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Report

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Publication date:

2016

Permanent link:

<https://doi.org/10.3929/ethz-a-010677834>

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**Pie in the Sky:
Negotiating an equitable distribution of the
carbon budget**

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Abstract. The science is unequivocal: if we wish to limit global warming to 2°C we have at our disposal a certain carbon budget. We may burn this coal, oil or gas in the next thirty or fifty years and must leave the rest of the fossil fuels in the ground. How this carbon pie can be shared equitably has been the subject of fierce debate and is one of the most intractable problems of any climate change negotiation.

We present a simple mathematical model which will facilitate the negotiations: first participants will propose the equity principles by which they want to share the pie, then they will determine the weights they want to accord to each principle.

The model can also be used to assess the outcomes of past negotiations: by linear regression we can calculate the weights which best fit a negotiated result, and with the current “bottom-up” approach, we can assess the fairness of the individual contributions.

Keywords: climate negotiations, carbon budget, equitable distribution, fairness

Mots-clés: négociations relatives au climat, budget carbone global, répartition équitable, équité

1 Introduction

On Earth Day 2016, 175 parties signed the *Paris Agreement* [1] in New York, a record number for an international treaty. It seems that the international community is starting to take climate change seriously.

Indeed, the science is clear. The fifth report by the *International Panel on Climate Change* states that climate change is now ‘unequivocal’, and that human activity is the cause of it ([2], p. 2). The IPCC is also using the conceptually simpler carbon budget approach to convey what action is required: if we want to avoid disaster, there is a rather small amount of fossil fuel that can be burnt over the next century, and it has to be shared among nations.

This has reignited the discussion about justice: how can this budget be shared fairly? Some think that every human being should be entitled to his or her slice of the carbon pie. Others want to favor those that can make best use of their share or are in most need of it.

In the run-up to the Paris talks parties were asked to submit their claims and state why they thought their claim was fair. Some suggested cutting the carbon cake according to one principle, others according to another.

This apparent lack of system encouraged us to develop a very simple general model for the climate change negotiations: the goal of the negotiations is to find agreement on which fairness principles should be applied and which weight should be attached to each principle when sharing the budget among parties.

The model can also be used to assess the fairness of some proposed cutting of the carbon pie: using simple linear regression we can calculate with which weights certain fairness principles would have to be applied to arrive at such a cutting.

1.1 Related Work

The use of fairness principles for burden-sharing or the allocation of resources is quite common. The European Commission, for instance, recently suggested allocating refugees to its member states based on a weighted combination of population and GDP ([3], p. 88). The reason for this choice of factors and weights is not given in its proposal but is discussed in [4].

In the context of climate negotiations, a carbon pie cutting based on population and GDP, with equal weights, is proposed in [5]. The use of fairness principles

as a tool in those negotiations is investigated in [6]. The authors rank the principles, per party, according to their economic costs. They find that parties tend to emphasize those principles which generate least cost. Technical progress is injected as a dynamical element into the negotiation process in [7]. The author derives an allocation of the carbon budget based again on population and GDP.

The weights given to such principles in climate negotiations are inferred from empirical evidence in [8]. The authors obtained their data from a survey among delegates.

We see that there are instances of a general model but that the definition of a general model itself is lacking. With our work we try to fill this gap.

1.2 Acknowledgements

I wish to thank Tobias Langenegger and Philip Grech for their comments on a previous version of this paper.

2 Preliminaries

2.1 The Carbon Budget

Carbon dioxide is the most important of the greenhouse gases simply because so much of it is produced by the combustion of fossil fuels and cement production. About three quarters of the present change in global temperatures can be attributed to it.

Whereas other greenhouse gases like methane have a fairly short lifetime in the atmosphere, carbon dioxide will stay there for hundreds to thousands of years. This implies that we have a certain *carbon budget* at our disposal for staying below 2°C. If we exceed it, we (and future generations) will be in trouble.

An estimate of the size of this carbon budget is given as 2900 GtCO₂ in the most recent assessment report by the *International Panel on Climate Change* ([2], p. 10). About 1900 GtCO₂ of this have already been emitted, which leaves us with 1000 GtCO₂. This is our carbon pie.

2.2 Incompatible Claims

Parties to the climate negotiations each claim a slice of this pie.

In order to illustrate our model later, we select five of them. Due to their dissimilar backgrounds their positions diverge significantly.

- The *Alliance of Small Island States* (AOSIS) is a group of low lying countries that suffer most from the ongoing climate change. Members include countries like Tuvalu and Vanuatu, which are also on the UN's Least Developed Countries (LDC) list, but also rich Singapore. Emissions from these countries have steadily increased over the past twenty-five years, but have always been at a lower level than the global average.
- *China's* emissions have soared in the same period because of its economic growth and use of coal to feed it. In absolute terms it is currently the biggest emitter of greenhouse gases and responsible for more than one quarter of the global annual total of 34 GtCO₂. Its emissions per capita are also greater than average and range now above those of many industrialized countries. To be fair, one has to add that much of China's heavy industry now works to satisfy Western demand.
- Emissions from the twenty-eight *European Union* countries have, in relative terms, decreased considerably but are still above world average. The decline is thanks to the fact that many of the former Eastern Bloc's inefficient factories have been closed down or replaced by more efficient ones.
- *India's* emissions per capita are the lowest of all the parties considered here, only a third of the global average. Industrialization has not been at the same pace as China's but India is keen to catch up.
- Finally, the *USA* is the biggest emitter of greenhouse gases per capita in this list at almost three times the European level, although this value has been coming down lately.

All our data are from the World Resources Institute's Climate Data Explorer [9].

Here then are some basic facts for 2012, the last year for which the data is available. We take it as our base year.

Party	Population	Emissions		GDP	
		Total MtCO ₂	Per capita tCO ₂	Total Million USD	Per capita USD
AOSIS	57,998,380	171	2.96	312,263	5,384
China	1,350,695,000	9,313	6.89	4,517,460	3,345
EU28	501,340,957	3,611	7.20	15,123,050	30,165
India	1,236,686,732	2,075	1.68	1,393,627	1,127
USA	313,873,685	5,122	16.32	14,136,307	45,038
RoW	3,582,586,660	13,551	3.78	19,778,079	5,521
World	7,043,181,414	33,843	4.81	55,260,786	7,846

Table 1: Carbon dioxide emissions (2012)

2.3 Fairness in the Kyoto and Paris Agreements

The first legally binding international agreement that dealt with climate change was the *Kyoto Protocol*. It had been negotiated in 1997 during the third annual *Conference of Parties* (COP 3) to the *United Nations Framework Convention on Climate Change* (UNFCCC) which itself was an offspring of the Rio de Janeiro Earth Summit in 1992.

The Kyoto Protocol made an attempt to define a fair allocation of duties by applying the two Rio principles *Equity* and *Common But Differentiated Responsibilities* (CBDR): the developed countries (roughly the OECD members) listed in Annex I of the UNFCCC gave themselves reduction targets (a smaller slice of the pie) and had to provide financial and technical help to the developing Non-Annex I countries, which had no such targets and some lesser responsibilities.

The Kyoto Protocol managed to keep greenhouse gas emissions from Annex I countries roughly steady. Nonetheless, when in 2011 it was time to think about a follow-up agreement, annual global emissions had risen by a third, caused almost entirely by an increase in the use of fossil fuels, especially coal, in the developing world. As a result, Annex I parties were now only responsible for two fifth of global emissions.

There was greater sense of urgency, too: temperatures had risen faster than predicted, and COP 17 noted “with grave concern” that with current efforts chances

to hold the global average temperature below 2°C or even 1.5°C were getting slim indeed [10].

Parties therefore agreed that the old way of implementing the principles of Equity and CBDR by allocating burdens based on the distinction between Annex I and Non-Annex I countries was too crude and in need of an overhaul.

As a result, COP 17 launched the *Ad Hoc Working Group on the Durban Platform for Enhance Action* (ADP) and gave it the mandate to “develop a protocol, another legal instrument or an agreed outcome with legal force under the Convention applicable to all Parties” by 2015 [10].

Parties submitted contradicting proposals to the ADP, developing countries wishing to maintain the Annex I-Non-Annex I distinction, while developed countries argued against it. Brazil wanted to refer to historical emissions “since 1850” while India rejected any binding commitments for the developing countries.

The US suggested to continue with a bottom-up approach. In its submission dated 11 March 2013 to the ADP, it proposed for “Parties to define their own mitigation contributions, taking into account national circumstances, capacity, and other factors that they consider relevant.” It argued that parties could best judge their situation and derive appropriate measures. It also thought that no alternative would work: “An approach that imposes contributions from without is neither realistic nor likely to result in wide participation/implementation. It is hard to imagine agreement on any formula or criteria for imposition of contributions, as this would get into the most controversial issues; it is also hard to imagine that Parties would be willing to have other Parties dictate their contributions, even if not based on a formula/criteria, given national sensitivities.”

To address the danger of under-ambition with this approach, the US proposal suggested having a consultative period after draft contributions were put forward. This would allow parties and also the public to scrutinize the contributions and determine whether they were sufficient in view of the objective of the Convention. The consultative period would also induce parties to make their contributions clear and transparent with respect to “scope/timing/stringency/assumptions, etc.”

This idea of “self-differentiation” was adopted by the ADP, and the COP 19 in Warsaw 2013 invited parties to submit their pledges in the form of *Intended Nationally Determined Contributions* (INDCs) to the COP “by the first quarter of 2015 by those Parties ready to do so.” [11]

What the concept of self-differentiation lacked was a reference to the principles of the Convention. If everybody defined their own efforts, would the resulting burden sharing really be fair? The COP 20 in Lima tried to address this question. The Lima Call for Action [12] said, rather diffusely, that “information to be provided by Parties communicating their intended nationally determined contributions may include, as appropriate, inter alia, quantifiable information on the reference point (including, as appropriate, a base year), time frames and/or periods for implementation, scope and coverage, planning processes, assumptions and methodological approaches including those for estimating and accounting for anthropogenic greenhouse gas emissions and, as appropriate, removals, and how the party considers that its intended nationally determined contribution is fair and ambitious.”

The UNFCCC secretariat was then to give its judgement on whether with the parties’ INDCs the objective of the Convention, i.e. the 1.5 or 2°C target, could be met, or whether there was an “ambition gap,” and also assess the aggregate (but not the individual) fairness of the parties’ submissions.

This the secretariat did in its synthesis report to the COP 21. It noted that “specific criteria for evaluating fairness include responsibility, capability, mitigation potential and cost of mitigation, the degree of progression/stretching beyond the current level of effort, and the link to objectives and global goals. Most Parties in their INDCs view responsibility directly or indirectly in the context of their past, current and future share in the global emissions and per capita emissions in comparison with global averages. Regarding the capacity to contribute, considerations include the level of development, GDP per capita, ability to invest in mitigation, and international support received. Some Parties listed the potential for cost-efficient mitigation and past efforts among the fairness criteria.” ([13], section C.27).

3 Fairness Principles

In this section we list some of the fairness principles which can be extracted from the secretariat’s report. Each principle is applied by selecting an indicator which defines a cutting of the carbon pie. For a discussion of the ethical background see [14] or [15].

3.1 EQUAL PER CAPITA

The most intuitive way to share the carbon budget is to give a slice of identical size to every person on Earth, and the party gets a slice proportional to the size of its

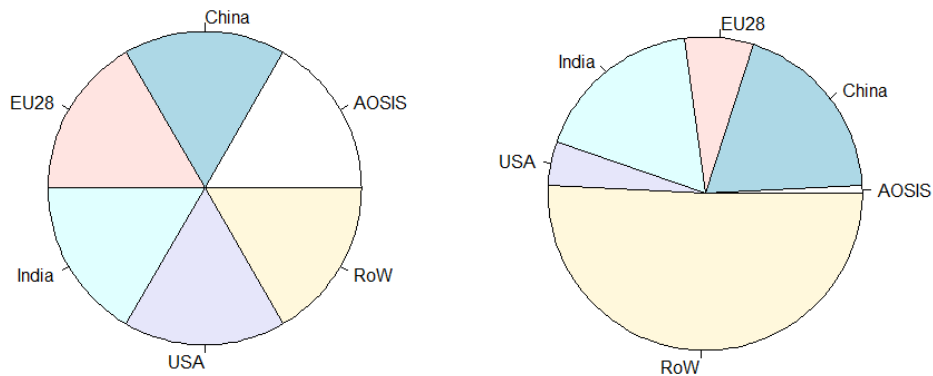


Figure 1: EQUAL PER CAPITA (per capita/per party)

population. Yet this approach has its own problems. First of all, it is not clear which reference year should be used for population size. Between the years 1990 and 2010, India added 40%, Nigeria 70% to its population, whereas it was almost stable in Japan (2014 data from The World Bank [16]) .

Taking the average over some period might help, but since the budget concerns the future, the size of a party's population in ten or twenty years should be taken into account, too. Predictions of this kind are however difficult to make. 22% of the Japanese are younger than 25, whereas this number is 66% in Nigeria. On the other hand, life expectancy at birth in Nigeria is only 52 years, while the Japanese on average live up to 85.

3.2 EQUAL ACCESS

There is another complicating factor: people may not get the same benefit out of burning one ton of coal.

How much energy is needed to keep one's home at a pleasant temperature depends of course on the local climate. Similarly does living in a sparsely populated area increase one's need for transportation. EQUAL ACCESS states that unequal access to some basic services should be compensated by a larger share of the emission budget.

3.3 BASIC NEEDS

According to this principle everybody should receive a share of the budget which meets their basic needs and the remainder could be distributed following some other principle.

What is problematic with this approach is that there is wide disagreement among individuals and countries as to how much is enough.

3.4 EQUAL BURDENS

The cost of mitigation also varies considerably. First of all, in general prices differ across countries even when they are adjusted for purchasing power or GDP. But marginal costs in a country which has invested heavily in mitigation will also be high since it will have exhausted the cheap means to reduce emissions. A per head allocation of the budget on the other hand would favor the laggards.

3.5 ABILITY TO PAY

Apart from cost, there is also the ability to pay which should be taken into consideration. Even when mitigation costs are high, if a party can afford to pay then it should. Usually GDP is taken as an indicator for this principle, and the size of the

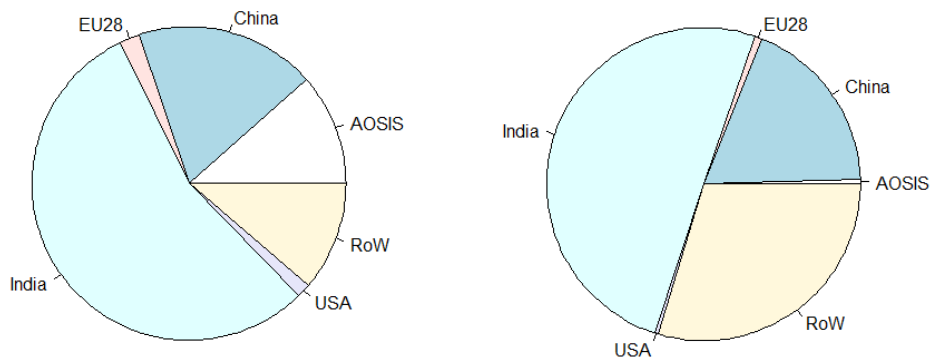


Figure 2: ABILITY TO PAY (per capita/per party)

slice relative to its inverse. We see that India under ABILITY TO PAY gets more than half of the carbon pie, reflecting the size of its population and low GDP, which restricts its potential for mitigation.

3.6 GRANDFATHERING

Finally, the principle of GRANDFATHERING allocates future emissions in proportion to past or current emissions. It is not equitable since it rewards those who have with

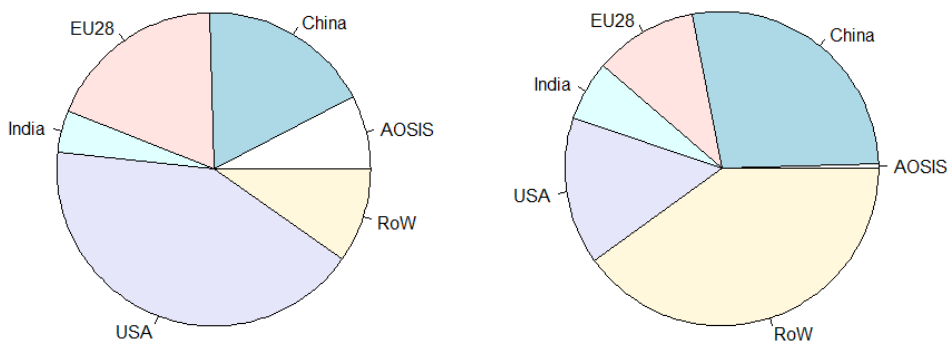


Figure 3: GRANDFATHERING (per capita/per party)

more. Nevertheless, this was the principle used in the Kyoto Protocol, at least for the industrialized nations.

4 A Model for Negotiation on Principles

4.1 Notation

We introduce some notation.

In general, we have $n \geq 2$ parties to the negotiations. Let Π denote a *principle* which assigns a fraction p_i^Π of the global carbon budget B to each party i . Denote party i 's budget by B_i^Π . The fractions p_i add up to 1 but they can be negative (meaning a party has *debts*) or larger than 1 (meaning a party is owed by the others).

If we wish to look at budgets or fractions of a particular year y we indicate this by writing ${}_yB$ or ${}_yp$.

P stands for (global) *population*, E for (global) *carbon emissions*, ${}_yE$ for emissions of a certain year, and ${}_{y_0}^{y_1}E$ for aggregate emissions from (and including) year y_0 up to (and not including) year y_1 .

More notation will be introduced as we go along or will be self-explanatory.

4.2 Introductory Example: EQUAL PER CAPITA **versus** GRANDFATHERING

We start by looking at the two principles EQUAL PER CAPITA and GRANDFATHERING discussed in sections 3.1 and 3.6.

EQUAL PER CAPITA means that allocation is according to population size. So let B_i^{EPC} be party i 's share of the carbon budget according to EPC. We have

$$p_i^{\text{EPC}} = \frac{P_i}{P}$$

and hence

$$B_i^{\text{EPC}} = B \times p_i^{\text{EPC}} = B \times \frac{P_i}{P}$$

GRANDFATHERING on the other hand allocates a share of the budget to a party i which is proportional to its share of carbon dioxide emissions or

$$p_i^{\text{G}} = \frac{E_i}{E}$$

and hence

$$B_i^{\text{G}} = B \times p_i^{\text{G}} = B \times \frac{E_i}{E}$$

If we let A denote global emissions per capita and A_i emissions per capita of a party i (A for *average*) we can write $E = P \times A$ and $E_i = P_i \times A_i$, and have

$$B_i^{\text{G}} = B \times \frac{E_i}{E} = B \times \frac{P_i \times A_i}{P \times A} = B \times \frac{P_i}{P} \times \frac{A_i}{A} = B_i^{\text{EPC}} \times \frac{A_i}{A}$$

From this we note that GRANDFATHERING is more favorable to a party if its average emissions are higher than the global average, whereas EQUAL PER CAPITA favors countries with low emissions.

4.3 Mixing EQUAL PER CAPITA, ABILITY TO PAY and GRANDFATHERING

Let us now apply the model to three principles. In order to represent intermediate positions we simply take their linear combination. So let $\alpha_{\text{EPC}} + \alpha_{\text{ATP}} + \alpha_{\text{G}} = 1$ and define for party i

$$p_i^{\alpha_{\text{EPC}}\text{EPC} + \alpha_{\text{ATP}}\text{ATP} + \alpha_{\text{G}}\text{G}} := \alpha_{\text{EPC}} p_i^{\text{EPC}} + \alpha_{\text{ATP}} p_i^{\text{ATP}} + \alpha_{\text{G}} p_i^{\text{G}}$$

and

$$B_i^{\alpha_{\text{EPC}}\text{EPC} + \alpha_{\text{ATP}}\text{ATP} + \alpha_{\text{G}}\text{G}} := \alpha_{\text{EPC}} B_i^{\text{EPC}} + \alpha_{\text{ATP}} B_i^{\text{ATP}} + \alpha_{\text{G}} B_i^{\text{G}}$$

We note that by linearity the fractions of the different parties add up to a whole.

If we mix the principles equally we get the following fractions

Party	Fraction based on principle			Mixed principles
	p^{EPC}	p^{ATP}	p^{G}	$p^{(\text{EPC} + \text{ATP} + \text{G})/3}$
AOSIS	0.81	0.48	0.50	0.60
China	19.17	18.48	27.52	21.72
EU28	7.11	0.76	10.67	6.18
India	17.57	50.25	6.14	24.66
USA	4.45	0.32	15.11	6.62
RoW	50.88	29.70	40.05	40.21

Table 2: Mixed principles

Let us quickly interpret these numbers.

Grandfathering represents the status quo, so AOSIS countries would be entitled to a slightly increased share.

China's emissions are more than average today and despite its relatively low GDP per capita it would have to cut emissions somewhat but not as much as the European Union, which because of its financial strength would get rather less of the carbon pie.

India on the other hand has the lowest GDP per capita of all parties considered and also had below average emissions, so it will be entitled to a much larger share than it has had in the past.

The USA, finally, would get a lot less than today yet still more than average because of current high emissions.

4.4 Calculating the Best Fit: How Principled was Kyoto?

We cannot today assess the fairness of the submitted INDCs since their impact on parties' future emissions has not been sufficiently investigated. We can however use our model to calculate the fairness of the Kyoto Protocol.

In order to do this we ask the question how much the allocation of the individual budgets to our six parties matched the application of the three principles EQUAL PER CAPITA, ABILITY TO PAY and GRANDFATHERING. Had countries decided

in 1997 to use our principled approach and agreed on appropriate weights, could we from the result today infer what the most likely value would have been?

Of course only Annex I countries made pledges, and AOSIS, China, India and all others were left to do business as usual. So for the EU28 and USA we take their pledged reductions for 2012 based on the parties' emissions in 1990 whereas for AOSIS, China, India and the Rest of the World we take the actual emissions in 2012. We let the budget 2012 be the sum these numbers.

Doing this we get three numbers for each party: fractions of the budget p^{EPC} , p^{ATP} and p^{G} calculated with EQUAL PER CAPITA, ABILITY TO PAY and GRANDFATHERING, and its fraction p of the current budget.

Party	Fraction based on principle			Pledges MtCO ₂	Emissions MtCO ₂	Real values p	Fitted values p^{fitted}
	p^{EPC}	p^{ATP}	p^{G}				
AOSIS	0.82	0.34	0.54		171	0.48	0.61
China	20.99	36.34	14.05		9,313	26.13	17.68
EU28	8.21	0.53	16.98	4,954		13.90	13.52
India	16.90	52.81	3.80		2,075	5.82	11.33
USA	4.65	0.19	23.45	5,572		15.64	17.17
RoW	48.45	9.78	41.19		13,551	38.03	39.68

Table 3: Best fit for Kyoto

We want to find coefficients α_{EPC} , α_{ATP} and α_{G} for this set of data which sum up to 1 and best describe the relationship

$$\alpha_{\text{EPC}}p^{\text{EPC}} + \alpha_{\text{ATP}}p^{\text{ATP}} + \alpha_{\text{G}}p^{\text{G}} = p.$$

To achieve this we do a simple linear regression to obtain $\alpha_{\text{EPC}} = 0.21$, $\alpha_{\text{ATP}} = 0.10$ and $\alpha_{\text{G}} = 0.69$ (the fit is quite bad, though).

Let us now say that these values were indeed agreed on by negotiation. We can interpret this thus: GRANDFATHERING was given much more consideration than the ABILITY TO PAY, whereas EQUAL PER CAPITA lies somewhere in the middle. When we look at the fitted values we see that China has emitted more than its proper share, whereas the AOSIS nations and India made do with rather less than their due.

4.5 Mixing Principles: the General Model

We now give a general definition of our model.

Definition. A *Model of Negotiation on Principles* for n parties consists of

- A family $\{\Pi_j\}_{0 \leq j < k}$ of k principles each defining a family of fractions of I , i.e. n real numbers $\{p_i^{\Pi_j}\}_{0 \leq i < n}$ such that $\sum_i p_i^{\Pi_j} = 1$ for all j .
- k real non-negative weights α_j such that $\sum_j \alpha_j = 1$.

Also, for k principles Π_j and weights α_j we define the principle $\Pi = \alpha_0 \Pi_0 + \dots + \alpha_{k-1} \Pi_{k-1}$ by setting for all i

$$p_i^{\alpha_0 \Pi_0 + \dots + \alpha_{k-1} \Pi_{k-1}} := \alpha_0 p_i^{\Pi_0} + \dots + \alpha_{k-1} p_i^{\Pi_{k-1}}$$

We can easily check that the fractions thus defined add up to 1.

4.6 Assessing Proposals

Using regression as we did in the previous section we can determine the weights which would have to be attached to the different principles to define a certain allocation of the budget to parties.

Simply let p be the proposed fraction of the budget for all parties and let p^{Π_j} their fraction by principle j , $0 \leq j < k$, then do a multiple linear regression for

$$\sum_{j=0}^{k-1} \alpha_j p^{\Pi_j} = p$$

with side condition $\sum_{j=0}^{k-1} \alpha_j = 1$.

This way we can judge which set of fairness principles come closest to describing a certain cutting of the carbon pie and whether under these principles individual parties receive more or less of their due share.

4.7 Historical Emissions

Next we turn to historical emissions. Here the discussion centers on whether historical emissions should be taken into account when calculating the budget.

If we decide that past emissions should be disregarded then allocations are as defined in the previous section. On the other hand, we could also decide to have

emissions count in their entirety starting from some year in the past when calculating the budget for the current year.

Let us again look at an example. If in 2012 we have a global budget of 1000 GtCO₂ to keep the 2°C limit then in 1990 we had a budget of 1000 GtCO₂ plus the aggregated global emissions in between. Based on this global budget and using 1990 numbers we can calculate what each party's budget would have been for 1990 and then subtract its emissions since then to arrive at its adjusted budget for 2012. Of course we could also decide to only count a fraction α of the historical emissions.

Here are the details:

- The total budget in 1990 consists of the budget of 2012 plus the aggregated global emissions

$${}_{1990}B = \alpha {}_{1990}^{2012}E + {}_{2012}B$$

- For every party i we calculate its share ${}_{1990}B_i^\Pi$ of the total budget according to some principle Π with 1990 numbers as defined above.
- We then subtract the emissions of party i since the base year from its share to arrive at its present budget

$${}_{2012}B_i^\Pi = {}_{1990}B_i^\Pi - \alpha {}_{1990}^{2012}E_i$$

- We calculate its fraction of the total budget as

$${}_{2012}P_i^\Pi = \frac{{}_{2012}B_i^\Pi}{{}_{2012}B^\Pi}$$

5 Discussion

5.1 How realistic is the model?

Let us reflect on what we did in section 4: we introduced our simple model of negotiation building on fairness principles. Each principle defines an allocation of the carbon budget to the parties. Negotiators have to agree on how much weight they want to give to each principle to arrive at a fair distribution.

This is a top down approach which was rejected in Paris. Executive secretary of the UNFCCC Christiana Figueres had said that carbon budgets were a good scientific exercise but that they could not be the basis for negotiations. ‘I don't think

it's possible,' she told the Guardian in an interview [17]. 'Politically it would be very difficult. I don't know who would hold the pen [in setting out allocations of future budgets].'

The United States concurred: 'It is hard to imagine agreement on any formula or criteria for imposition of contributions, as this would get into the most controversial issues.' [18].

The Paris Agreement [1] hence abandoned Kyoto's top-down approach in favor of a bottom-up mechanisms: every five years parties are to submit ever more ambitious climate action plans. These are published and their aggregate effect on the climate is calculated by the climate secretariat. Any explicit reference to fairness has been omitted from the agreement and been replaced by the previous equity and CBDR.

Individual contributions will however continue to be critically assessed by others also with respect to fairness and ambition.

5.2 Bottom-Up Allocation

Let us go back to our example in section 4.3 and see what will happen if our five parties and the rest of the world each define an allocation based on the three available principles of EQUAL PER CAPITA, ABILITY TO PAY and GRANDFATHERING. Let us further assume that they all opt for the principle that is most beneficial to them. From Table 2 we get the following allocations:

Party	Most beneficial	
	principle	allocation
AOSIS	EPC	0.81
China	G	27.52
EU28	G	10.67
India	ATP	50.25
USA	G	15.11
RoW	EPC	50.88
World		155.24

Table 4: Bottom up allocation

We see that the budget is overshoot by some 50 percent, which tallies quite well with the climate secretariat's estimates ([13], section D).

6 Conclusion

Phased top-down

While for the above reason a bottom-up approach is not likely to keep us on a 1.5°C or even 2°C emissions pathway, releasing the budget in phases while working top-down might actually be a good idea.

The main argument for a phased approach is that the world changes. An allocation of the greenhouse gas budget based on whichever mix of principles is certain to become obsolete over time. It therefore makes sense to reassess the situation pe-

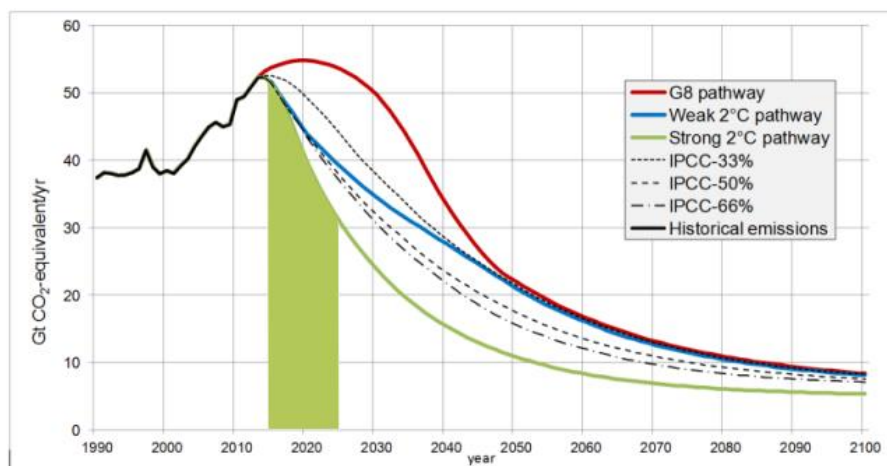


Figure 4: Phased top-down approach (modified IPCC graphic)

riodically, say every ten years. This would have to be done the following way:

- Apportion the total budget to the next decades in line with the recommendations of the IPCC [2].
- At the start of every decade allocate the next portion of the budget to the parties using our Model of Negotiation on Principles with numbers reflecting the new situation.

7 Further Work

The work presented here can be expanded in a number of ways.

7.1 Search for good Indicators

As we explained in section 3 the choice of indicators for our principles, although common, is quite controversial. For instance, it would be desirable to find an economic justification for $1/\text{GDP}$ to be selected as an indicator for ABILITY TO PAY.

Little work seems to have been done on BASIC NEEDS and EQUAL BURDENS. While a strong case can be made for these principles to be reflected in a formula, finding good indicators is a challenge.

7.2 Determination of weights

When the principles and indicators are selected, the weights have to be determined. This can be done by negotiation, but there might also be a natural choice, for instance to minimize associated cost.

7.3 Relation to game and negotiation theory

As we noted in section 5.2, when parties select the principles by which to stake their claims, the sum of those claims is likely to be bigger than the cake. This is an instance of the well-known *bankruptcy problem*. There are several solutions to this (see [19]), each leading to a different set of weights.

In general, the methods provided by game and negotiation theory should be applied to probe our model further.

7.4 Use in other contexts

Finally, our approach might be useful in contexts other than climate negotiations. The allocation of funds or the calculation of refugee quotas needs to be seen as fair and transparent to be acceptable to parties. Here, too, our approach might prove useful.

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