International reductions of greenhouse-gas emissions

An equitable and efficient approach

Barry D. Solomon and Dilip R. Ahuja

A strategy for a successful climate protection convention must highlight the role of equity in order to bring more nations to the bargaining table. The authors propose two commercial energy protocols for consideration by negotiators in this light. The first links international trading in greenhouse-gas emission 'rights' to a country's historical per capita carbon emissions. The charge for these rights should be based on the negotiated reduction in global emissions and the demand for them, via the marketplace. The second requires inefficient countries to make steady improvements in energy efficiency or fuel substitution away from carbon as their economies develop.

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[1]Roger E. Kasperson and Kirstin Dow, 'Developmental and geographical equity in *continued on page 344*

An effective strategy to increase international participation in the framework climate convention (scheduled for completion in 1992) must highlight the role of equity in order to bring more nations to the negotiating table. In this article we propose two commercial energy protocols for consideration by the UN-sponsored Intergovernmental Negotiating Committee for a Framework Convention on Climate Change. The first one ties international trading in greenhouse-gas (GHG) emission rights to a country's historical per capita carbon emissions. The charge for these rights would be based on the negotiated reduction in global emissions ('supply') and demand for them, via the marketplace. The second protocol requires the most 'inefficient' countries, as defined below, to make steady improvements in energy efficiency or fuel substitution away from carbon as their economies develop. But first we consider the many views of equity that have been offered in previous proposals for GHG negotiating targets.

A range of views on equity

Though there is no universally accepted definition of equity, the varying positions taken by different countries on the global climate change issue seem to be motivated by some conception of equity or fairness. We accept the definition offered by Kasperson and Dow[1] that equity is fairness both of the process by which a particular decision or policy is enacted and of the associated outcomes. The latter, distributional equity, is the main concern of this article. At a fundamental level there is a concern for intergenerational equity and planetary stewardship, since human-induced global climate change is usually considered a phenomenon that may happen only in the future. Intergenerational equity involves determining whether the effects of climate change on the environment that future generations will receive are acceptable, and if the resources they will inherit for adapting to a changed natural environment are adequate.[2] Few people would argue with the

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stewardship principle, though there are many alternative views of acceptability, and the principle provides little help in determining how best to accomplish reductions in GHG emissions. For this we need to consider the concept of intragenerational, interregional equity.

Utilitarianism, or 'the greatest good for the greatest number', is a long-standing distributive principle of aggregate equity which is really an efficiency criterion, and which dominates mainstream economics.[3] This principle requires that emission reductions be focused in those countries or sectors with the greatest potential to reduce at least cost – countries or sectors that may not necessarily be the largest emitters of GHGs. To implement this principle, we would need to know the relative marginal cost and benefit of emission reduction in each country, for each sector, and for each important project, and thereby devise a global least-cost control strategy. This approach is in theory the most economically efficient, but in practice it may be unworkable – it does not directly consider problems of free ridership, emissions accounting, discounting, culpability for past emissions, and the need for global leadership and administration of such a scheme. Japan, for example, may take the defensible view that its economy is already energy-efficient, and it would be economically efficient to ask the relatively energy-inefficient USA and Canada to make greater emission reductions.

Objections to utilitarianism raise questions about just means to just ends, and focus attention on individual rights and responsibilities. John Rawls argued that all social primary goods are to be distributed equally unless an unequal distribution of any or all of these goods is to the advantage of the least favoured.[4] Such a case can easily be made for climate-related technology transfer, since a poor, flood-prone country would have the most to lose, both in terms of lives and as a percentage of GDP, from a rise in sea level and storm surges induced by global warming. Some formulation of this equity principle may become prominent in negotiations over reduction in GHG emissions. For instance, very poor countries could be exempted from their proportional responsibility for mitigation of GHG emissions.[5]

One application of the Rawlsian principle is benefit/burden concordance,[6] more popularly known as the 'polluter pays' principle, which requires those who benefit or have benefited from an activity such as generating GHGs to bear proportional burdens. This position would require much less emissions-reduction expenditures from a country such as India or Indonesia than from the USA or the UK. Other developing countries, such as China and those with huge debt burdens, could argue for a different equity principle, requiring proportionality of benefits to need and burden to ability.[7] Since this version of the equity principle seeks to achieve more equal end states *for their own sake*, its popularity may be limited.

The ultimate stage for defining and refining these principles of distributional equity and their balance with economic efficiency is the climate convention under current international discussions. For the convention to succeed, serious attention must be given to procedural equity, allowing as many nations as possible (including the largest emitters) to participate fully in negotiations in an open and flexible forum, and to be assisted in preparing *their* own analyses. The Intergovernmental Panel on Climate Change (IPCC) has succeeded in including developing countries in its meetings, as have other interna-

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global environmental change: a framework for analysis', *Evaluation Review*, Vol 15, No 1, February 1991, pp 149–171.

[2]Edith B. Weiss, 'Climate change, intergenerational equity and international law: an introductory note', *Climatic Change*, Vol 15, 1989, pp 327–335; Edith B. Weiss, 'In fairness to future generations', *Environment*, Vol 32, No 4, April 1990, pp 6–11, and 30–31.

[3]Michael Enbar, 'Equity in the social sciences', in Roger E. Kasperson, ed, *Equity Issues in Radioactive Waste Management*, Oelgeschlager, Gunn & Hain, Cambridge, MA, USA, 1983, pp 3–23.

[4]John Rawls, *A Theory of Justice*, Harvard University Press, Cambridge, MA, 1971. For a discussion of Rawls's maximin principle in the context of global warming policy, see Adam Rose, 'Reducing conflict in global warming policy: the potential of equity as a unifying principle', *Energy Policy*, Vol 18, No 10, December 1990, pp 927–935.

[5]For discussion of related proposals, see Christopher Flavin, 'Slowing global warming', in Lester R. Brown *et al, State of the World 1990*, Norton, New York, NY, 1990; Michael Grubb, *The Greenhouse Effect: Negotiating Targets*, Royal Institute of International Affairs, London, 1989.

[6]Roger E. Kasperson, Patrick Derr and Robert W. Kates, 'Confronting equity in radioactive waste management: modest proposals for a socially just and equitable program', in Roger E. Kasperson, ed, *Equity Issues in Radioactive Waste Management*, Oelgeschlager, Gunn & Hain, Cambridge, MA, 1983, pp 331–368.

[7]*Ibid.*

Table 1. Sequence for determining global limits of greenhouse-gas emissions.

Parameter	Examples of suggested responses[a]
Adverse impact of climatic change	Limit rate of sea-level rise to current levels
↑	
Temperature change:	
rate	< 0.1°C per decade[b]
amount	< 2.5°C over pre-industrial level by 2030[c]
↑ (climate sensitivities)	
Radiative forcing	Limit increase to < 2–5 W/m^2
↑	
Atmospheric concentrations	< 400 ppm[d]
	equivalent doubling by 2060[e]
↑	
Emissions	Emit less than allowed globally, nationally; < 340 Pg C until 2030
↑	
Activities	No net deforestation, no new production of CFCs, use best available or most efficient technologies, switch to cleaner fuels, etc

[a]Different examples given are not necessarily compatible with each other; [b]From the meetings held at Villach and Bellagio – see Ref 10; [c]*Op cit*, Ref 11; [d]Krause *et al*, *op cit*, Ref 12; [e]IPCC.

tional fora on the global environment. Several authors have argued for similar open processes as a major step towards solving a variety of environmental and resource problems.[8] Predetermined rules should not bias the outcome of the climate convention, but rather should seek to ensure full and meaningful participation.

As the world weighs evidence about the science and economics of global environmental change, much of which has been documented by the IPCC and other international bodies, it is confronted by a dilemma. Effective responses may be difficult to formulate and slow to emerge, but the problems of global change are growing steadily worse. That is to say, we may not be able to afford the luxury of waiting for the most equitable *and* economically efficient response to be devised – the former helping to determine responsibility for past emissions and the latter a utilitarian distribution of future emission reductions.

Target-setting: science and politics

A causal chain is thought to run between human activities and potentially adverse climatic change induced by greenhouse warming (see Table 1). Our concern about this issue stems from wanting to minimize potential adverse changes which are presumed to be in proportion to the rate of change of warming and the absolute ultimate amount of warming that will result.[9] Extrapolating from observed temperature changes in paleoclimatic records, scientific meetings, such as those in Villach, Austria, and Bellagio, Italy in 1985 and 1987, have suggested that the rate of warming should be limited to 0.1°C per decade and the ultimate average warming of the global surface should be limited to 2.5°C by 2030.[10] Within these limitations, ecosystems will have an opportunity to adapt without being stressed beyond their capacity to rebound.

Once the maximum rate of temperature increase is chosen, for a given range of climatic sensitivities, the range of radiative forcings is specified, as well as the range of concentrations of GHGs. The latter will determine the maximum allowable global emissions (Table 1).

Wirth and Lashof have calculated the CO_2 concentration and emission limits that would be required to limit global warming to 2.5°C by 2030 for the most widely accepted range of climate sensitivities between 1.5°C and 4.5°C.[11] Sensitivity of the climate system is defined as the increase in average global surface temperature for an equivalent doubling of atmospheric CO_2 concentrations. For the middle-of-the-range

[8]See, eg, Peter M. Morrisette, 'The Montreal Protocol: lessons for formulating policies for global warming', *Policy Studies Journal*, Policy Studies Journal, Vol 19, No 2, 1991, pp 152–161; Lawrence E. Susskind, L.S. Bacow and M. Wheeler, *Resolving Environmental Regulatory Disputes*, Schenkman, Cambridge, MA, 1983; Barry D. Solomon and Diane M. Cameron, 'Nuclear waste repository siting: an alternative approach', *Energy Policy*, Vol 13, No 6, December 1985, pp 564–580, among others.

[9]Stephen H. Schneider, 'The greenhouse effect: science and policy', *Science*, Vol 243, 10 February 1989, pp 771–781; Stephen H. Schneider, *Global Warming: Are We Entering the Greenhouse Century?*, Sierra Club Books, San Francisco, CA, 1989.

[10]International Council of Scientific Unions, United Nations Environment Programme, and World Meteorological Organization, *Report of the International Conference on the Assessment of the Role of Carbon Dioxide and of Other Greenhouse Gases in Climate Variations and Associated Impacts* (Report of a Conference Held Under the Auspices of the World Climate Program at Villach, Austria, 9–15 October 1985), 1986; World Meteorological Organization and United Nations Environment Programme, *Developing Policies for Responding to Climatic Change* (Summary of Workshops Held in Villach, Austria, 28 September–2 October 1987, and Bellagio, Italy, 9–13 November 1987, Under the Auspices of the Beijer Institute, Stockholm), 1988.

[11]David A. Wirth and Daniel A. Lashof, 'Beyond Vienna and Montreal: multilateral agreements on greenhouse gases', *Ambio*, Vol 19, October 1990, pp 305–310; National Research Council, Board on Atmospheric Sciences and Climate, *Changing Climate* (Report of the Carbon Dioxide Assessment Committee), National Academy Press, Washington, DC, 1983. See also Irving M. Mintzer, *A Matter of Degrees: The Potential for Controlling the Greenhouse Effect*, World Resources Institute, Washington, DC, 1987.

value of climate sensitivity of 3°C, they report a maximum CO_2 concentration of 440 ppm and a carbon budget of 340 Pg C (petagrams of carbon). However, these calculations assume that the concentrations of other GHGs can be frozen at current levels. Similarly, Krause *et al* suggest a maximum CO_2 concentration of 400 ppm and a global carbon budget of 300 Pg C for the period 1985–2100.[12] It seems very unlikely, given the tremendous current inertia, that a doubling of equivalent CO_2 can be avoided in the 21st century, and the prudent policy is to ensure that it occurs as late as possible.[13]

If and when an initial global budget is agreed upon along with a process for revising it (through framework conventions), international negotiations will have to grapple with the most crucial and thorny protocols about how to allocate this budget among various countries. This process will be influenced by a variety of actors with overlapping roles.[14] Every country will tend to muster as many different arguments as it can as to why its situation is unique and why it should be exempt from reduction targets.

Anticipating these negotiations, analysts have proposed several ways to divide this budget. Some of these proposals consider equity, some consider efficiency, some both and some neither. All have merits and shortcomings, as shown in Table 2. Finally, a criterion that is able to ensure the acquiescence of as many countries as possible, including the largest emitters, is preferable to one that is satisfying analytically but is unable to forge a consensus. Michael Grubb has provided an excellent discussion of these issues.[15]

Criteria for allocating carbon budgets

The easiest conceptual approach would be to allocate emissions rights equally among all countries and couple this with the right to sell or lease the rights. While simple and apparently equitable, such a scheme does not link emissions either to human beings or to economic activities. Thus it is least likely to prevail and has few, if any, proponents.

A second basis for allocating rights is land area.[16] It is a reasonably stable and measurable quantity. In fact, the USA has been arguing informally in international fora that its continental size necessitates huge energy expenditures in having to move goods and people.[17] Yet this distribution will discriminate against small nations and reward those countries that are already endowed with huge natural resources.

The third alternative is to subdivide permits in some proportion to current emissions, such as 80 or 90% of current emissions to start with. A similar approach was taken in the original Montreal Protocol when the signatories agreed in 1987 to reduce emissions of CFC-111, -12, -113, -114 and -115 by 50% from their 1986 levels by 1999.[18] This alternative not only fails on grounds of equity but also on grounds of efficiency – it will reward those countries that are the most inefficient and emit the most, and will penalize those that have already successfully instituted measures to make their economies more efficient.

Japan has argued in the past for allocating global emissions reductions on a per gross domestic product (GDP) basis, on the grounds that emissions should be tied to economic activity. There are several potential problems in this approach. Many countries have large informal sectors that are not reflected in the GDP statistics. Exchange rates fluctuate, as do the purchasing powers of different currencies – witness the difficulties in comparing the national products of market and

[12]Florentin Krause, Wilfrid Bach and Jon Koomey, *Energy Policy in the Greenhouse, Volume One: From Warming Fate to Warming Limits: Benchmarks for a Global Climate Convention*, International Project for Sustainable Energy Paths, Final Report to the Dutch Ministry of Housing, Physical Planning and Environment, 1989.
[13]J.T. Houghton, G.J. Jenkins and J.J. Ephraums, eds, *Climate Change: The IPCC Scientific Assessment*, Cambridge University Press, Cambridge, 1990.
[14]William B. Wood, George J. Demko and Phyllis Mofson, 'Ecopolitics in the global greenhouse', *Environment*, Vol 31, No 7, September 1989, pp 12–17 and 32–34.
[15]Grubb, *op cit*, Ref 5.
[16]A.H. Westing, 'Law of the air', *Environment*, Vol 31, No 3, March 1989, pp 3–4.
[17]Grubb, *op cit*, Ref 5.
[18]F. Sherwood Rowland, 'Chlorofluorocarbons, stratospheric ozone, and the Antarctic "Ozone Hole" ', *Environmental Conservation*, Vol 15, Summer 1988, pp 101–115; F. Sherwood Rowland, 'Stratospheric ozone depletion by chlorofluorocarbons', *Ambio*, Vol 19, October 1990, pp 281–292; David A. Wirth, 'Climate chaos', *Foreign Policy*, Vol 74, Spring 1989, pp 3–22.

Table 2. Criteria for evaluating bases for allocating carbon budgets among countries.

	Equal emissions	Proportional to area	Proportional to current emissions	Per GDP (corrected for purchasing power)	Per capita	Per adult capita	Historical per capita	0.5 x (per GDP + per capita)
Proponents	–	Westing[a]	cf Montreal Protocol	Japan?; this article (for investment in reducing emissions)	Princeton[b]	Grubb[c]	K. Smith;[d] Krause *et al*;[e] this article	Wirth-Lashof[f]
Simplicity	Yes	Yes	Yes	Somewhat	Yes	Less	Less	Less
Equity (equal rights to commons)	No	No	No	No	Yes	Yes	Yes	Yes
Efficiency (increased by trading)	No	No	No	Yes	No	No	No	Yes
Accounts for differences in:								
Geographic spread	No	Yes	Somewhat	No	No	No	No	Some
Climatic conditions	No	Yes	Somewhat	No	No	No	No	Some
Resource endowments	No	Some	Yes?	No	No	No	No	Some
Economic structure and trade	No	No	Yes?	Yes	No	No	No	Some
Discourages grandfathering (of current emissions)	Yes	Yes	No	Yes	Yes	Yes	Yes	No
Disincentives for population growth (increased by pegging population to a year)	Yes	Yes	Yes	Yes	No	Some	Yes	Yes
Accomplishes transfers from industrialized countries to developing countries	Some	Little	Some	No, reverse	Yes	Some	Yes	Some
Ease of getting developing countries to agree	No	No	No	No	Yes	Maybe	Yes	Maybe
Ease of getting industrialized countries to agree	No	No	Yes	Some	Difficult	Less Difficult	Difficult	Difficult
Example of country that 'benefits'	Maldives	USSR	USA	France	Nigeria	China	India	Japan
Example of country that 'loses'	USSR	Japan	Nigeria	China	Canada	Kenya	USA	Maldives

[a]*Op cit*, Ref 16; [b]*Op cit*, Ref 20; [c]*Op cit*, Ref 5; [d]*Op cit*, Ref 22; [e]*Op cit*, Ref 12; [f]*Op cit*, Ref 11.

[19]Robert Summers and Alan Heston, 'A new set of international comparisons of real product and price levels estimates for 130 countries, 1950–1985', *The Review of Income and Wealth*, Vol 34, No 1, 1988, pp 1–25; more reliable real GDP data for China, Cuba, North Korea and Vietnam are provided by Donald J. Roy, 'Real product and income in China, Cuba, North Korea and Vietnam', *Development Policy Review*, Vol 8, 1990, pp 77–81.

[20]*Princeton Protocol on Factors that Contribute to Global Warming*, Woodrow Wilson School of Public and International Affairs, Princeton University, Princeton, NJ, Fall 1988.

hitherto centrally planned economies. Consequently, GDP data should be corrected for purchasing power parity, as with the Penn World Table of Summers and Heston.[19] Incorporating the real value of economic output in various countries, many of which have non-convertible currencies, is the attractive feature of this criterion.

Any equitable scheme for allocating entitlements must incorporate the principle that human beings should have equal rights to use atmospheric resources. The most obvious basis is to allocate equal per person rights and to distribute emissions permits in proportion to national populations.[20] Those countries above the global average would then buy or lease rights from countries that were below the average.

If rights in every subsequent year continue to remain proportional to

Table 3. Carbon emissions from fossil fuels and cement in selected countries, average historical per capita, 1950–1988 (tonnes).[a]

United Arab Emirates (1959–88 only)	10.23
Kuwait	6.05
USA	**5.10**
Canada	3.96
Czechoslovakia	3.40
Germany[b]	3.28
Australia	3.11
Belgium	3.06
UK	2.92
USSR	2.63
Denmark	2.62
Poland	2.54
Trinidad and Tobago	2.53
Saudi Arabia	2.50
Singapore	2.26
Netherlands	2.25
Sweden	2.13
Bulgaria	2.13
France	1.99
South Africa	1.91
Romania	1.59
Japan	1.52
Switzerland	1.42
Italy	1.20
Spain	0.92
Mexico	0.71
Republic of Korea	0.57
China	0.31
Brazil	0.29
Nigeria	0.14
India	0.12
Indonesia	0.12
Pakistan	0.09
World	1.10

[a]Calculated as the historical sum of national carbon emissions divided by the historical sum of national populations; [b]includes what was then East and West Germany.
Source: Tom Boden, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, TN, SAS File of October 1990.

national populations, this scheme provides an incentive for population growth. For this reason and to increase the palatability of the scheme to industrialized countries, Grubb has suggested that entitlements be proportional to adult populations.[21] This would have the effect of reducing net transfers from industrialized countries with rectangular age distributions to developing countries with pyramidal age structures. This proposal, of course, discriminates against children already born. An incentive for population stabilization can be built in by pegging the allocation to the population in any recent year and insisting that future entitlements would not increase beyond the populations in the chosen year. The CO_2 policy of Japan in fact embodies this principle.

Kirk Smith argues that cumulative past emissions of GHGs such as CO_2 ('natural debt') should be used as a basis for determining responsibility for paying for future emission reductions.[22] Arguing that nations should pay back their natural debt in the same proportion as that in which it was borrowed, he proposes that an appropriate index for establishing responsibility of nations is the total historic emissions integrated over time. Using CO_2 from fossil fuels as an indicator, and the period from 1900 to the present (since most of the CO_2 emitted during this period still remains in the atmosphere) he calculates that the ratio of the integrated contributions of the USA and India is 43:1, as opposed to 26:1 based on emissions in a recent year. Grubb objects to this on the grounds of impracticality and ignorance – countries in the past were not aware that they were depleting a finite resource.

Wirth and Lashof, citing the practical difficulty of making the 75% reduction in emissions if some version of the per capita index is chosen, argue for incorporating GNP as a component in budget calculations.[23] They favour an apportionment half of which is based on population and half on gross national product.

To summarize, three principles emerge from our discussion thus far:

- Emissions allocations should be proportional to a country's population. To prevent incentive for future population growth, allocation should be pegged to a population in a recent year. (Equity Criterion)
- Emissions allocations should also reflect economic activity. Because currencies fluctuate according to the vagaries of the marketplace, comparisons of gross products should be corrected for differences in purchasing power parity. Future entitlement would increase with real GDP to account for the concerns of developing countries but there would be a continual downward pressure exerted on the efficiency (emissions per unit of real adjusted GDP). (Efficiency Criterion)
- Finally, future allocations should in some way be proportional to the difference between the allocations calculated on the 2 bases above and the actual historic emissions. Those that have emitted more than their fair share of allocations should be allowed less. (Fairness Criterion).

Below we argue in favour of using separate indexes for equity and efficiency, which serve different purposes.

Proposed commercial energy protocols

We begin by noting our objection to a comprehensive and integrated

[21]Grubb, *op cit*, Ref 5; Michael Grubb, 'International marketable emission permits: key issues', paper presented at the IPCC/OECD Workshop on Financial and Economic Measures as a Response to Climate Change, Paris, 1990.
[22]Kirk R. Smith, 'Allocating responsibility for global warming: the natural debt index', *Ambio*, Vol 20, No 2, April 1991, pp 95–96.
[23]Wirth and Lashof, *op cit*, Ref 11.

Table 4. Carbon emissions from fossil fuels and cement in selected countries, per $US real GDP adjusted for purchasing power parity, 1985 (g).

Bulgaria	741
Poland	671
China	602
United Arab Emirates	599
Romania	577
Czechoslovakia	572
USSR	565
Trinidad and Tobago	532
South Africa	496
Saudi Arabia	495
Kuwait	369
Australia	346
USA	**313**
Canada	297
Germany[a]	297
Republic of Korea	295
Singapore	289
Nigeria	281
Belgium	266
Denmark	250
UK	246
Netherlands	218
Mexico	210
Japan	188
Italy	186
India	184
Spain	170
Sweden	163
France	150
Indonesia	134
Switzerland	125
Pakistan	93
Brazil	90

[a]Includes what was then East and West Germany.
Source: Boden, *op cit*, source to Table 3; Summers and Heston, *op cit*, Ref 19; Roy, *op cit*, Ref 19 – for China GDP only.

approach to emissions accounting for purposes of allocating existing carbon 'rights'. While the use of a comprehensive index, such as the World Resources Institute's Greenhouse Index,[24] should ultimately make sense for international emissions trading in GHGs, its use for allocating rights to emissions *today* with such inequities in international wealth would be a political non-starter. This follows from the fact that developing countries are the largest sources of CO_2 emissions from deforestation, and the smallest users of CFCs, which will be greatly reduced anyway by the industrialized countries in order to protect the stratospheric ozone layer (that is, another free rider problem).

We have calculated a range of carbon indexes for 33 countries that fit into one or more of five categories: the top 20 carbon emitters from national energy systems in 1988; a minimum emission of 5 million tonnes in 1988; countries with a human population of 100 million or more; countries with a total GDP of $100 billion or more; and countries with a per capita emissions rate of 3.0 tonnes or more.

Few countries have agreed on a specific carbon *reduction* target or tax, and not many more can be expected to do so. An alternative approach with growing support underlies our first protocol, which requires nations to hold GHG emissions permits in order to generate future emissions.[25] As noted above, the most equitable way to allocate these rights, which then can be used for international trading, is based on a nation's historical per capita carbon emissions, or natural debt. In this manner, a large emitter such as the USA will have a strong economic incentive to lower its emissions by investing in energy efficiency or fuel switching, if it is less expensive to do so than to buy emissions rights from a nation with a surplus of such permits, say India or Indonesia.[26] If its investment is large enough and effective enough, the USA could also generate excess emissions rights saleable on the open market. The international marketplace would determine the charge for emissions rights by equilibriating the demand to emit with the total supply of rights based on the required reduction in total emissions. A nation that chooses to buy emission rights in this international marketplace will have to pay that rate for each marginal unit it desires to emit. The charge would fluctuate periodically and the total emissions rights may have to be adjusted every few years in response to national energy and environmental policies.[27] The monies paid for emission permits should be used only for less emission-intensive development paths.

As an illustration we have calculated per capita carbon emissions from fossil fuels and cement from 1950–88, using data from the Oak Ridge National Laboratory.[28] The leading emitters are small oil-rich emirates that have had high levels of oil consumption and natural gas flaring. Following this group are the USA at 5.1 tonnes per capita; Canada (4.0); Czechoslovakia (3.4); and the 'new' Germany (3.3). The lowest emitters have been Pakistan; India; Indonesia; Nigeria; China; and Brazil, at roughly 0.1–0.3 tonnes per capita. Australia and the UK are in between, at about 2.9–3.1 tonnes per capita, with the USSR at 2.6 and Japan at 1.5 (Table 3).

Our second energy protocol requires currently 'inefficient' nations to make steady improvements in energy efficiency or fuel substitution in order to reduce carbon emissions, until they fall below some desired level.[29] We define this metric as current carbon emissions from fossil fuels and cement, per $US GDP, adjusted for purchasing power parity.

[24]The World Resources Institute, in collaboration with The United Nations Environment Programme and The United Nations Development Programme, *World Resources 1990–91*, Oxford University Press, New York, 1990, pp 11–31. There are several technical problems with the WRI Greenhouse Index. the most important of which is that it does not account for differences in the atmospheric lifetimes of the various trace gases.

[25]Materials for the informal seminar on US experience with 'comprehensive' and 'emission trading' approaches to environmental policy, Washington, DC, February 1990; Daniel J. Dudek, *A Short Discussion of Greenhouse Gas Trading*, Environmental Defense Fund, Prepared for the Keystone Global Warming Dialogue Policy Evaluation Working Group, New York, NY, August 1990.

[26]Steve Rayner, 'The United States of America', in Michael Grubb, ed, *Energy Policies and the Greenhouse Effect, Volume II: Country Studies and Technical Options*, Dartmouth, Aldershot, 1991.

[27]Michael Grubb and James K. Sebenius, 'Participation, allocation and adaptability in international tradeable emission permit

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When international data quality improve, the index should be expanded to include CH_4 and N_2O. This metric accounts for the efficiency concern, and allows a country to lower its index by expanding its economy in an energy-efficient manner. This protocol is needed to ensure that small, relatively inefficient and rich economies (among others) that may forego emissions-reduction opportunities for non-economic reasons have additional incentive to lower carbon emissions as their economies develop and expand. Alternatively, larger countries in search of emissions credits may be attracted to invest emissions-reduction capital in these countries, which otherwise might be ignored.[30]

By this measure of carbon efficiency, countries with the highest emission rates include what were in 1985[31] the centrally planned economies of Eastern Europe and Asia (including the Soviet Union and China); the oil-rich emirates; Trinidad & Tobago; and South Africa (Table 4). The most carbon-efficient countries include Brazil; Pakistan; Switzerland; Indonesia; and France. The USA, Canada and Germany fall in the middle. In order to enforce this protocol, a penalty would have to be agreed upon if the relevant countries did not demonstrably improve their carbon efficiency measure periodically, perhaps by a fine to be paid into a global environmental fund. Similarly, more efficient countries would be subject to the same penalty if they were to backslide into the inefficient range. An analogous sanction could be devised for countries whose emissions exceeded their permit holdings. Allowances could also be made for voluntary payments into such a fund. A precedent for this exists, in that many OECD countries have already made voluntary contributions into the World Bank's new multilateral Global Environment Facility (GEF).

Conclusion

When discussing the protection of Earth's atmosphere, it is critical to separate the issue of allocating responsibility for greenhouse-gas build-up from that of allocating emissions-reduction investment. Clearly, since past emissions of CO_2 and other trace gases accumulate in the atmosphere, the only fair way to determine responsibility for the potential damage that these emissions may cause in the future is to tally up past emissions. The historical per capita index does this while recognizing that no person in one country has more of a right to pollute than a person in another country.

Use of this index alone, however, would fail to provide an incentive for the inefficient nations of the former Eastern Bloc and China to lower GHG emissions as their economies are modernized. The emissions per purchasing power adjusted GDP index accomplishes this, and could be used to help channel flows of development capital in a global emissions trading programme or from the World Bank's GEF. We hope that these indices will be considered in the design of protocols for review by the UN-sponsored Intergovernmental Negotiating Committee for a Framework Convention on Climate Change.

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systems for greenhouse gas control', paper prepared for OECD Workshop on Tradeable Greenhouse Gas Permits, Paris, June 1991.

[28]G. Marland, T.A. Boden, R.C. Griffin, S.F. Huang, P. Kanciruk and T.R. Nelson, *Estimates of CO_2 Emissions from Fossil Fuel Burning and Cement Manufacturing, Based on United Nations Energy Statistics and the US Bureau of Mines Cement Manufacturing Data*, ORNL/CDIAC–25, NDP–030, Oak Ridge National Laboratory, Oak Ridge, TN, May 1989. We have updated these data with more recent estimates, available from the same source on a floppy diskette.

[29]A more general energy efficiency protocol for all countries has been proposed in William A. Nitze, 'A proposed structure for an international convention on climate change', *Science*, Vol 249, 10 August 1990, pp 607–608; William A. Nitze, *The Greenhouse Effect: Formulating A Convention*, Royal Institute of International Affairs, London, 1990, pp 37–38. A similar proposal that also calls for a reduction in population growth has been made in Duane Chapman and Thomas Drennan, 'Equity and effectiveness of possible CO_2 treaty proposals', *Contemporary Policy Issues*, Vol 8, No 3, July 1990.

[30]Rayner, *op cit*, Ref 26.

[31]The latest data available to us at the time of this analysis on purchasing power parity were for 1985.