionary factors), then $C_{glob}(p)$ can be determined from model studies within the bounds of specific uncertainties (Meinshausen et al., 2009). The global emission pathway $E_{glob}(t)$ must be compatible with this constraint, i.e. it must fulfil the following equation

Of course, 'under-utilization' of the resource 'atmosphere' is also conceivable, but it can be assumed that, in reality, the leeway for global emissions will be fully exhausted. It is important to bear in mind that equation 1 only fixes the area below the global emissions curve but otherwise allows full freedom to determine the reduction schedule.

$$\int_{T_1}^{T_2} E_{glob}(t)dt = C_{glob}(p) \quad (1)$$

The national emissions budget C_{nat} is the total amount of CO_2 that a specific country is allowed to emit in the time period T_1 - T_2. It is calculated as a proportion of the global emissions budget $C_{glob}(p)$, based on the relative demographic weight of the given country in the demographic reference year T_M. The coefficient is therefore the quotient from the national population figure $M_{nat}(T_M)$ at time T_M and total world population $M_{glob}(T_M)$ at the same point in time.

A country's emission pathway $E_{nat}(t)$ must thus be managed in such a way that it matches the allocated budget:

Equation 2 can be regarded, to some extent, as the global 'climate formula' within the budget approach's philosophy.

$$\int_{T_1}^{T_2} E_{nat}(t)dt = C_{nat} = C_{glob}(p)\frac{M_{nat}(T_M)}{M_{glob}(T_M)} \quad (2)$$

- proposing an institutional design for a low-carbon world economy—setting incentives for a deep transformation process; and
- outlining new climate and development partnership patterns among high-emitting and low-emitting countries.

C. Taking stock based on national emission budgets

The budget approach allows one to discuss—in quantitative terms—different policy options based on different decisions regarding the four parameters of the climate formula. Here we outline one of the evident (although by no means self-evident) options, termed "future responsibility" (see Table I). It already constitutes a compromise between what is scientifically necessary on the one hand and politically and economically feasible on the other; the probability of holding the 2 °C-line is set at 67%, and the global emission budget is apportioned based on the current

TABLE I. Allocation option future responsibility, 2010–2050; 67% probability of compliance with the 2 °C-guardrail; and 2010 as the reference year for population data. Only includes CO_2 emissions from fossil sources. CO_2 emissions for 2008 and population numbers for 2010 are estimations. Source: Ref. 10 using data from Ref. 8, WRI-CAIT 2009, and U.S. Census Bureau 2009.

	Share of world population in 2010 (%)	Budget 2010–2050 (Gt CO_2)		Estimated emissions in 2008 (Gt CO_2)	Reach of the budget lifetime, assuming annual emissions as in 2008 (year)
		Total period	Per year		
Germany	1.2	9.0	0.22	0.91	10
USA	4.6	35	0.85	6.1	6
China	20	148	3.6	6.2	24
Brazil	2.8	21	0.52	0.46	46
Burkina Faso	0.24	1.8	0.043	0.000 62	2892
Japan	1.8	14	0.34	1.3	11
Russia	2.0	15	0.37	1.6	9
Mexico	1.6	12	0.29	0.46	26
Indonesia	3.4	25	0.62	0.38	67
India	18	133	3.2	1.5	88
Maldives	0.0058	0.043	0.0011	0.000 71	61
EU	7.2	54	1.3	4.5	12
World	100	750	18	30	25

reference year (i.e., 2010). The historical responsibility of developed countries for past emissions would not be considered explicitly in the national budgets available. Therefore, additional compensation mechanisms in developing countries, particularly support and financial resources for adaptation measures, could help bring about a more politically acceptable yet reasonably equitable agreement.[10] We also calculated a "historical responsibility" scenario, with a 75% probability of compliance with the 2 °C-guardrail, adopting 1990 as the start year for the budget period.[10]

Table I shows examples of the national emission budgets based on a permissible global budget of 750 Gt CO_2 from fossil sources between 2010 and 2050 that is allocated to the countries on an equal per-capita basis. In this option, the start year 2010 would appear to be a suitable demographic reference year. As a consequence, every person (based on the 2010 world population) would be allocated a budget of around 110 t CO_2 emissions for the next 40 years, equivalent to average annual per-capita emissions of approximately 2.7 t CO_2. However, in order to safeguard the transition to those low emissions that are permissible post-2050, global mean per-capita emissions at the end of the budget period must lie well below this average: By 2050, global CO_2 emissions must be around two-thirds lower than the 1990 baseline despite a growing world population. This would result in an entitlement to annual per-capita emissions of around 1 t CO_2 by 2050! Figure 2 shows selected countries and the mean annual budget to which they would be entitled, as compared with their respective emissions in 2005.

The results depict a dramatic state of affairs for the USA, Germany, and the EU; for instance, at current emission levels the German CO_2 budget allocated according to the option discussed would be exhausted within 10 years. In the light of this situation, it is clear that the industrialized countries must carry out a rapid and comprehensive decarbonization of their economies by 2050. However, even drastic domestic reduction efforts will not be enough to keep industrialized countries countries within their budget constraints. It is remarkable that within this scenario, the situation for China (and similar for Mexico, Argentina, Chile, or Thailand) is also rather challenging. If China maintains its emissions on a 2008 level, its budget would only last for some 24 years—a similar observation applies for the world as a whole. All figures refer to fossil CO_2 emissions (i.e., without land-use changes). The emissions from land-use changes between 2010 and 2050 are estimated at around 60 Gt CO_2. We consider these additional emissions in our calculations of future climatic warming. However, in relation to land-use changes, we suggest that

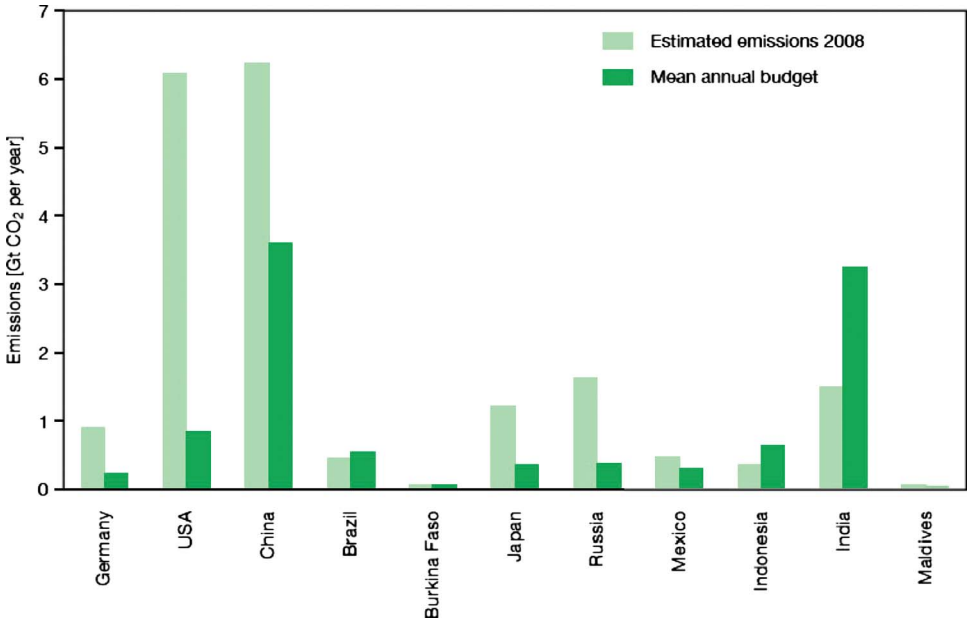

FIG. 2. Fossil CO_2 emissions in 2008 (estimated figures) and permissible average annual budgets under allocation option future responsibility for selected countries (source: Ref. 10).

a separate regime is likely to be more successful. The key issue is that allocating the national emission budgets creates a shared responsibility for climate change mitigation.

On the other hand, it is neither possible nor necessary for all countries to tackle mitigation solely through their own domestic emission reductions efforts. The allocation scheme proposed is equitable, yet should be regarded as the basis for effective and efficient burden-sharing. This can take place in a variety of ways; alongside domestic emission reductions, the trading of emission allowances is likely to play a key role, but other flexible mechanisms for international climate cooperation, along with financial and technology transfers, can help to speed up progress toward low-carbon development all over the world.

D. Foundations for a new global climate architecture

The budget approach has the potential to make two critical contributions to the construction of a global climate architecture, namely, to maintain the environmental integrity of a new climate regime while breaking the negotiation stalemate between the major global emitters. This "Gordian Knot of climate policy"—a knot tied mainly by the USA, the EU, China, and the G77 countries—can be described in terms of game theory as a "social dilemma:" Rationally justified individual preferences lead collectively to an outcome whereby all players end up worse off in the future and furthermore—in the case of climate change—sustain massive and irreversible damage to the Earth's life-support systems. Unless the key players rise above the tactics of self-interest at the ongoing and forthcoming climate negotiations, "dangerous anthropogenic interference with the climate system" (Article 2 UNFCCC) can no longer be prevented.

A further factor impeding the negotiations is that even an agreement on ambitious and binding greenhouse gas reductions between the industrialized countries and the populous or fast-growing newly industrializing economies is no longer enough to keep warming below the 2 °C-limit. Many developing countries are now achieving high dynamic economic growth, accompanied by rising fossil fuel consumption. For that reason, a course must be set on a global basis toward a low-carbon economy. It is clear that even for the majority of developing countries, doggedly

pursuing fossil-fuel-driven growth is no longer an option if dangerous climate change is to be averted. Economic and social development must be decoupled from greenhouse gas emissions worldwide.

However, any future attempt to accomplish this based on the business-as-usual model of international climate policy would require all 194 signatories (as of December 2009) to the UNFCCC to negotiate emission stabilization and reduction targets for around 100 countries! This is the group of countries that already is emitting more than the yearly emission allowance of around 2.7 t CO_2 per capita for the 2010–2050 budget period. The process is at risk of deteriorating into a "talking shop" in which negotiators haggle over every decimal point and comma at marathon bargaining sessions even as global warming spirals out of control. Against this background, the budget approach presents the basic structure for a global architecture for climate protection and shows how compliance with the 2 °C-guardrail can be achieved. The proposal that countries agree on a simple and equitable climate formula as the basis on which all countries can be allocated a precisely determined national emission budget in the future is the fundamental concept behind the global climate compromise. As a result, the budget approach reduces the complexity of the climate negotiations and thus identifies a way forward for the climate negotiation process, which helps countries to move on from their narrow national agendas.

Based on this analysis, we conclude that parties to the UNFCCC will have to agree on the following general principles in the next negotiation rounds.

- The 2 °C-*guardrail* is adopted as legally binding in international law.
- For carbon dioxide—the greenhouse gas crucial to climate protection efforts in the long term—a *global emission budget* for fossil sources up to the year 2050 that is compatible with the 2 °C-guardrail is adopted on a legally binding basis as well.
- The following *milestones* are stipulated: (1) The peak year of worldwide CO_2 emissions is to be reached between 2015 and 2020 and (2) global emissions by midcentury are to be reduced to a level consistent with the narrow emission budget remaining post-2050.
- The global CO_2 budget is distributed among the world's population on an equal per-capita basis so that *national* CO_2 budgets can be calculated for all countries and adopted on a legally binding basis. These budgets provide orientation for countries on how swiftly and substantially their CO_2 emissions need to be reduced.
- Each country is committed to producing internationally and objectively verifiable *decarbonization road maps*, which provide information on the planned national emissions path up to the year 2050. These road maps should be based on the national CO_2 budgets as well as on the respective national emission reduction potentials.
- In addition, for the countries with presently high per-capita emissions, *reduction commitments up to 2020* are agreed in order to avoid delaying decarbonization efforts.
- *Flexible mechanisms* [(international emission trading and joint implementation (JI)] as well as appropriate additional financial and technological transfers by the industrialized countries are agreed upon.
- The *separate regulation* of CO_2 *from nonfossil sources, other relevant greenhouse gases, and future radiative-forcing substances* is to be pursued intensively as it creates opportunities for swift reductions in total emissions harmful to the climate.

IV. THE INSTITUTIONAL DESIGN FOR A LOW-CARBON GLOBAL ECONOMY

The budget approach not only serves as a compass for the future climate regime, it provides at the same time the fundamental elements of an institutional design for a global low-carbon economy. The approach provides great transparency as it explicitly reveals the global and national CO_2 scarcities that have to be accounted for in the creation of public and private welfare. The pertinent scarcities are actually of a character that should compel many countries to develop low-carbon strategies without further delay. Moreover, the obvious quantitative limitations as reflected in the global and the national budgets create clear incentives for the transition toward a transfossil era. The budgets define the space in which the economic actors need to accommodate

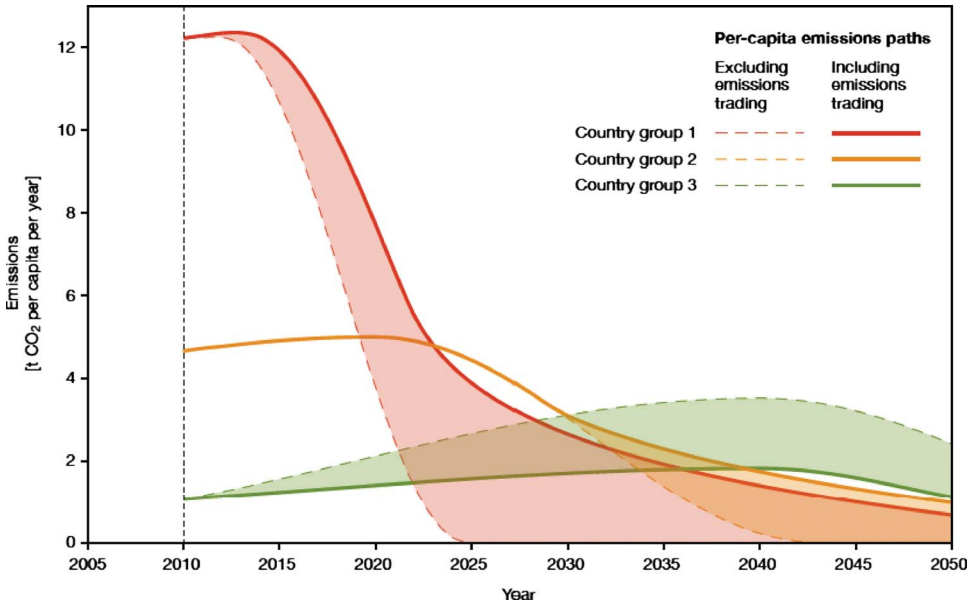

FIG. 3. Examples of per-capita emission paths of CO_2 from fossil sources for three groups of countries according to the WBGU budget approach, which could emerge through emission trading (*unbroken curves*). Here it is assumed that the countries in group 1 (>5.4 t CO_2 per capita per year) will raise their budgets by 75% by purchasing emission rights for 122 Gt CO_2. The countries in group 2 (2.7–5.4 t CO_2 per capita per year) purchase additional emission rights for a total amount of 41 Gt CO_2. The countries in group 3 (<2.7 t CO_2 per capita per year) become sellers of a total of 163 Gt CO_2 and, accordingly, their budget sinks by approximately 43%. Toward the end of the budget time period, there is a convergence of the actual CO_2 emissions at approximately 1 t CO_2 per capita per year (relating to the population in 2010). The *broken curves* show the theoretical per-capita emission paths for CO_2 without emission trading. The areas between the curves illustrate the traded amount of emission allowances. Due to the fact that the illustration shows the per-capita situation and the country groups have varying sizes of population, the areas between the purchasing country groups 1 and 2 do not coincide with the area of the selling country group 3 (source: Ref. 10).

their strategies and activities. For the private sector, this transparency and the long-term constraints agreed upon result in stability, anticipatory certainty for the whole budget period from 2010–2050, a global level playing field, and a clear system of incentives for investments in the future and low-carbon innovation efforts. Within the framework of the budget approach, every success in reducing emissions is rewarded equally regardless of the country in which it is achieved. CO_2-emission reductions translate into a form of capital. Climate protection and carbon efficiency become key factors in boosting competitiveness. International competition for the most innovative decarbonization strategy, i.e., a race to the top, can finally start to roll.

We have demonstrated that the high-emitting countries will not be able to meet their climate challenges within their own national budgets. When implementing the budget approach, the industrialized countries in particular would need to decide to what extent they wish to undertake the necessary greenhouse gas reductions at home or would rather make use of flexible mechanisms (emission trading and JI), which permit cost-efficient fulfillment of national reduction commitments. Emission trading will therefore be a key institutional element of a global low-carbon economy and a major driver of low-carbon innovation.

How would the trading patterns between countries look like? Three major groups can be distinguished (Fig. 3) according to the number of years that their allocated budgets can be expected to last (excluding emission trading).

- Group 1. Countries whose budget—at their current rate of emissions—would be exhausted in *less than 20 years*. Under the assumption of a linear reduction trajectory, these economies (around 60 countries including the EU, U.S., Saudi Arabia, Venezuela, and Malaysia) would therefore have to achieve zero emissions before 2025/2030 if they are to stay within the budget.

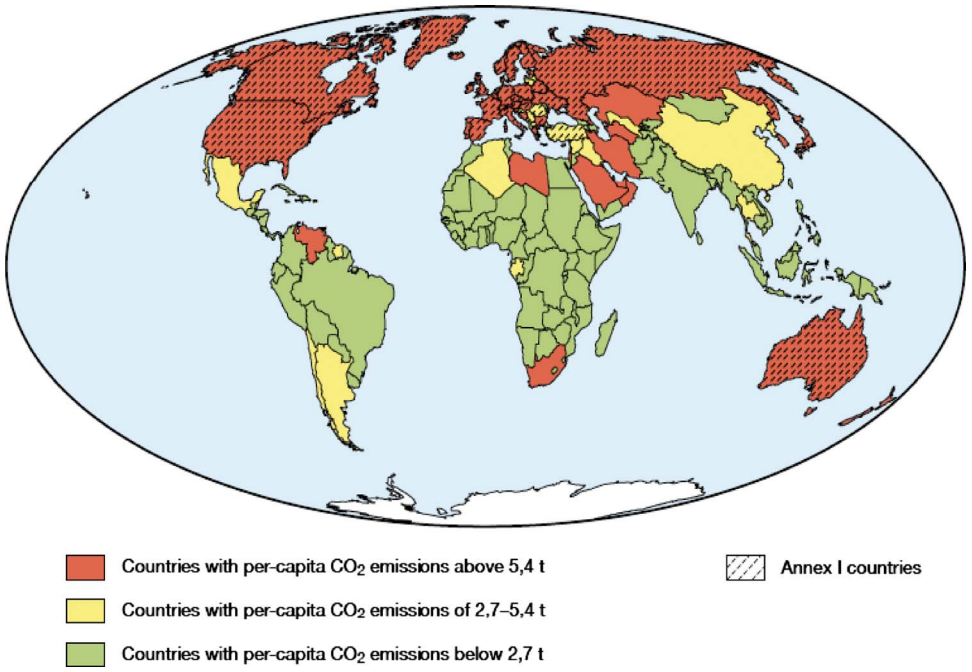

FIG. 4. Per-capita CO_2 emissions in 2005, differentiated by emissions level and country (not including land-use changes). Source: WBGU 2009 (as in Ref. 10); using data from WRI-CAIT 2009 (World Resources Institute, Climate Analysis Indicators Tool (2009), Version 6.0, WRI website, http://cait.wri.org/ (viewed 3 June 2009).

- Group 2. Countries whose budget—at their current rate of emissions—would last for at most *20–40 years* (around 30 countries including China, Mexico, Chile, and Thailand), i.e., roughly till the end of the global budget period in 2050.
- Group 3. Countries whose budget—at their current rate of emissions—would last for *more than 40 years* (some 95 countries in total including the least developed countries in Sub-Saharan Africa, Vietnam, and India), i.e., beyond the end of the global budget period.

For all our calculations, assumptions for the "current rate of emissions" are based on estimated values for 2008. Group 3 countries (Fig. 4) would be the main suppliers of allowances, as even group 2 countries would probably only be able to generate small emission surpluses over the entire budget period. Emission trading would create novel prospects for income generation for the suppliers of emission allowances. For climate policy to succeed, it would be essential that those group 3 countries that do not fully exploit their emission budgets (even when experiencing rapid economic growth) invest their revenues from the sale of allowances in low-emission technologies rather than remaining on "fossil trajectories." Thus not only national decarbonization milestones should be set, but there should also be at least a partial earmarking of revenues from intercountry emission trading. In such a scheme, a substantial proportion of the so-generated revenues should be invested in low-emission technologies, especially into energy production from renewable sources.

JI is a further flexible mechanism, established by the Kyoto Protocol, and also relevant for the budget approach. JI allows countries subject to reduction commitments to create additional domestic emission rights by carrying out emission reduction projects in other countries that have also accepted commitments to limit emissions. Within the budget approach, JI would create incentives for industrialized and other high-emission countries to invest in mitigation technologies in developing countries and emerging economies, i.e., countries belonging to group 2 or group 3. For countries in those groups that are unable to sell emission rights, JI is a promising mechanism by which to finance their transformation processes. The basis for this very mechanism would be

substantially broadened in comparison to the Kyoto Protocol because national CO_2-emission budgets would be allocated to all states, with the Clean Development Mechanism being subsumed under JI.

To make the budget approach and the global emission trading scheme work, we recommend the establishment of a World Climate Bank (for a similar concept embedded in a global climate architecture, see Ref. 21). The World Climate Bank would have several important tasks. First, it would be responsible for the monitoring of the actual emissions of countries and the imposition of sanctions. To ensure, in a systematic manner, that budgets are not exceeded, it would be helpful to set national milestones for manageable time periods and to develop other corresponding rules. The sanction rules should be publicized at the beginning of the budget period and should be sufficiently effective to create strong incentives to remain within the budget constraints. Second, to avoid countries from making wasteful use of their national budgets in the early phases of the budget period and thus becoming "carbon bankrupt" later, all nations should be obliged to develop and publish decarbonization roadmaps. They have to be assessed by and improved with the help of the World Climate Bank. Third, the World Climate Bank should play an important role in shaping JI partnerships. Fourth, the bank would need to monitor the development over time of the national (and thus of the global) emissions in order to ensure compliance with the 2 °C-guardrail. In particular, it is important to make sure that global CO_2 emissions start to decrease at some point during the period from 2015 to 2020 and reach very low levels toward the year 2050. In order to accomplish that global CO_2 emissions actually peak prior to 2020, it would be expedient to structure the use of the flexible mechanisms by introducing trading periods. The World Climate Bank, as an institutional innovation, would form a "climate pillar" of the revised global economic governance architecture, becoming as important as the Bretton Woods institutions (International Monetary Fund and World Bank) and the World Trade Organization.

V. NEW CLIMATE PARTNERSHIP PATTERNS

If the world succeeds in setting a course toward a global low-carbon economy via the budget approach, then the national actors will need to stick closely to the following script: More than 100 countries, whose emissions are already today beyond the 2.7 t-CO_2-per-capita-emissions amount that would be available on average between 2010 and 2050, should initiate, as quickly as possible, a transformation process that allows them to stabilize their emissions before long and then to move toward almost complete decarbonization. Only 65 countries have economies whose emissions are currently below 1–1.5 t CO_2 per capita per year and are thus (mostly *nolens volens*) climate friendly. The CO_2 budgets of the industrialized countries are extremely limited. These countries should therefore combine strategies for the radical restructuring of their "fossil" economies with the use of flexible mechanisms (such as technology transfer to reduce greenhouse gas emissions in developing countries) and the purchase of substantial quantities of emission allowances. Many emerging economies also need to make substantial decarbonization efforts if they are to stay within their budgets by midcentury without having to purchase additional emission certificates. The majority of emerging economies is therefore highly unlikely to become suppliers of tradable allowances. This gives developing countries with consistently low levels of emissions an overwhelming strategic importance as owners—and sellers—of such emission rights. The budget approach offers them an unprecedented opportunity to accelerate their future development through technology and financial transfers and to move toward a low-carbon industrial metabolism from the outset. It becomes clear that the budget approach binds together climate policies, the creation of essential elements of on institutional design for a climate-efficient economy, and mechanisms for a global low-carbon development partnership.

From the above clusters of interests, it becomes apparent, *first*, that a historic climate partnership between group 1 countries (essentially the industrialized countries) and group 3 countries (essentially today's poorest countries) is vital in solving the climate problem. They will operate on the principle of technology and financial transfers in exchange for "budget surpluses." The "donors" and "recipients" who have traditionally been the key actors in development cooperation thus become partners with mutual common interests.[22] International climate change mitigation must

thus go hand in hand with a global development partnership between "high-emission countries" and "low-emission countries."[23] For many developing nations, these transfers hold the key to a zero-emission future, as the development of their sustainable energy systems could largely be funded through emission trading. The dual benefit is that these countries can avoid the burden of fossil path dependency without forfeiting their opportunities for development.

A more detailed analysis of the potential suppliers of emission allowances generates the following fairly realistic scenario: Sub-Saharan Africa is the region with the largest number of countries that could sell their surpluses. However, many of the suppliers in group 3 are small economies which—from a potential purchaser's perspective—have only very modest amounts of greenhouse gas emissions available to sell. From the perspective of the group 1 countries, the more attractive potential suppliers with large volumes of emission allowances are India (population: 1.2 billion; budget would last for 88 years if emissions remain constant; see Table I), Bangladesh (population: 164 million; 384 years), Pakistan (population: 185 million; 125 years), and Ethiopia (population: 85 million; 1251 years). Although their geostrategic role is negligible at present, climate change issues in the future could make them major players with whom the industrialized countries should maintain particularly constructive relations.

Second, it is clear that emission trading between group 1 countries and group 2 countries is likely to be very limited due to the minimal or modest budgets available to both groups. Nonetheless, the industrialized countries are likely to have great interest in technology partnerships on equal terms in order to reduce the greenhouse gas intensity of the newly industrializing countries (especially China) and thus to prevent these countries from becoming major purchasers of emission allowances themselves. Competition between group 1 and group 2 for group 3's limited supply of emission allowances would undoubtedly drive up prices. This insight could encourage the formation of climate alliances between China, the EU, and the USA, for example. Despite such common interests, however, there is likely to be intense future competition between the industrialized countries and China in particular regarding technological leadership during the phase of global decarbonization.

Third, our analysis shows that the two most important emerging economies in Asia, namely, China and India, will be confronted with very different challenges under the budget approach. China, due to its impressive economic growth dynamics and an already highly level of per-capita emissions, will need to implement a comprehensive decarbonization strategy with great urgency.[12] India, by way of contrast, due to its still relatively low per-capita emissions, has the chance to pursue a gentler transformation pathway toward a low-carbon economy, despite its high economic growth potential. In other words, India will face far less time pressure than China in starting to decouple economic development from greenhouse gas emissions. The sooner India recognizes this opportunity to avoid catch-up carbonization, the greater its prospects of becoming a major supplier of emission allowances in the future. India could thus greatly facilitate its pathway toward a low-carbon future through partnership with the industrialized countries. Equally, climate cooperation with India would be of great strategic interest for the North, especially for securing its own access to India's emission allowances. In summary, India could become a key actor and major winner if a world climate treaty would be adopted in line with the budget approach after all.

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