SkyShares

Modelling the distributive and economic implications of a future global emissions budget

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Abstract

The kyShares model helps policy-makers explore a range of diffe ent policy scenarios. It enables users to relate a target limit for temperature change to a global emissions ceiling; to allocate this emissions budget across countries using diffe ent policy rules; and then to calculate the costs faced by each country of decarbonising to meet its emissions budget using estimated marginal abatement costs, depending in part on whether and how much carbon trading is allowed.

This paper uses the kyShares model to explore one such scenario in detail. We look at the consequences of an agreement to stabilise climate change at 2 degrees Celsius; with convergence to equal per capita allocations of emissions by 2030; and to allow global emissions trading. We find that high income countries would fac relatively low costs of 0.56% of GDP in 2025 and 1.45% in 2030, rising to 2.97% by 2050. Low income countries would gain substantially because of their low per capita emissions. Ethiopia, for example, could increase GDP by a quarter in 2025 by selling unused emissions rights. Net financial flows to LICs would total approximately $153 billion a year in 2025, representing a major new source of finance for de elopment and for delivering the Sustainable Development Goals. Costs to developed countries of reducing carbon emissions to fit within thei emissions budget would be substantially higher without carbon trading.

This scenario offers t ee attractive characteristics: environmental security, because the global carbon budget is set to keep global warming below 2 degrees; economic efficien   , because carbon trading allows the reductions to be made for least overall cost; and global social justice, because emission rights are allocated equally to all people. It is the most affo dable approach for developed countries, while providing significant n w sources of development finance to tackle p verty in the developing world.

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Summary

2015 is a crucial year for sustainable development, on two counts. First, it will see the COP-21 climate change summit in Paris – a key moment in global efforts on climate change, at a point when the window of opportunity for limiting global average warming to 2 degrees Celsius is closing rapidly.

September 2015 will see a major summit in New York tasked with agreeing to new global Sustainable Development Goals to take over from the Millennium Development Goals. While the shape of the Goals is already clear, it remains to be seen whether governments can summon the political will to agree a delivery framework of equivalently high ambition – above all on financing the new goals (itself the subject of a key summit in Addis Ababa in July 2015).

In this paper, we explore the potential for an approach that could potentially offer a breakthrough on both stabilising the climate *and* financing development. Specifically, we imagine a framework in which:

- Countries agree to create a scientifically-derived global 'emissions budget', under which the world's total emissions decline steadily from year to year in order to stabilise the climate below a chosen maximum temperature increase.
- This emissions budget is then allocated between countries on the basis of convergence to equal per capita entitlements by an agreed date, from when countries' emission allowances would be in proportion to their populations.

We then set out findings from a detailed quantitative model that we have constructed, called SkyShares (available online at www.skyshares.org), which calculates both:

- what countries' emission allocations would be, under user-defined parameters, and;
- what their net costs would be, including both decarbonisation costs at home, and financial flows through international emissions trading if emissions trading is permitted. (The model automatically calculates each country's optimal mixture of the two for cost-effectiveness.)

Our headline finding is that an approach based on fair shares of a global emissions budget is both affordable for higher emitting countries, and potentially game-changing as a source of finance for development for lower income countries if emissions trading is permitted – something that higher emitting countries also have every incentive to push for, given that it substantially reduces their costs of compliance.

In our Reference Scenario (a 2° Celsius emissions budget, with early mitigation, and convergence to equal per capita allocations by 2030), we find that **high income countries as a group would face net costs of only 0.56% of GDP a year in 2025 and 1.45% in**

2030, rising to 2.97% by 2050. The United States would face net costs of 0.73% of GDP a year in 2025, and the European Union 0.30%.

Among emerging economies, China would face net costs of 1.37% of GDP a year in 2025, and Russia 1.59% - in both cases, higher than the equivalent figure for the United States. (This raises important issues about equity and fairness, which are discussed below.) On the other hand, lower emitting emerging economies would be net beneficiaries of the framework in early decades: India would gain 2.63% of GDP a year in 2025 and Brazil 0.50%, though they would then face net costs rather than benefits from around 2045 onwards.

Low income countries (LICs), finally, would stand to gain substantially in our Reference Scenario, given their very low per capita emissions. Ethiopia, for example, would stand to make 27.23% of its GDP a year by 2025, and Bangladesh 10.96%; low income countries as a group would gain 6.45% in 2025.

In dollar terms, the net financial flows to lower middle income countries would amount to $262.8 billion in 2025 (nearly twice as much as the $134.8 billion of *total* global Official Development Assistance flows in 2013), while those to LICs would total approximately $153 billion. This would therefore represent **a major new source of finance for development and for delivering the Sustainable Development Goals**.

The paper also sets out an Equal Stocks Scenario for comparison purposes. This is based on the same mitigation parameters as the Reference Scenario, and is again based on convergence to equal per capita entitlements. Unlike the Reference Scenario, however, this version converges to equal per capita shares of *stocks* of atmospheric carbon – in other words taking account of past emissions as well as current ones, going back to 1800, and then adapting future allowances correspondingly.

Overall, this has the effect of reducing upper middle income countries' costs and increasing those of developed countries. Under the Equal Stocks Scenario, we find that:

- Upper middle income countries' net costs are 0.62% of GDP in 2025 and 3.29% in 2050 – as compared to 0.73% and 4.20% respectively in the Reference Scenario.
- High income countries' net costs are 1.46% of GDP in 2025 and 5.87% in 2050 – as compared to 0.56% and 2.97% respectively in the Reference Scenario.

China is an outlier in the Equal Stocks Scenario in that while its costs become *proportionately* cheaper than those of the US in both 2025 and 2050, they rise in *absolute* terms in the earlier years of the framework. Under the Equal Stocks Scenario, China's net costs are 1.44% of GDP in 2025 and 4.20% in 2050 – as compared to 1.37% and 5.22% respectively in the Reference Scenario. The United States's net costs are 1.87% of GDP in 2025 and 7.07% in 2050 – as compared to 0.73% and 3.35% respectively in the Reference Scenario.

Our model is available online at www.skyshares.org to explore other alternative scenarios – including ones based on a specified 'coalition of the willing' rather than assuming full global participation at the outset – and for adaptation of the source code, which is open source and freely available.

1. Introduction: one year, two agendas

Climate change

The world is approaching the point at which it needs to start to get serious about international action to address climate change. The UN climate change process has now been underway for nearly a quarter of a century since the UN Framework Convention on Climate Change (UNFCCC) was signed in 1992. Over that period, global CO_2 emissions have risen by 60%.[1]

Atmospheric physicists have calculated that the world can emit no more than 3,500 billion metric tonnes of CO_2-equivalent in total in order to have a less than 50% chance of exceeding 2° Celsius of global average warming.[2] The world has already emitted nearly 2,000 billion tonnes of this 'emissions budget' since the mid-18th century, leaving it only 1,500 billion tonnes remaining – which, on current rates, are likely to be used up within the next two decades.[3]

As governments approach the 2015 COP-21 climate summit in Paris, then, there are strong scientific reasons for them to consider basing international climate policy on a global carbon budget, designed to keep the world below the 2°C threshold, and which would be allocated between all 196 of the world's countries.

The idea of emissions budgets is already embedded in some national contexts – most notably the United Kingdom, where the 2008 Climate Change Act set a long term, legally binding emissions reduction target for the UK of at least 80% below 1990 levels by 2050. The Act also created an independent Committee on Climate Change charged with advising the government on emissions targets and reporting to Parliament (and the public) on progress made towards them.

However, the idea of doing the same at global level has to date made much less headway, with the idea of a global emissions budget often seen as politically impractical by country negotiators – above all because of the charged issues of equity and fairness involved.

On one hand, it is hard to imagine developing countries ever agreeing that a common property resource like the atmosphere should be allocated indefinitely on the basis of 'grandfathering', with countries' allocations in proportion to their current emissions. Given that countries' emission levels are themselves usually proportionate to GDP, allocating an emissions budget on this basis would in effect be to create new property rights to a global commons, and then share them out on the basis that the richer a country is, the larger its share should be.

But on the other hand, many developed country negotiators have to date assumed that an allocation of emissions quotas on an equal per capita basis would be ruinously expensive for them, and as a result politically unsellable to their electorates.

While proposals have been advanced as ways of bridging this gap – most notably, the idea of a managed process of *convergence* to equal per capita rights over a negotiated period that could potentially be decades long, first proposed by the Global Commons Institute[4] – these to date have not achieved a major breakthrough in the UNFCCC negotiations.

The idea of a global emissions budget has hence remained off the table for most of the UN climate process to date – despite the fact that the need for such an approach could easily be seen as implied in Article 2 of the UNFCCC, which defines the overall objective of the Convention as "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system".[5]

Instead, the need for an equitable approach – defined in the Convention in terms of countries' "common but differentiated responsibilities and respective capabilities"[6] – has to date been interpreted as implying a sub-global approach in which only some countries would have quantified, binding emission targets.

Under the 1997 Kyoto Protocol, quantified targets were limited to developed countries only, with the US among the countries that declined to participate as a result, arguing that a global approach to climate change could only work if major developing country emitters had targets too. Subsequently, in 2009, the Copenhagen summit agreed a voluntary approach based on non-binding targets, known as 'pledge and review', at the behest of the US and major emerging economies.

However, the result of this approach, according to the International Energy Agency in its 2013 *World Energy Outlook*, has been to put the world on course not for limiting global average warming to 2°C, but instead for long term warming of 3.6°C – 5.3°C, with most of this warming likely to occur before the end of the 21st century.[7]

In this light, the need for a global emissions budget does not appear to have receded. Significantly, the last few months have seen some 'weak signals' that the issue may finally be starting to come on to the formal agenda. In November 2014, a 'non-paper' tabled by the UN climate secretariat mooted the possibility of "a global carbon budget to be divided amongst Parties in accordance with historical responsibilities, ecological footprint, capabilities, and state of development".[8]

More recently, in February 2015, an 86 page draft negotiating text for Paris – compiled on the basis of all Parties being able to submit whatever text they wished for discussion in later negotiating rounds in the run up to Paris – also included multiple mentions of the idea of a "global emission budget to be divided among all Parties".[9]

Against this backdrop, then, a key question for the future of the UN climate process – and for prospects for limiting global average warming to 2° Celsius – is how such an emissions budget might be shared out, and what the financial implications for individual countries might be.

Meanwhile, the vexed issue of climate finance also continues to be a major focus of the negotiations. Overall, around $331 billion a year of climate finance is flowing within, to, or between countries, with nearly 60% from private investment.[10] However, this is less than half the estimated total needed, and access to climate finance is especially challenging for Least Developed Countries (LDCs). Around 80% of Certified Emissions Reductions generated through the Clean Development Mechanism, an emissions trading mechanism under the Kyoto Protocol, went to just four countries, for example: India, China, Brazil, and Mexico.[11]

Now, with COP-21 in prospect, many LDCs are hoping that they will benefit from the Green Climate Fund, a UNFCCC mechanism that is supposed to raise $100 billion a year by 2020. But arguments remain unresolved over what proportion of this amount will come from public and private sources respectively, and as of May 2015 only around a tenth of the headline figure had been pledged by developed country governments.[12]

Financing the Sustainable Development Goals

2015 is also significant as a key milestone year for international development. The Millennium Development Goals (MDGs) expire at the end of 2015, and governments are due to agree their successors – Sustainable Development Goals (SDGs) – at a summit in New York in September 2015.

At the time of writing, the likely shape of the new SDGs is already clear, following the report of a UN-mandated intergovernmental 'Open Working Group' (OWG) on the agenda.[13] The OWG's report sets out proposals for a 17 Goal framework that includes a mixture of Goals that aim to finish what the MDGs began – most notably in SDG 1's ambition to eradicate absolute poverty altogether by 2030 – and Goals in wider areas, including climate change, sustainability, and inequality within and between countries.

However, while the content of the new SDG framework appears clear, less progress has been made on agreeing a concrete global delivery plan for achieving the new Goals ('means of implementation' in the process's jargon), despite a major summit on financing for development (FFD) held in Addis Ababa in July 2015, which was hallmarked by a lack of political will among higher income countries to agree on ambitious new action plans.

In part, this reflects momentous changes in the development agenda since the MDGs were agreed. Many developing countries are now increasingly able to finance their own development: total developing country tax revenue has increased from $1.5 trillion a year in 2000 to $7 trillion in 2011, for example.[14] Developing countries are also likely to account for 62-64% of global savings by 2030, up from 45% in 2010.[15]

Private sector flows to developing countries have also become far more significant than aid flows as a source of finance for development. In 2010, foreign direct investment (FDI) to developing countries was worth $514.3 billion, migrant worker remittances $325.3 billion, and portfolio equity flows $129.7 billion – as compared to Official Development Assistance (ODA) flows of $128.7 billion in the same year (0.32% of donor countries' gross national income).

But not all developing countries have benefited equally from these shifts. The main beneficiaries of higher FDI and domestic resource mobilisation have been middle income countries (MICs), especially those at the higher end of the bracket. While aid accounts for just 0.3% of the average MIC's GDP, it still accounts for 9.7% of that of the average low income country (LIC).[16]

Yet although least developed countries (LDCs) remain disproportionately reliant on ODA, compared to developing countries as a whole, they are also receiving a steadily diminishing share of it, with the OECD Development Assistance Committee (DAC) warning of a "worrying trend of declines in programmed aid to LDCs and low income countries, in particular in Africa".[17]

As a result, the post-2015 development agenda has seen growing calls for LDCs to receive a larger share of global ODA – whether through developed countries making good on their long standing promise to allocate at least 0.15% of gross national income to ODA in LDCs, or more recent proposals for at least 50% of total ODA to go to LDCs.[18]

However, while the Addis Ababa outcome document included language encouraging donors to spend more ODA in LDCs, it did not generate concrete, timetabled commitments by individual donors – a source of significant frustration and disappointment for LDCs.

Cascading failure or creative synergy?

While 2015 offers a major opportunity to achieve breakthroughs on both climate change and international development, it also presents real risks. As this section has discussed, both agendas have hugely challenging ambitions, whether limiting long term global average warming to 2°C, or eradicating absolute poverty by 2030.

Yet both agendas could also fall prey to much lower ambitions when it comes to delivery – with the attendant risk that the world fails to achieve its stated aims on climate change and development. While governments in both processes appear to believe that their best option may be to aim to play a long game and ratchet up ambition on delivery over the 2-3 years following 2015, this approach is fraught with danger. 2015 is, after all, a key 'moment in the sun' for each agenda; the political context will only get more difficult as other issues and priorities make their way on to the global agenda. There is also the risk that disappointing outcomes on either agenda create 'summit fatigue' among governments and further reduce already constrained political space for collective action at a time when the need for it has never been greater.

But it is also possible that 2015 could see the opposite dynamic, with progress on one agenda unlocking momentum and room for manoeuvre on the other, and vice versa – in particular if potential synergies between the two agendas can be identified and maximised.

As we set out in the next section, we believe that just such a potential synergy exists in the combination of a safe global emissions budget with equitable shares of that budget for all countries. The former offers a way of stabilising greenhouse gas concentrations; the latter, a major new finance for development flow that also helps higher emitting countries to keep their mitigation costs to a minimum.

2. Sharing the sky

Many climate negotiators have long believed that however desirable discussion of a global emissions budget as a way of stabilising atmospheric greenhouse gas concentrations might be in principle, in practice the idea is a political non-starter.

This belief has in turn been often based on an assumption that discussions of how to share a global emissions budget would inevitably become a purely zero sum game, with political dynamics collapsing in on the fact that a larger share for developing countries would imply a smaller share for developed countries, and vice versa.

We wanted to put this assumption to the test by putting some concrete numbers on possible scenarios, and exploring the potential for emissions trading to drive win-wins for countries in all income groups. To do this, we built a detailed quantitative model, which we called SkyShares.

The model is designed not only to explore potential ways of allocating a global emissions budget between 195 countries (or of a smaller, user-defined 'coalition of the willing'), but also to investigate what the financial implications would be on a country-by-country basis – including both

- the costs of decarbonisation at home, and
- the financial flows through international emissions trading between countries, if this is included as part of the framework – with the model automatically calculating the most cost-effective mix of the two.

Design principles

In overview, our approach to constructing the model was as follows (a detailed technical paper is also available [link]).

First, we created the capacity for the user to define a global emissions mitigation scenario. The most important variable here is the size of the carbon budget, which is defined by the desired maximum amount of global average warming, and by how cautious or optimistic the user decides to be about atmospheric variables. (As noted earlier, a 3,500 billion tonne CO_2 emissions budget carries a 50/50 chance of hitting the 2°C target. Raising the likelihood of keeping global warming below 2°C to 66% would reduce the overall carbon budget to 2,800 billion tonnes of CO_2.)

The other key variable in determining the mitigation scenario is how soon mitigation activity begins in earnest under the agreed framework. Waiting until 2020 rather than commencing mitigation activity on 1 January 2016, for example, makes a highly significant difference to the size of the emissions budget in later years and decades.

If mitigation begins immediately, emissions peak in 2019 at 40 billion metric tonnes of CO_2, requiring emissions reduction rates of 6.2% a year from then on. Starting a global mitigation regime 5 years later in 2020, by contrast, sees emissions peak in 2023 at a significantly higher level of 44 billion tonnes of CO_2 per year followed by a global average emissions reduction rate of 7.8% per annum from then on – a much harder sell politically for domestic electorates. Procrastinating on mitigation hence not only shrinks our window of opportunity for stabilising the climate, but also significantly increases the likelihood that policy-makers will renege on emissions pledges.

Second, we built in functionality for the user to define how the emissions budget should be allocated between countries. Four allocation algorithms are available in the model:

- **Per Capita.** Permits are allocated on the basis of equal per capita shares of each year's emissions budget (i.e. in proportion to countries' population sizes) – either as soon as the framework starts to operate, or by the end of a phased convergence period (this is the 'contraction and convergence' approach first proposed by the Global Commons Institute[19]).

- **Equal Stocks.** Permits are allocated on the basis of equal per capita shares of the *total* emissions budget from 1800 to 2100 – in other words, adjusted so that countries that emitted more in the past receive correspondingly fewer allowances in the future. (The user has the option to toggle to a start date of 1990, reflecting arguments that this was the start of the period when policy-makers knew that excessive concentrations of CO_2 were damaging.)

- **Per Dollar.** This scenario allows users to visualise the distributional implications of perpetuating the status quo, with countries' emission levels broadly (though not exactly) proportionate to their GDP per capita.

- **Historical Responsibility.** This scenario shares the burden of mitigation out among countries in proportion to their share of past emissions, so that the required rate of mitigation for each country is defined by the share of historic emissions that they are responsible for.

The allocation function also allows the user to select either a scenario in which the whole world participates in the framework, or any subset of countries – thereby allowing users to model potential 'coalitions of the willing'.[20]

Third, we built in capacity to model both the costs of emissions reductions, and the international financial flows that would result from permitting emissions trading. Any country with business as usual emissions set to overshoot their allocated quota would have two options. One is to introduce decarbonisation policies at home that are sufficient to bring their emissions down to within their quota.

Alternatively, if international emissions trading is permitted in the framework, the country in question may purchase the required emission permits from another country whose actual emissions total *less* than their allocated quota. (The model allows the user either to allow unrestricted emissions trading; or to disallow it altogether; or to stipulate that countries may use it only up to a defined cap.)

Assuming that emissions trading is permitted, we designed the model to calculate automatically the most cost-effective combination of domestic decarbonisation and international emissions trading. (In other words, higher emitting countries only purchase emissions trading permits from abroad when this is cheaper than undertaking the equivalent decarbonisation at home.)

Finally, we needed to make some assumptions about emission abatement costs, by using data on the Marginal Abatement Cost (MAC) of emissions abatement for each country. (MAC curves work by plotting emissions reductions below a given baseline against the cost of reducing the last additional tonne of CO_2 in the abatement target – in effect, showing how the cost of reducing emissions increases or decreases as the country goes further in reducing its emissions.)

We generated MAC curves by running the Global Change Assessment Model (GCAM) of the Pacific Northwest National Laboratory and the University of Maryland.[21] GCAM is an integrated assessment model with a technology-rich representation of the economy, energy, land use, and water sectors linked to an atmospheric physics model of the climate system. (GCAM is also used by the Intergovernmental Panel on Climate Change, which employs it to model Representative Concentration Pathway 4.5.)[22]

While the GCAM data-set is the default option, SkyShares also allows users to use data from the Massachusetts Institute of Technology's Emissions Prediction and Policy Analysis (EPPA) model[23], and from McKinsey's global greenhouse gas cost curve[24].

To calculate the most cost-efficient level of domestic abatement that each country should provide, SkyShares first numerically solves for the equilibrium price of CO_2 (or the shadow cost of carbon) – the price which will clear the market while ensuring that the coalition as a whole meets its abatement target.

Then, SkyShares looks up the quantity of domestic decarbonisation that the country will provide at that price in each country's MAC curve. Some countries will face higher costs of decarbonising at home than others, according to each country's particular institutional make-up, resource endowments and technological constraints. The full trade scenario in SkyShares thus ensures that decarbonisation happens where it is the cheapest to do so.

Defining a Reference Scenario and an Equal Stocks Scenario

For our benchmark Reference Scenario findings, we assumed a framework designed to limit global average warming to 2°C, with mitigation activity commencing immediately after agreement of the framework.

The scenario assumes that all countries participate from the outset, and that allocations of the global emissions budget converge from being in proportion to current emissions to start with, to equal per capita entitlements in the year 2030. Our rationale here was that, while there is no obviously intuitive way of sharing out the *burden* of mitigating emissions between countries, this changes when the question is how to share out property rights that are part of a *global emissions budget*.

We reasoned that the atmosphere is, after all, the quintessential example of a shared commons. At the point when climate mitigation requirements make it necessary to share out allocations to this resource, and new property rights within it are created, we believe that it makes intuitive sense that all people should enjoy the same share.

At the same time, the inclusion of a managed convergence period is intended to recognise the fact that time will be needed for countries to adjust from their current emission levels (which are broadly proportionate to their GDP) to a new allocation of entitlements proportionate instead to population. We selected 2030 as a middle of the road convergence date.

However, we also recognised that many developing countries will point to the issue of historical responsibility for past emissions as an important factor to take into consideration, including in how an emissions budget is shared out. The basis for these claims rests on the fact that many greenhouse gases have considerable longevity in the air, to the extent that emissions from Great Britain in the early years of the industrial revolution are still present in the atmosphere, exerting radiative forcing effects and contributing to climate change.

In recognition of this argument, we included in the model capacity for permits to be allocated on the basis of equal per capita shares of the *total* emissions budget from 1800 to 2100 – and we use this as the basis of an Equal Stocks Scenario to complement the Reference Scenario. (All other variables are held constant across the two scenarios.)

Finally, both scenarios permit unrestricted emissions trading between countries and assume that countries use this option where doing so is more cost-effective than undertaking the equivalent decarbonisation at home. Undiscounted financial flows[25] in the Reference

Scenario accruing to low income and lower middle income countries in 2030 are $431 billion and $699 billion respectively, with upper middle income countries paying $388 billion and high income countries paying $742 billion. With a 3% discount rate, these figures would decrease to an inflow of $269 billion and $436 billion in 2030 for low income and lower middle income countries respectively. Outflows would be $242 and $463 billion for upper middle income and high income countries, respectively.

Reference Scenario findings

Given the parameters just set out, our key findings were as follows.

First, an approach based on equal per capita shares of a cautious 2°C emissions budget is surprisingly affordable. In 2025, for example, the total global cost to keep within the global emissions budget comes to 0.13% of world GDP in that year. While costs do then rise in later decades, they never exceed 5% of global GDP, instead peaking at 4.97% of global GDP in 2080.

Costs are relatively low for high income countries. In 2025, net costs for high income countries as a group come to 0.56% of their GDP, rising to 1.91% in 2035. Costs do then rise in later decades, but always remain well below 5% of GDP, peaking at 3.55% of GDP in 2075. To give some examples:

- The United States's net costs are 0.73% of GDP in 2025, 2.38% in 2035, and 3.28% in 2075.
- The equivalent figures for the European Union are significantly lower in both the near and long term: 0.30% in 2025, 1.02% in 2035, and 3.05% in 2075.
- Russia faces proportionately higher costs than many other high income countries, at 1.59% in 2025, 5.25% in 2035, and 6.67% in 2075.

Costs are also affordable for middle income countries – although for upper middle income countries (UMICs), greater than those of high income countries as a proportion of GDP, a finding that is both counter-intuitive, and at odds with the principle of historical responsibility for past emissions (see below). For upper middle income countries as a group, costs are 0.73% of GDP in 2025, rising to 2.86% of GDP in 2035, and 5.58% in 2075.

- China's costs are significantly higher still than for those of UMICs as a group, at 1.37% of GDP in 2025, 4.40% in 2035, and 5.65% in 2075.
- Brazil, on the other hand, is a net beneficiary in the early years, gaining 0.50% of GDP from emissions trading in 2025 and 0.71% in 2035 (both figures are net gains as they takes into account the cost of decarbonisation undertaken at home), although it then faces net costs of 1.42% of GDP in 2050 and 2.79% in 2075.

Lower middle income countries (LMICs) are strong net beneficiaries in the early years of the framework as a result of their capacity to sell spare emissions permits through emissions trading: they gain 2.86% of GDP in 2025 and 4.09% in 2035. By 2050, however, they incur net costs of 2.13% of GDP, rising to 8.83% in 2075. Among LMICs,

- India gains 2.63% of GDP in 2025 and 2.56% in 2035, but then faces a net cost of 4.51% in 2050 and 9.59% in 2075.

- Nigeria gains 7.15% of GDP in 2025, 15.34% in 2035, and 8.86 % in 2050; it faces a net cost for the first time only in 2075 of 1.89% of GDP.

- Indonesia gains 0.60% in 2025 but already faces a net cost of 2.28% of GDP by 2035, rising to 15.54% in 2050 and as much as 25.03% in 2075.

In dollar terms, net financial flows to LMICs amount to $262.8 billion in 2025 (approximately twice as much as the $134.8 billion of *total* global Official Development Assistance flows in 2013)[26], and $833.8 billion in 2035. These inflows are particularly significant in view of the 'financing gap' faced by many LMICs, who find after they have graduated from LIC status that they are no longer eligible for many concessional aid flows, but not yet benefiting from foreign direct investment on the scale of UMICs nor as able to mobilise domestic resources through tax revenue.[27]

Low income countries, as the lowest per capita emitters, are the biggest beneficiaries of the framework, which creates a major new source of finance for development. As a group, LICs make a net gain 6.45% of GDP from emissions trading in 2025 (again taking into account any cost of domestic decarbonisation), 14.17% in 2035, and 8.72% in 2050.

- Ethiopia gains 27.23% of GDP in 2025, rising to 54.36% by 2035. In dollar terms, it would stand to make $17 billion in 2025 and $62 billion by 2035 from selling its allowances alone (the dollar figures represent gross flows of permit sales, and do not account for any decarbonisation costs).

- Bangladesh gains 10.96% of GDP in 2025 and 22% in 2035. Gross revenue from selling permits is $24.3 billion in 2025 and $81.9 billion a decade later.

The net flows of money to LICs and LMICs are large sums of money, then, that would potentially be game-changing both for individual LICs, and at global scale for prospects for achieving the Sustainable Development Goals that the world is about to agree.

But it is also worth reiterating that **each dollar spent by higher emitting countries on buying emissions permits from LICs saves these higher emitting countries money** – because, as noted earlier, our model only assumes that emissions trades take place where doing so is cheaper for the purchasing country than undertaking the equivalent emissions reductions at home.

	2025	2035	2050	2075
Low income countries	+6.45%	+14.17%	+8.72%	+0.62%
Lower middle income countries	+2.86%	+4.09%	-2.13%	-8.83%
Upper middle income countries	-0.73%	-2.86%	-4.20%	-5.58%
High income countries	-0.56%	-1.91%	-2.97%	-3.55%
World	**-0.13%**	**-1.04%**	**-2.76%**	**-4.89%**

Table 1. Net gains and costs as a share of GDP under the Reference Scenario (international emissions trading plus domestic decarbonisation)

Equal Stocks Scenario findings

As noted in the last section, one counter-intuitive finding of the Reference Scenario is that upper middle income countries face proportionately higher costs than high income countries. We therefore outline here an alternative scenario for comparison.

Like the Reference Scenario, the Equal Stocks Scenario is still based on convergence to equal per capita shares and the same overall mitigation parameters. Where it differs, however, is that countries are allocated equal per capita shares of the total *stock* of the carbon budget over time – so that countries that emitted more in the past receive correspondingly lower allocations in the future. (Under the Reference Scenario, by contrast, once convergence to equal per capita shares has taken place it is *each year's* emissions budget that is shared equally.)

The headline findings for each income group under the Equal Stocks Scenario (ESS) are summarised in Table 2 below, with the equivalent Reference Scenario (RS) figures shown alongside for comparison.

	2025		2035		2050		2075	
	ESS	RS	**ESS**	RS	**ESS**	RS	**ESS**	RS
LICs	**+12.94%**	+6.45%	**+20.72%**	+14.17%	**+15.94%**	+8.72%	**+7.87%**	+0.62%
LMICs	**+7.16%**	+2.86%	**+9.09%**	+4.09%	**+3.37%**	-2.13%	**-2.87%**	-8.83%
UMICs	**-0.62%**	-0.73%	**-2.14%**	-2.86%	**-3.29%**	-4.20%	**-4.32%**	-5.58%
HICs	**-1.46%**	-0.56%	**-3.62%**	-1.91%	**-5.87%**	-2.97%	**-7.56%**	-3.55%
World	**-0.13%**	-0.13%	**-1.04%**	-1.04%	**-2.76%**	-2.76%	**-4.89%**	-4.89%

Table 2. Net gains and costs as a share of GDP under the Equal Stocks Scenario and Reference Scenario (international emissions trading plus domestic decarbonisation)

As would be expected, **the lowest emitters – LICs and LMICs – are substantially better off under an equal stocks allocation**. LICs as a group benefit from financial inflows of some $305.8 billion by 2025 (compared to $153 billion in the Reference Scenario), while LMICs see inflows of $622.8 billion in the same year (compared to $262.8 billion in the Reference Scenario).

Upper middle income countries also face lower costs than under the Reference Scenario – although as a group, they still face net costs rather than benefits more or less as soon as the framework is up and running. As Table 2 shows, however, the differences in UMICs' net costs as a proportion of GDP between the Reference Scenario and the Equal Stocks Scenario are not dramatic (with less than 1% of GDP difference between the two until well after 2050).

High income countries' costs rise substantially under the Equal Stocks Scenario, and are higher than those of UMICs in every decade to 2100 – unlike in the Reference Scenario. However, their costs as a group are still only 1.46% of GDP in 2025 and 3.62% in 2035, though they later rise to 5.87% in 2050 and 7.56% in 2075.

For the world as a whole, the total costs remain unchanged across the two scenarios – the result that would be expected, given that the model automatically optimises domestic action versus emissions trading for maximum cost-effectiveness (unless the user restricts or disallows trading as a scenario parameter).

3. Conclusions

A moment of potential crisis or opportunity

The world's window of opportunity to limit global average warming to 2° Celsius is closing rapidly, but policymakers seem little closer to recognising up to what it will take to stabilise greenhouse gas concentrations at a safe level – a global emissions budget – than when the UN Climate Convention was agreed in 1992.

At the same time, policymakers are about to agree a Sustainable Development Framework of breathtaking ambition – but without so far showing much sign of willingness to be as ambitious when it comes to delivery, and above all financing.

At a point when mistrust and or acrimony risk becoming standing features of negotiations on both development and climate, there is a real risk that 2015 will see a breakdown of efforts to marshal collective action on both of these crucial global issues. But there is also the possibility that 2015 will live up to its billing, and mark an historic breakthrough on both of these intimately linked agendas.

This paper has set out a potential way of squaring this circle through a synergy that would both establish the comprehensive framework for solving climate change that the world has long needed, and in doing so create a major new source of finance for development.

Three key principles

The approach outlined in this paper is based on three principles.

The first is recognition of the need to translate scientific assessments more directly into political application, through the mechanism of a single global emissions budget. The size of the emissions budget could in principle be amended in future to take account of emerging scientific findings. (This raises the question of what kind of process – or institution – might be charged with exercising this review function, but we do not address that in this paper.)

Second, the approach outlined here is based on an assumption that if science dictates that it is necessary to allocate targets within this global emissions budget – targets that are, in effect, atmospheric property rights or 'sky shares' – then common sense dictates that it will be impossible to achieve global agreement on this unless the principle of per capita equity is front and centre.

We do not accept that this would constitute a form of global redistribution, as some might argue. Rather, it would be more accurately described as a form of *pre*-distribution, given that the property rights in question have not yet been created. Alternatively, it could be regarded as a *de jure* recognition of an existing *de facto* distribution of wealth. This can be seen as an interpretation of the vexed principle of Common But Differentiated Responsibilities that tends towards, rather than away from, a shared solution to climate change.

As we have seen, the principle of equal per capita entitlements still leaves considerable flexibility – for example through negotiating a delayed period of convergence during which emissions allocations move from current levels to per capita parity, or equal per capita shares of the total *stock* of emissions past, present, and future.

But we struggle to see how the principle of 'one person, one share of the sky' could be excluded altogether and forever from the question how a global emissions budget is allocated, given that the resource being shared is the most fundamental example of a global commons, and a shared inheritance that manifestly belongs to all of humanity.

Third and finally, the approach outlined here is based on a strong belief in the need for a market-based approach. We believe that a framework based on property rights, on pricing in environmental externalities, and on avoiding situations in which governments attempt to 'pick winners' from among technological options will be superior to one in which these attributes are absent.

A positive sum outcome

Finally, it is worth considering one of the objections sometimes made to proposals based on defining a global emissions budget and then sharing it out between 195 countries: that it would create a 'zero sum' dynamic as countries squabble over shares of a finite resource, and would make no allowance for future advances in technology that would bring down the cost of emissions reductions in future.[28]

We believe this argument to be wrong on two counts.

First, we think it is based on a misapprehension of how to manage shared environmental commons. Back in 1968, Garrett Hardin argued in his famous essay *The Tragedy of the Commons*[29] that common resources would inevitably lead to overuse and ultimately collapse as individuals rationally maximised their use of the commons. After its publication, he was rightly criticised for failing to allow for the fact that humans could – equally rationally – agree shared management frameworks for commons. Instead, as Nobel economics laureate Elinor Ostrom and others would point out, recognition of the need to cooperate to manage shared commons can be a powerful driver for *positive* sum dynamics.

Second, we believe that this argument overlooks the fact that it is precisely quantified caps on emissions that are most likely to bring down the costs of clean technology – in effect creating a virtuous circle whereby demand for lower emission technologies reduces their costs and makes them more widely available. Our approach does not merely anticipate future advances in technology; it *prices* them in, and takes seriously what will be necessary to *drive* those advances.

We think that the approach set out here is practical, not utopian. A framework based on the principles we have outlined would not depend on full global participation at the outset: on the contrary, it can work with a coalition of the willing, as the Sky Shares model will illustrate for any combination of countries.

While recognising that any comprehensive approach to climate change will involve costs, unrestricted use of emissions trading between participants keeps these costs as low as they can be.

Above all, we believe that the recent disappointing track record of multilateralism and the ongoing deficit of global leadership on today's defining issues points to an unmet need for big ideas about how we can take control of our shared global future. We believe that this is just such an idea.

Appendix: Why it makes sense to include emissions trading

SkyShares clearly illustrates why it makes economic sense (for *all* countries, rich or poor) to include emissions trading as part of the framework. Trading allows emissions reduction to happen where it is cheapest. The total costs faced by countries will be the cost of international emissions trading (buying allowances on the market) and the costs of decarbonisation at home. Since SkyShares calculates the most cost-effective mix of trading and domestic decarbonisation for each country, some countries may even choose to decarbonise further at home to be able to sell the equivalent amount of permits on the market.

Table 3 below shows the Reference Scenario results both with international emissions trading (column on the left), and without it (column on the right). All results are shown as a share of GDP.

(Carbon trading costs with a plus sign in front represent financial *outflows* to purchase emissions permits; carbon trading costs represented with a minus sign in front refer to financial *inflows*, i.e. money coming in to countries as a result of selling their permits. Since SkyShares simulates an efficient market, supply matches demand, and the sum of the flows is zero. Total costs are the sum of carbon trading costs and decarbonisation costs, therefore a net gain from the SkyShares regime is represented with a minus sign in front.)

	IF TRADING IS ALLOWED		**IF TRADING IS NOT ALLOWED**		
Decarbonisation Costs	*2030*	*2050*	*2030*	*2050*	
	0.52%	**2.76%**	**3.38%**	**4.17%**	*World*
	0.27%	1.24%	0.09%	0.41%	*LIC*
	1.01%	3.97%	0.17%	4.24%	*LMIC*
	0.78%	3.66%	3.85%	4.69%	*UMIC*
	0.33%	1.90%	3.84%	4.13%	*HIC*
plus Carbon Trading Costs	*2030*	*2050*	*2030*	*2050*	
	0%	**0%**	**0%**	**0%**	*World*
	-14.08%	-9.96%	0%	0%	*LIC*
	-6.42%	-1.84%	0%	0%	*LMIC*
	+1.25%	+0.54%	0%	0%	*UMIC*
	+1.12%	+1.07%	0%	0%	*HIC*
equals Total Costs	*2030*	*2050*	*2030*	*2050*	
	0.52%	**2.76%**	**3.38%**	**4.17%**	*World*
	-13.81%	-8.72%	0.09%	0.41%	*LIC*
	-5.41%	2.13%	0.17%	4.24%	*LMIC*
	2.03%	4.20%	3.85%	4.69%	*UMIC*
	1.45%	2.97%	3.84%	4.13%	*HIC*

Table 3. Comparison of costs if full trade is allowed or not

As the table shows, if trading is not allowed, then all costs naturally stem from domestic decarbonisation. As a result, **developing countries** not only miss out on the finance for development flow from emissions trading that they would otherwise gain, but actually incur net costs rather than a net gain.

If emissions trading *is* allowed, on the other hand, then developing countries are able to profit from the fact that their emissions are low. Revenues to low income countries more than make up for any emissions reduction costs at home, leading to net benefits of 13.81% in 2030 and 8.72% of GDP in 2050. Low income countries would also have clear incentives to maximise emissions reductions at home in order to continue selling permits on the international market, creating a strong incentive to 'leapfrog' past high polluting growth pathways and invest in green growth instead.

It is also worth highlighting that the benefits of emissions trading would flow most of all to low income countries, followed by lower middle income countries – in marked contrast to every other main form of finance for development. Low income countries have benefited much less than middle income countries from foreign direct investment and migrant worker remittances; they have less capacity to mobilise development finance from domestic sources; and they are also receiving a declining share of global ODA flows, despite their higher dependence on aid.

In this sense, the financial flows that would result from the scenarios discussed in our paper would be a valuable counterweight to current structural problems in development finance, with a powerful inbuilt poverty focus that results from the fact that the poorest countries are also almost invariably the lowest per capita emitters.

For **higher emitters**, emissions trading allows commitments to be met flexibly and at least cost (in both of our scenarios in this paper, emissions trading is only assumed to take place where it is cheaper than decarbonising at home) – with the result that their decarbonisation costs are reduced by a factor of almost 5 in the early years of the framework.

At **global level**, finally, the welfare gains of allowing trading are also clear. If emissions trading is allowed, then the total costs for the world to keep warming below 2°C come to 0.52% of world GDP in 2030. If countries are *not* allowed to trade, on the other hand, overall costs become multiplied by a factor of 6.5 to reach 3.38% of world GDP. And while the cost of purchasing permits on the market for high income countries is still only 1.07% of GDP in 2050, inflows to poor countries would be an order of magnitude larger and would represent nearly 10% of their GDP in 2050.

The use of emissions trading in our two scenarios stands in marked contrast to the current 'pledge and review' approach that has been the key idea in global climate policy since the Copenhagen summit in 2009. Under pledge and review, the fact that no provision is made for emissions trading means in effect that national pledges have to be carried out entirely through domestic decarbonisation – despite the additional expense and economic inefficiency entailed as a result.

But the provision for emissions trading in SkyShares is also very different from the way emissions trading was included in the 1997 Kyoto Protocol. Under Kyoto, emissions trading was open even to countries that did not have quantified caps on their emissions, through the Clean Development Mechanism (CDM) – a form of trading known as 'baseline and credit' (as opposed to 'cap and trade').

In baseline and credit trading, emissions reduction permits are issued to projects such as wind farms or installation of energy efficiency equipment by comparing the *actual* emissions from the project with a counterfactual estimate of what the emissions *would* have been in the absence of the project. This comparison with what would have happened in a hypothetical parallel universe naturally introduces severe uncertainty about whether real emissions reductions have actually taken place or not – an uncertainty compounded by the fact that various companies supposed to approve project accreditation for the CDM have had to be suspended by the United Nations amid alleged failures to check projects properly, including the world's largest such CDM accreditor, SGS UK.[30]

However, these problems do not apply to the scenarios outlined in this paper, because:

- All emissions trading envisaged in our scenarios would take place within a single global emissions budget.
- All countries engaged in emissions trading would have quantified, binding ceilings on their emissions; there is no potential for 'carbon leakage'.
- All trading would take place through 'cap and trade' emissions trading rather than 'baseline and credit'. No emissions permits are issued on the basis of hypothetical estimates of what emissions might have been in the absence of a given mitigation project.

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References

1 Calculations using data from the Carbon Dioxide Analysis Center (http://cdiac.ornl.gov/GCP/). The 2014 Global Carbon Project (version 1.1) shows global emissions of CO2 as 22.6 billion tonnes in 1992, and 36.2 billion tonnes in 2013. The raw data is quoted in tonnes of carbon. We convert them to tonnes of CO2 by multiplying by 44/12.

2 Raupach, M. R., S. J. Davis, G. P. Peters, R. M. Andrew, J. G. Canadell, P. Ciais, P. Friedlingstein, F. Jotzo, D. P. van Vuuren and C. Le Queré (2014), 'Sharing a quota on cumulative carbon emissions', Nature Climate Change. Available at http://www.nature.com/nclimate/journal/v4/n10/pdf/nclimate2384.pdf.

3 Meinshausen, M., M. Meinshausen, W. Hare, S. C. B. Raper, K. Frieler, R. Knutti, D. J. Frame and M. R. Allen (2009), 'Greenhouse-gas emission targets for limiting global warming to 2°C', Nature Climate Change. Available at http://www.nature.com/nature/journal/v458/n7242/abs/nature08017.html.

4 Aubrey Meyer (2001), Contraction and Convergence: The Global Solution to Climate Change, Green Books.

5 http://unfccc.int/resource/docs/convkp/conveng.pdf Article 2

6 Ibid Article 3

7http://www.iea.org/media/freepublications/executivesummary/WEO2013_Climate_Excerpt_ES_WEB.pdf

8 http://unfccc.int/resource/docs/2014/adp2/eng/11nonpap.pdf

9 http://unfccc.int/files/bodies/awg/application/pdf/negotiating_text_12022015@2200.pdf

10 http://www.worldbank.org/en/news/feature/2014/09/05/climate-finance-is-flowing-but-not-enough-yet

11 http://www.cdmpipeline.org/cdm-projects-region.htm

12 http://news.gcfund.org/wp-content/uploads/2015/04/GCF_contributions_2015_may_28.pdf

13 https://sustainabledevelopment.un.org/owg.html

14 Greenhill, R. and Prizzon, A. (2012), 'Who Foots the Bill? What new trends in development finance mean for the post-MDGs', ODI Working Paper 360, London: Overseas Development Institute.

15 World Bank (2013), 'Capital for the Future: Saving and Investment in an Interdependent World', Global Development Horizons report, Washington DC: World Bank.

16 Greenhill, R. and Prizzon, A. (2012), 'Who Foots the Bill? What new trends in development finance mean for the post-MDGs', ODI Working Paper 360, London: Overseas Development Institute.

17 http://www.oecd.org/newsroom/aid-to-developing-countries-rebounds-in-2013-to-reach-an-all-time-high.htm

18 See for example http://oecdinsights.org/2014/07/21/half-of-all-oda-should-go-to-the-least-developed-countries/

19 Aubrey Meyer (2001), Contraction and Convergence: The Global Solution to Climate Change, Green Books.

20 Our assumption here is that participating countries would receive exactly the same allocation as they would have under full global participation. The door would be left open for other countries to join in future, in each case taking on the same entitlement, for that year onwards, that they would have received had they joined from the outset. However, late entrants would of course forfeit the opportunity to be part of the initial negotiation about the size of the emissions budget and date of convergence.

21 The code of GCAM is publicly available at http://www.globalchange.umd.edu/models/gcam/. Please refer to 'SkyShares – Technical Background' for further detail on our methodology.

22 Thomson, A. M., K. V. Calvin, S. J. Smith, P. Kyle, A. Volke, P. Patel, S. Delgado-Arias, B. Bond-Lamberty, M. A. Wise, L. E. Clarke and J. A. Edmonds (2011), 'RCP4.5: A Pathway for Stabilization of Radiative Forcing by 2100', Climatic Change, 109:1-2, DOI 10.1007/s10584-011-0151-4.

23 The code for MIT's EPPA model is publicly available at http://globalchange.mit.edu/research/IGSM/eppadl. We have made some modifications to EPPA's underlying code to generate our MAC curves. Modifications of the model and interpretation of the results remain our responsibility. Please refer to 'SkyShares – Technical Background' for further detail on our methodology.

Paltsev, S., J. M. Reilly, H. D. Jacoby, R. S. Eckaus, J. McFarland, M. Sarofim, M. Asadoorian and M. Babiker (2005), 'The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Version 4.1', MIT Joint Program on the Science and Policy of Global Change Report 125, Cambridge, MA. See http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt125.pdf.

24 We are grateful to McKinsey & Company for allowing us access to version 3 of their Global Greenhouse Gas Abatement Cost Curve. See http://www.mckinsey.com/client_service/sustainability/latest_thinking/greenhouse_gas_abatement_cost_curves.

25 Adding a discount rate would not change the results presented as % of GDP, since GDP would also be discounted. A discount rate only affects the reported dollar values of financial flows, decarbonisation, and total costs.

26 http://www.oecd.org/newsroom/aid-to-developing-countries-rebounds-in-2013-to-reach-an-all-time-high.htm

27 See Homi Kharas, Annalisa Prizzon and Andrew Rogerson (2015), Financing the post-2015 Sustainable Development Goals: A rough roadmap, London: Overseas Development Institute

28 See for example http://www.theguardian.com/environment/2013/oct/24/ipcc-carbon-budget-warsaw-climate-change-christiana-figueres

29 http://www.sciencemag.org/content/162/3859/1243.full

30 http://www.businessgreen.com/bg/news/1806434/updated-carbon-market-un-suspends-british-cdm-project-accreditor