- machine translation of the original in German -

Paris-compatible emissions targets for the six largest emitters

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published on zenodo

Abstract

What are realistic emissions targets for the six largest emitters that are Paris-compatible in total? To investigate this question, key framework data on the available budget and its allocation mechanism are varied and top-down national emissions targets are calculated. The Paris ambition mechanism[1] stipulates a combination of top-down and bottom-up. Individual countries must therefore ask themselves to what extent their bottom-up targets fit with global requirements. This can initiate a goal-oriented discourse on the global framework data, which contributes to Paris-compatible NDCs.

Global CO2 budgets

CO2 accumulates in the atmosphere. Therefore, the sum of CO2 emissions is crucial for keeping global warming within certain limits. The IPCC published the following figures on the remaining global CO2 budget in its 2018 Special Report:

Approximate Warming since 1850 – 1900	Remaining Carbon Budgets		Key Uncertainties and Variations					
			Earth System Feedbacks	Non-CO_2 scenario variation	Non-CO_2 forcing and response uncertainty	TCRE distribution uncertainty	Historical temperature uncertainty	Recent emissions uncer-tainty
Probabilities:	*50%*	*67%*						
[°C]	[$GtCO_2$ from 2018 on]		[$GtCO_2$]	[$GtCO_2$]	[$GtCO_2$]	[$GtCO_2$]	[$GtCO_2$]	[$GtCO_2$]
~ 1.50	580	420	Budgets on the left are reduced by about −100 on centennial time scales	±250	-400 to +200	+100 to +200	±250	±20
~ 1.57	710	530						
~ 1.60	770	570						
~ 1.67	900	680						
~ 1.75	1040	800						

Tab. 1: Remaining global CO2 budgets as of 2018 [2]

In the Summary for Policymakers, the IPCC states:

"C.1.3 ***Limiting global warming requires limiting the total cumulative global anthropogenic emissions of CO2*** *since the preindustrial period, that is, staying within a total carbon budget (high confidence). (...) The associated remaining budget is being depleted by* ***current emissions*** *of* ***42*** *± 3* ***GtCO2 per year*** *(high confidence). (...) Using global mean surface air temperature (...) gives an estimate of the* ***remaining carbon budget*** *[from 2018] of 580 GtCO2 for a 50% probability of limiting warming to* ***1.5°C****, and* ***420 GtCO2*** *for a* ***66% probability*** *(medium confidence). (...)* ***Uncertainties in the size of these estimated remaining carbon budgets are substantial*** *and depend on several factors. (...)*" (IPCC, 2018b, p. 14). [3]

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[1] For a description of the ambition mechanism see (BMU, 2019). The Parties should have submitted their revised NDCs in 2020. Unofficially, this first round of revisions was extended until the climate conference in Glasgow (COP26) in November 2021, which was postponed due to Corona. The UNFCCC also intends to submit an updated synthesis report by then (cf. UNFCCC, 2021). If the first round of improvements does not lead to Paris-compatible targets, the second round of improvements scheduled for 2025 seems late in view of the reductions already needed by 2030. In 2023, the Paris Agreement stipulates a global review of progress towards the Paris climate goals (Global Stocktake).

[2] Tab. 1 based on Table 2.2 in the IPCC Special Report 2018, which is not reproduced here on a one-to-one basis (cf. IPCC, 2018a). The probabilities given indicate the percentage of scenarios examined in which the temperature target was met (cf. MCC, 2020). For further scientific background information, please refer to the IPCC report.

[3] Emphasis and [from 2018] not in the original.

The need to assess societal impacts of the pace of decarbonisation and the probabilities/ranges in the budgets mentioned by the IPCC necessitate a political decision, based on scientific knowledge on which global CO2 budget nationally determined contributions (NDCs) should be guided by.

If the States Parties make transparent an underlying global CO2 budget and its allocation in their NDCs, this could initiate a discourse that eventually leads to converging global benchmarks.

Current emission targets of the six largest emitters

At the April 2021 climate summit convened by US President Biden, the following - in part new - commitments were made by the six largest emitters, who together are currently responsible for around 70% of annual global CO2 emissions:

<table>
<tr><th>Country</th><th>Target year 2030</th><th>Reference year (base year)</th><th>Long-term goal</th></tr>
<tr><td>United States</td><td>-50%</td><td>2005</td><td rowspan="3">Climate neutrality by 2050</td></tr>
<tr><td>EU</td><td>-55%</td><td>1990</td></tr>
<tr><td>Japan</td><td>-46%</td><td>2013</td></tr>
<tr><td>India</td><td>33 to 35% lower emission intensity in relation to the national product</td><td>2005</td><td>Per capita emissions should never exceed those of the developed world</td></tr>
<tr><td>Russia</td><td>-25% to -30</td><td>1990</td><td>Reduce emissions significantly by 2050</td></tr>
<tr><td>China</td><td>Turning point CO2 emissions before 2030</td><td>-</td><td>CO2 neutrality before 2060</td></tr>
</table>

Tab. 2: Current emission targets of the six largest emitters [4]

Are these pledges sufficient to meet the Paris climate targets, especially for the target year 2030? To approach the answer to this question, one possibility is to calculate national emission targets as reference values that arise top-down under different global framework data.

Principles used here to calculate national emission targets

For the calculation of concrete national emission targets on the basis of global framework data for the six largest emitters, the Extended Smooth Pathway Model (ESPM) is used below, which consists of two calculation steps (cf. Wiegand, et al., 2021):

(1) Determining national budgets

In order to derive national budgets from a global budget, an **allocation key is** needed.[5] In the following exemplary national emission targets, a weighted key is used that takes into account a country's share of global emissions and its share of the global population in 2019. This multidimensional distribution key allows to represent both the reality with current *emissions*

[4] Sources: Climate Action Tracker (https://climateactiontracker.org) and current reporting.

[5] In contrast, in convergence models, such as the Regensburg model, a global pathway is divided among countries, with per capita emissions converging (cf. Sargl, et al., 2017). Both the ESPM and convergence models can be classified as resource sharing models. (cf. Sargl, et al., 2021).

and the issue of climate justice with *population* (cf. Raupach, et al., 2014).[6] However, our Excel tools can also be based on national budgets calculated differently.

(2) Derivation of national emission paths

Plausible emission paths are derived that adhere to the budget. With the Regensburg Model Scenario Types, we offer the entire range of plausible possibilities. For reasons of simplification, a linear progression of the **emission paths** (RM-6) is assumed below.

Excursus:

Regensburg Model Scenario Types (cf. Wolfsteiner & Wittmann, 2021a)

From an overall climate policy perspective, other trajectories than a linear emissions path (straight line) may make more sense (cf. Wiegand, et al., 2021). Additional scenario types also offer the possibility of taking country-specific features into account.

The Regensburg Model Scenario Types 1 - 5 are based on the course of the annual reduction rates. The following four basic types can be distinguished with regard to the increase in annual reduction rates with a monotonous course:

(1) Constant: constant annual reduction rate (RM-1)
(2) Linear: linear increase (RM-3)
(3) Concave: initially under-proportional increase (RM-4, RM-2)
(4) Convex: initially over-proportional increase (RM-5)

In addition, we offer the scenario type RM-6, which maps linear emission paths (constant annual reduction amount). The annual reduction rates have a concave course in RM-6.

With our **web application for the** EU http://eu.climate-calculator.info the different scenario types can be graphically traced.

The following questions can play a role in the assessment of a reasonable scenario type:

(1) Which reduction rates are realistic and when?
(2) Do initially slowly increasing reduction rates (RM-4) imply an unjustifiable mortgage for the future, as these later require very high reduction rates?
(3) Or do high later reduction rates (RM-4) even make sense because this gives a greater lead time for the necessary investments? The necessary investments could then take place more within the framework of normal investment cycles. However, this would require a very credible climate policy with effective instruments.
(4) Do initially rapidly increasing reduction rates (RM-3 and RM-5) convey a more credible climate protection policy that creates planning security for public and private investments in a fossil-free future?

The German Advisory Council on the Environment recommends against linear emission paths: "*A slow start, hoping for steep emission reductions in later years, jeopardises compliance with the budget and climate targets*". (SRU, 2020, p. 56). This would also apply to an even greater extent to the RM-2/4 scenario types.

The ruling of the Federal Constitutional Court in Germany April 2021 on the Climate Protection Act also implicitly poses the question of which annual reduction rates we must already provide today and which we can expect society to provide in the 30s or 40s (cf. BVerfG, 2021). Excerpt from the guiding principles of the decision of the Federal Constitutional Court: *"Under certain conditions, the Basic Law obliges us to safeguard freedom protected by fundamental rights over time and to distribute opportunities for freedom proportionately across generations. In terms of subjective law, the fundamental rights, as an intertemporal safeguard of freedom, protect against a unilateral shift of the greenhouse gas reduction burden imposed by Article 20a of the Basic Law into the future. The objective-law protection mandate of Article 20a of the Basic Law also includes the necessity to treat the natural foundations of life with such care and to leave them to posterity in such a condition that future generations could not continue to preserve them only at the price of radical abstinence of their own. The protection of future freedom also requires that the transition to climate neutrality be initiated in good time. In concrete terms, this requires that transparent targets for further*

[6] Other criteria that could be considered: responsibility for historical emissions and the economic performance of a country (e.g. in the form of per capita income). However, the inclusion of historical responsibility would lead to more unrealistic results; but makes the responsibility of the "old" industrialised countries for the decarbonisation process clear. The 10 countries with the highest per capita incomes according to the World Bank have a share of just under 2% of global emissions (own calculation). Including per capita income would therefore not lead to significantly different results for the six largest emitters.

greenhouse gas reductions are formulated at an early stage, which provide orientation for the necessary development and implementation processes and give them a sufficient degree of development pressure and planning certainty".

To avoid very high annual reduction rates in later years, the scenario types RM-5 or also RM3 are -suitable (the graphics in our web application should make this clear: http://eu.climate-calculator.info).

For the following comparisons of emission targets for the six largest emitters, linear emission paths are nevertheless used for reasons of simplification, as the differences between the scenario types are not the focus here. If the scenario types RM-5 or RM-3 were applied, the emission targets for 2030 would be more ambitious for all of them (see here our further exemplary results on our website).

Excursus 1: Regensburg Model Scenario Types

The EU EDGAR database provides CO2 emissions excluding emissions from land use change (**LUC**) and international shipping and aviation (**ISA**) for all countries in the world (cf. EDGAR, 2020).

Before national budgets can be calculated on this data basis, budgets for LUC and ISA emissions must be deducted from the global budget (see exemplary calculations in Tab. 3).

The national budgets derived from this global CO2 budget thus include CO2 emissions from the use of fossil fuels (except ISA) and from cement production. As the current emission targets of the six largest emitters listed in Tab. 2 generally refer to all greenhouse gases, the reference values shown in the next chapter are only to a limited extent directly comparable.

The assumption about the global LUC budget can have a significant impact on the concrete emission targets for countries. For the LUC budget, for example, the illustrative model pathways P1 - P4 of the IPCC from its Special Report 2018 could be used as a reference (cf. Wolfsteiner & Wittmann, 2021c). However, the range for cumulative LUC emissions there is from +144 Gt to -222 Gt for the period 2018 - 2100. [7]

In the following calculations of the reference values for the six largest emitters, a value of **zero is** assumed for the **LUC budget** as an example (except in Tab. 16 and Tab. 17). This implies that annual net positive LUC emissions occurring until 2100 are compensated by annual net negative LUC emissions.

A budget of 3% of the global budget is reserved for ISA, which corresponds more or less to the current share of global CO2 emissions. In the Excel tool used (Wolfsteiner & Wittmann, 2021b), a different value can also be used for ISA emissions.

In order to be able to calculate the national budgets for the period 2020 - 2100, the global emissions of 2018 and 2019 still have to be subtracted from the total global budget from 2018.

[7] Currently assumed to be around +7 Gt of LUC emissions annually (cf. Global Carbon Project, 2021).

	Gt	Gt	Gt
LUC budget 2018 – 2100	-100	0	100
global CO2 budget 2018 - 2100	**680**	**680**	**680**
- LUC budget 2018 - 2100	-100	0	100
- ISA budget 2018 - 2100	20	20	20
- global CO2 emissions 2018 - 2019 excluding LUC/ISA	73	73	73
= global CO2 budget 2020 - 2100 to be distributed	687	587	487

Tab. 3: Calculation scheme of the global budget to be distributed here

Exemplary national emission targets for the six largest emitters

Tab. 4 shows the baseline data for the six largest emitters in 2019. We have selected Nigeria as an example of a country with low per capita emissions and a low share of global emissions.

	emissions 2019 in Gt	per capita 2019 in t	share in global emissions 2019	accu-mulated share	share in global population 2019	accu-mulated share
China	11.5	8.0	31.5%	31%	18.6%	19%
United States	5.1	15.5	13.9%	45%	4.3%	23%
EU27	2.9	6.6	8.0%	53%	5.8%	29%
India	2.6	1.9	7.1%	61%	17.7%	46%
Russia	1.8	12.3	4.9%	65%	1.9%	48%
Japan	1.2	9.1	3.1%	69%	1.6%	50%
Nigeria	0.1	0.5	0.3%		2.6%	

Tab. 4: Baseline data of the six largest emitters plus Nigeria [8]

The following global framework data are varied for the exemplary national emission targets:

(1) Global CO2 budget 2020 - 2100

(2) Weighting of the population in the determination of national budgets

(3) Calculation of a national volume overshoot in the non-LUC sector

(4) Calculation of a negative global LUC budget

A baseline of 420 Gt is used for the remaining global CO2 budget from 2018. Due to the historical responsibility of the "old" industrialised countries for past emissions, there is much to be said for dividing the remaining global CO2 budget among the countries according to their population size (weighting population 100%).[9] This would lead to the following emission targets for 2030 and 2050:

[8] These are the CO2 emissions due to the use of fossil fuels (except international shipping and aviation; ISA) and cement production.

[9] Corresponding global per capita emissions in 2019 were 4.8 t (cf. EDGAR, 2020).

global CO2 budget 2018 - 2100 in Gt					420	minimum annual emissions		0%
weighting population					100%	LUC budget 2018 - 2100 in Gt		0
reference values (linear emission paths)					budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	reduction rate 2020
target year:	2030		2050					
reference year:	1990	2010	1990	2010				
China	-69%	-92%	-100%	-100%	62	5	0.0	-8.5%
United States	-100%	-100%	-100%	-100%	14	3	0.0	-15.3%
EU27	-83%	-81%	-100%	-100%	19	7	0.0	-7.1%
India	231%	13%	45%	-51%	59	23	0.0	-2.1%
Russia	-100%	-100%	-100%	-100%	6	4	0.0	-12.4%
Japan	-100%	-100%	-100%	-100%	5	5	0.0	-9.5%
Nigeria	37%	13%	41%	17%	9	87	0.0	0.2%

Tab. 5: Reference values - B420 / LUC0 / P100 / NNE0 [10]

If, by contrast, a global CO2 budget of 570 Gt is assumed, these results are obtained:

global CO2 budget 2018 - 2100 in Gt					570	minimum annual emissions		0%
weighting population					100%	LUC budget 2018 - 2100 in Gt		0
reference values (linear emission paths)					budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	reduction rate 2020
target year:	2030		2050					
reference year:	1990	2010	1990	2010				
China	59%	-58%	-100%	-100%	89	8	0.0	-6.1%
United States	-100%	-100%	-100%	-100%	20	4	0.0	-11.1%
EU27	-66%	-62%	-100%	-100%	28	9	0.0	-5.0%
India	261%	23%	131%	-21%	85	33	0.0	-1.5%
Russia	-99%	-99%	-100%	-100%	9	5	0.0	-9.0%
Japan	-75%	-76%	-100%	-100%	8	7	0.0	-6.8%
Nigeria	53%	27%	89%	56%	13	125	0.0	1.3%

Tab. 6: Reference values - B570 / LUC0 / P100 / NNE0

It can be seen that the framework data underpinned here are not realistic. This is particularly evident in the results for countries with high per capita emissions, such as the USA and Russia.

If the factors *population* and *emissions* are weighted with 50% each, this leads to the following results:

[10] Structure of the reference value tables: For the two target years 2030 and 2050, the change in emissions is given as a percentage compared to the reference years (base years) 1990 and 2010. The percentage given for the minimum annual emissions is applied to the national emissions in the base year 2019. A temporary overshoot occurs if the minimum value is negative until 2100. The budget for the period 2020 - 2100 results from applying the weighted distribution key to the global budget to be distributed here (see calculation logic **Fehler! Verweisquelle konnte nicht gefunden werden.**). The range in years is obtained by dividing the national budget by the n ational emissions in 2019 (see Tab. 4). The reduction rate in 2020 results endogenously for this scenario type (RM-6). For other scenario types (RM 2 - 5), the starting rate of change is an input value (cf. Wolfsteiner & Wittmann, 2021a).

global CO2 budget 2018 - 2100 in Gt				570	minimum annual emissions			0%
weighting population				50%	LUC budget 2018 - 2100 in Gt			0
reference values (linear emission paths)					budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	reduction rate 2020
target year:	2030		2050					
reference year:	1990	2010	1990	2010				
China	138%	-38%	-100%	-100%	120	10	0.0	-4.6%
United States	-60%	-64%	-100%	-100%	44	9	0.0	-5.5%
EU27	-59%	-54%	-100%	-100%	33	11	0.0	-4.3%
India	231%	13%	46%	-50%	60	23	0.0	-2.1%
Russia	-68%	-56%	-100%	-100%	16	9	0.0	-5.2%
Japan	-52%	-54%	-100%	-100%	11	10	0.0	-4.8%
Nigeria	29%	6%	19%	-2%	7	69	0.0	-0.4%

Tab. 7: Reference values - B570 / LUC0 / P50 / NNE0 [11]

Here, too, it can be doubted whether it is realistic for China to reduce its emissions by almost 40% and the USA by almost 65% by 2030 compared to 2010. The results for Russia and Japan also do not seem very realistic.

Weighting the population by only 15% would yield the following results:

global CO2 budget 2018 - 2100 in Gt				570	minimum annual emissions			0%
weighting population				15%	LUC budget 2018 - 2100 in Gt			0
reference values (linear emission paths)					budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	reduction rate 2020
target year:	2030		2050					
reference year:	1990	2010	1990	2010				
China	173%	-28%	-100%	-100%	142	12	0.0	-3.9%
United States	-45%	-50%	-100%	-100%	60	12	0.0	-4.1%
EU27	-56%	-50%	-100%	-100%	37	13	0.0	-3.8%
India	189%	-2%	-73%	-91%	42	16	0.0	-3.0%
Russia	-58%	-42%	-100%	-100%	21	12	0.0	-4.0%
Japan	-43%	-46%	-100%	-100%	14	12	0.0	-4.0%
Nigeria	10%	-9%	-34%	-46%	3	30	0.0	-1.6%

Tab. 8: Reference values - B570 / LUC0 / P15 / NNE0

Based on these framework data, the following results are obtained for 2030 in relation to the reference years named by the USA, the EU, Russia and Japan respectively (see Tab. 2):

[11] Tab. 18 in the appendix shows an example of the national budgets resulting from these framework data for countries up to one Gt.

	Current goals		Framework data Tab. 8
Country	Target year 2030	Reference year (base year)	2030 vs. base year
United States	-50%	2005	**-53%**
EU	-55%	1990	**-56%**
Russia	-25% to 30%	1990	**-58%**
Japan	-46%	2013	**-50%**

Tab. 9: Reference values - B570 / LUC0 / P15 / NNE0 - individual base years

If it is neglected that the countries' targets usually refer to all greenhouse gases, then the current targets of the EU, USA and Japan for 2030 could be mapped relatively well with these global framework data. However, China would have to reduce its emissions by almost 30% by 2030 compared to 2010. Even India, with a 15% population weighting, would already have to reduce its emissions by 2030 compared to 2010; despite low per capita emissions in the base year 2019. [12]

Even if the population is weighted at 0% (grandfathering), China would still have to significantly reduce its emissions by 2030. India and e.g. Nigeria would have to reduce their emissions significantly by 2030 compared to 2010:

global CO2 budget 2018 - 2100 in Gt				570	minimum annual emissions			0%
weighting population				0%	LUC budget 2018 - 2100 in Gt			0
reference values (linear emission paths)					budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	reduction rate 2020
target year:	2030		2050					
reference year:	1990	2010	1990	2010				
China	186%	-25%	-100%	-100%	151	13	0.0	-3.7%
United States	-40%	-45%	-100%	-100%	67	13	0.0	-3.7%
EU27	-54%	-49%	-100%	-100%	38	13	0.0	-3.7%
India	158%	-12%	-100%	-100%	34	13	0.0	-3.7%
Russia	-55%	-38%	-100%	-100%	23	13	0.0	-3.7%
Japan	-40%	-43%	-100%	-100%	15	13	0.0	-3.7%
Nigeria	-20%	-34%	-100%	-100%	1	13	0.0	-3.7%

Tab. 10: Reference values - B570 / LUC0 / P0 / NNE0

If the global budget is further increased to 680 Gt and the population is weighted at 50%, the results are as follows:

[12] It should be noted that the current targets presented by the US, EU and Japan can also be represented by a different combination of the framework data.

global CO2 budget 2018 - 2100 in Gt				680	minimum annual emissions			0%
weighting population				50%	LUC budget 2018 - 2100 in Gt			0
reference values (linear emission paths)					budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	reduction rate 2020
target year:	2030		2050					
reference year:	1990	2010	1990	2010				
China	180%	-26%	-100%	-100%	147	13	0.0	-3.8%
United States	-50%	-54%	-100%	-100%	53	10	0.0	-4.6%
EU27	-53%	-47%	-100%	-100%	40	14	0.0	-3.5%
India	249%	19%	98%	-33%	73	28	0.0	-1.8%
Russia	-61%	-46%	-100%	-100%	20	11	0.0	-4.3%
Japan	-43%	-45%	-100%	-100%	14	12	0.0	-3.9%
Nigeria	35%	12%	38%	14%	8	84	0.0	0.1%

Tab. 11: Reference values - B680 / LUC0 / P50 / NNE0

Weighting the population by 15% yields these results:

global CO2 budget 2018 - 2100 in Gt				680	minimum annual emissions			0%
weighting population				15%	LUC budget 2018 - 2100 in Gt			0
reference values (linear emission paths)					budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	reduction rate 2020
target year:	2030		2050					
reference year:	1990	2010	1990	2010				
China	210%	-19%	-99%	-100%	173	15	0.0	-3.2%
United States	-37%	-42%	-100%	-100%	73	14	0.0	-3.4%
EU27	-50%	-44%	-98%	-98%	45	15	0.0	-3.2%
India	215%	7%	-1%	-66%	51	20	0.0	-2.5%
Russia	-53%	-34%	-100%	-100%	26	15	0.0	-3.3%
Japan	-36%	-38%	-100%	-100%	17	15	0.0	-3.3%
Nigeria	14%	-6%	-22%	-36%	4	36	0.0	-1.4%

Tab. 1213: Reference values - B680 / LUC0 / P15 / NNE0

Excursus:

Relationship between weighting of population and potential for generating certificates

The national budgets resulting from the framework data in Tab. 11 and Tab. Tab. 12 (see Tab. 19 and Tab. 20 in the Annex) show: The lower the weighting of the population, the smaller the scope for newly industrialising and developing countries to be able to generate certificates within the framework of international emissions trading according to Article 6 (2) of the Paris Agreement.[13] The stated ranges of the national budgets can serve as a measure of this leeway. With a lower weighting of the population, however, the new pledges of the EU, USA and Japan could result in leeway to help out China with certificates, for example. The higher the weighting of the population, the higher the demand for certificates of the industrialised countries plus China, which have so far been less ambitious. Emissions trading alone does not solve the basic problem of the extremely tight global CO2 budget.

Excursus 2: Relationship between population weighting and potential for generating certificates

[13] The status of negotiations and implementation of Article 6 of the Paris Agreement and the flexible mechanisms of the Kyoto Protocol will not be considered here. In principle, international emissions trading must ensure that there is no double counting. The functioning of **emissions trading between states** could be ensured in particular if agreement could first be reached on the binding allocation of a global CO2 budget to countries and only then would be permitted emissions trading between states. However, such a (global) agreement possibility seems rather unlikely at the moment. Another possibility would be to allow emissions trading on the basis of existing NDCs that are Paris-compatible in total. But this also presupposes that national CO2 budgets have been set in the NDCs, which is not currently on the political agenda. If national CO2 budgets are not set before an emissions trade, it is very difficult to ensure the integrity of an emissions trade.

In the ESPM, a **quantity overshoot** means a temporary exceeding of a predefined CO2 budget. This overshoot is compensated by net negative emissions until 2100.[14] The potential for net negative emissions is expressed below by a percentage applied to the country's emissions in 2019.[15] The result represents the minimum emissions until 2100. Depending on the given potential for net negative emissions, the volume overshoot (column "temporary overshoot" in the reference value tables) may be higher or lower.

There are two aspects to consider:

(1) At present, the potential of negative emissions is still very uncertain technically, economically and in terms of their permanence (cf. SRU, 2020).

(2) Even if a budget is met that corresponds to the targeted limitation of global warming, a quantity overshoot can lead to the overshooting of tipping points in the climate system (cf. PIK, 2018) lead.

If a potential for net negative emissions of -2% is taken as a basis, the following results are obtained with a global CO2 budget of 570 Gt: [16]

global CO2 budget 2018 - 2100 in Gt					570	minimum annual emissions			-2%
weighting population					50%	LUC budget 2018 - 2100 in Gt			0
reference values (linear emission paths)					budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	reduction rate 2020	
target year:	2030		2050						
reference year:	1990	2010	1990	2010					
China	161%	-32%	-110%	-103%	120	10	13.1	-4.1%	
United States	-53%	-57%	-102%	-102%	44	9	6.2	-4.9%	
EU27	-56%	-51%	-102%	-102%	33	11	3.3	-3.9%	
India	234%	14%	54%	-48%	60	23	1.7	-2.1%	
Russia	-63%	-49%	-101%	-102%	16	9	2.1	-4.6%	
Japan	-47%	-49%	-102%	-102%	11	10	1.3	-4.3%	
Nigeria	29%	6%	19%	-2%	7	69	0.0	-0.4%	

Tab. 14: Reference values - B570 / LUC0 / P50 / NNE2

Weighting the population by 15%, leads to these results:

[14] In order to achieve climate neutrality, unavoidable methane and nitrous oxide emissions from agriculture, for example, must be offset by negative CO2 emissions. These must be provided in addition to the net negative CO2 emissions assumed here.

[15] This means that countries with high current emissions would also have to realise or finance high net negative emissions. Since a budget for LUC is provided here at global level, negative emissions here at country level refer to the non-LUC sectors.

[16] The illustrative model paths of the IPCC from the Special Report 2018 could be used as a reference. However, the corresponding values show a wide range from +2% to -55% (cf. Wolfsteiner & Wittmann, 2021c).

global CO2 budget 2018 - 2100 in Gt					570	minimum annual emissions			-2%
weighting population					15%	LUC budget 2018 - 2100 in Gt			0
reference values (linear emission paths)					budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	reduction rate 2020	
target year:	2030		2050						
reference year:	1990	2010	1990	2010					
China	189%	-24%	-110%	-103%	142	12	12.3	-3.6%	
United States	-41%	-46%	-102%	-102%	60	12	5.6	-3.8%	
EU27	-53%	-48%	-102%	-102%	37	13	3.1	-3.5%	
India	197%	1%	-51%	-83%	42	16	2.4	-2.9%	
Russia	-56%	-39%	-101%	-102%	21	12	1.9	-3.7%	
Japan	-40%	-42%	-102%	-102%	14	12	1.2	-3.6%	
Nigeria	10%	-9%	-34%	-45%	3	30	0.0	-1.6%	

Tab. 15: Reference values - B570 / LUC0 / P15 / NNE2

The volume overshoot to be offset by net negative emissions would roughly correspond to the current annual emissions of the major emitters.

The inclusion of a **negative LUC budget** would increase the global CO2 budget to be distributed here (see calculation logic in Tab. 3). However, it is questionable who would then have to ensure that this negative LUC budget is actually realised. Moreover, there are major doubts about the permanence of negative LUC emissions.[17] If, despite these doubts, a LUC budget of -100 Gt is used as a basis, a global budget of 420 Gt would result in the following figures:

global CO2 budget 2018 - 2100 in Gt					420	minimum annual emissions			-2%
weighting population					50%	LUC budget 2018 - 2100 in Gt			-100
reference values (linear emission paths)					budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	reduction rate 2020	
target year:	2030		2050						
reference year:	1990	2010	1990	2010					
China	142%	-36%	-110%	-103%	109	9	13.6	-4.5%	
United States	-58%	-61%	-102%	-102%	40	8	6.3	-5.3%	
EU27	-59%	-54%	-102%	-102%	30	10	3.4	-4.2%	
India	225%	11%	28%	-57%	54	21	1.9	-2.3%	
Russia	-67%	-54%	-101%	-102%	15	8	2.2	-5.0%	
Japan	-51%	-53%	-102%	-102%	10	9	1.4	-4.7%	
Nigeria	26%	4%	11%	-9%	6	62	0.0	-0.6%	

Tab. 16: Reference values - B420 / LUC100 / P50 / NNE2

Weighting the population by 15% yields the following results:

[17] For example, a reforested forest can also be destroyed again by climate change.

global CO2 budget 2018 - 2100 in Gt					420	minimum annual emissions		-2%
weighting population					15%	LUC budget 2018 - 2100 in Gt		-100
reference values (linear emission paths)					budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	reduction rate 2020
target year:	2030		2050					
reference year:	1990	2010	1990	2010				
China	173%	-28%	-110%	-103%	128	11	12.9	-3.9%
United States	-44%	-49%	-102%	-102%	54	11	5.8	-4.1%
EU27	-56%	-51%	-102%	-102%	33	11	3.2	-3.9%
India	184%	-3%	-87%	-95%	38	15	2.5	-3.1%
Russia	-58%	-42%	-101%	-102%	19	11	2.0	-4.0%
Japan	-43%	-46%	-102%	-102%	13	11	1.3	-4.0%
Nigeria	8%	-11%	-40%	-51%	3	27	0.0	-1.8%

Tab. 17: Reference values - B420 / LUC100 / P15 / NNE2

Conclusions

Only exemplary emission targets for the six largest emitters could and should be shown here, as important framework data still have to be discussed and decided politically.

Therefore, we propose the following policy agenda:

- Concretise global framework data based on the state of scientific knowledge, especially with regard to the global CO2 budget and the scope of negative emissions.
- On this basis, derive national CO2 budgets that do justice to a fair and economically sensible distribution of a global CO2 budget.
- Orientate emission targets to a climate policy-sensible course of annual rates of change (see Excursus 1: Regensburg Model Scenario Types).
- Regularly readjust the framework data and reduction targets on the basis of recent scientific findings and technical/real developments.

However, the exemplary results give important indications of what can still be considered realistic in the ESPM approach presented here and where it becomes difficult.

It seems very unlikely that the six largest emitters (except India) can achieve their share of compliance with a global CO2 budget of 420 Gt if population is included with a weighting of 50% or more in the calculation of national budgets. To achieve realistic emission targets, a significantly higher global CO2 budget, extensive negative LUC emissions or quantity overshoots in the non-LUC sector would be necessary. If this is not desired, the only alternative is to give less weight to climate justice and to support developing and emerging countries in building a fossil-free economy.

The calculations also show that China would have to significantly reduce its emissions before 2030 in order for the 1.5°C limit to remain achievable. This is a major challenge for China, especially since it has a relatively small share of historical emissions. Nevertheless, the figures clearly show that it cannot work without a substantial contribution from by far the largest emitter (see Tab. 4) in the near future.

The ESPM approach is a useful complement to other approaches, such as Integrated Assessment Models (IAMs), which can be used to identify globally cost-effective national emissions pathways (cf. van Soest, et al., 2021). However, the results of IAMs are based on many scientific, economic and technical assumptions. Consequently, on the one hand, their results have a wide range of variation and, on the other hand, it is a kind of "black box" for society and decision-makers how their results are achieved. In our approach, on the other hand, only a few politically decisive framework data are necessary and the resulting emission paths and emission targets are transparent, easy to understand and climate justice can be explicitly taken into account. Indirectly, however, IAMs can also provide valuable information in the ESPM approach for the ultimate political determination of the framework parameters, e.g. with regard to the sensible weighting of the population or the sensible course of annual rates of change. The course of the rates of change is specified in the ESPM via the choice of a scenario type, whereby the entire range of plausible possibilities is offered (see Excursus 1).

Tools and further exemplary results

On our website http://www.save-the-climate.info we provide Excel tools with which reference values can be calculated for each country of the world with different framework data. For the calculation of the examples used here, the Excel tool "ESPM" was used (Wolfsteiner & Wittmann, 2021b).

At http://eu.climate-calculator.info we offer a web application for the EU that includes LUC and ISA emissions.

At http://espm.climate-calculator.info we offer a universally applicable web application to derive plausible emission paths from a predefined budget.

At https://www.klima-retten.info/results_espm.html we show further exemplary results for the six largest issuers with different framework data and different scenario types.

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Appendix: Exemplary national budgets up to 1 Gt with different framework data

sorted by 'budget' - in Mill. t	budget 2020 - 2100	weighted key	emissions 2019	scope years
China	120,104	25.0%	11,535	10.4
India	59,506	12.4%	2,597	22.9
United States	43,665	9.1%	5,107	8.5
EU28	37,569	7.8%	3,304	11.4
EU27	33,080	6.9%	2,939	11.3
Russia	16,267	3.4%	1,792	9.1
Indonesia	12,514	2.6%	626	20.0
Japan	11,498	2.4%	1,154	10.0
Brazil	9,695	2.0%	478	20.3
Pakistan	8,201	1.7%	224	36.7
Germany	7,197	1.5%	703	10.2
Iran	7,174	1.5%	702	10.2
Mexico	7,143	1.5%	485	14.7
Nigeria	6,907	1.4%	100	68.9
South Korea	5,860	1.2%	652	9.0
Bangladesh	5,793	1.2%	110	52.6
Turkey	5,317	1.1%	416	12.8
Saudi Arabia	5,089	1.1%	615	8.3
South Africa	5,061	1.1%	495	10.2
Vietnam	4,999	1.0%	305	16.4
Canada	4,992	1.0%	585	8.5
Egypt	4,794	1.0%	255	18.8
United Kingdom	4,489	0.9%	365	12.3
Philippines	4,349	0.9%	151	28.9
France and Monaco	4,087	0.9%	315	13.0
Italy, San Marino and the Holy See	4,055	0.8%	332	12.2
Thailand	3,966	0.8%	275	14.4
Australia	3,621	0.8%	433	8.4
Ethiopia	3,606	0.8%	18	197.6
Poland	3,258	0.7%	318	10.3
Spain and Andorra	3,154	0.7%	259	12.2
Democratic Republic of the Congo	2,719	0.6%	3	911.3
Argentina	2,698	0.6%	199	13.5
Ukraine	2,654	0.6%	196	13.5
Malaysia	2,623	0.5%	249	10.5
Taiwan	2,551	0.5%	277	9.2
Algeria	2,521	0.5%	181	14.0
Iraq	2,516	0.5%	198	12.7
Kazakhstan	2,393	0.5%	277	8.6
Colombia	2,132	0.4%	87	24.6
Myanmar/Burma	1,997	0.4%	48	41.3
Tanzania	1,892	0.4%	13	141.8
Sudan and South Sudan	1,824	0.4%	23	80.8
Kenya	1,765	0.4%	20	89.1
United Arab Emirates	1,761	0.4%	223	7.9
Uzbekistan	1,648	0.3%	95	17.3
Morocco	1,618	0.3%	74	21.9
Venezuela	1,607	0.3%	110	14.6
Netherlands	1,556	0.3%	156	9.9
Uganda	1,412	0.3%	5	264.5
Peru	1,380	0.3%	56	24.5
Afghanistan	1,255	0.3%	11	114.1
Chile	1,178	0.2%	90	13.1
Angola	1,159	0.2%	26	44.9
Romania	1,117	0.2%	79	14.2
North Korea	1,074	0.2%	42	25.5
Ghana	1,056	0.2%	17	62.7
Belgium	1,042	0.2%	104	10.0
Czechia	1,024	0.2%	106	9.7
Mozambique	1,005	0.2%	9	108.6

Tab. 18: National budgets - global budget 570 Gt / LUC 0 / weighting population 50%.

sorted by 'budget' - in Mill. t	budget 2020 - 2100	weighted key	emissions 2019	scope years
China	146,808	25.0%	11,535	12.7
India	72,737	12.4%	2,597	28.0
United States	53,374	9.1%	5,107	10.5
EU28	45,922	7.8%	3,304	13.9
EU27	40,435	6.9%	2,939	13.8
Russia	19,884	3.4%	1,792	11.1
Indonesia	15,296	2.6%	626	24.4
Japan	14,054	2.4%	1,154	12.2
Brazil	11,850	2.0%	478	24.8
Pakistan	10,024	1.7%	224	44.8
Germany	8,797	1.5%	703	12.5
Iran	8,769	1.5%	702	12.5
Mexico	8,731	1.5%	485	18.0
Nigeria	8,443	1.4%	100	84.2
South Korea	7,163	1.2%	652	11.0
Bangladesh	7,081	1.2%	110	64.3
Turkey	6,499	1.1%	416	15.6
Saudi Arabia	6,220	1.1%	615	10.1
South Africa	6,186	1.1%	495	12.5
Vietnam	6,110	1.0%	305	20.0
Canada	6,102	1.0%	585	10.4
Egypt	5,860	1.0%	255	22.9
United Kingdom	5,487	0.9%	365	15.0
Philippines	5,316	0.9%	151	35.3
France and Monaco	4,996	0.9%	315	15.9
Italy, San Marino and the Holy See	4,956	0.8%	332	14.9
Thailand	4,848	0.8%	275	17.6
Australia	4,426	0.8%	433	10.2
Ethiopia	4,408	0.8%	18	241.5
Poland	3,982	0.7%	318	12.5
Spain and Andorra	3,855	0.7%	259	14.9
Democratic Republic of the Congo	3,324	0.6%	3	1,113.9
Argentina	3,298	0.6%	199	16.5
Ukraine	3,244	0.6%	196	16.5
Malaysia	3,206	0.5%	249	12.9
Taiwan	3,118	0.5%	277	11.3
Algeria	3,082	0.5%	181	17.1
Iraq	3,076	0.5%	198	15.6
Kazakhstan	2,925	0.5%	277	10.5
Colombia	2,607	0.4%	87	30.1
Myanmar/Burma	2,442	0.4%	48	50.5
Tanzania	2,312	0.4%	13	173.3
Sudan and South Sudan	2,229	0.4%	23	98.8
Kenya	2,158	0.4%	20	108.9
United Arab Emirates	2,153	0.4%	223	9.7
Uzbekistan	2,014	0.3%	95	21.2
Morocco	1,978	0.3%	74	26.8
Venezuela	1,965	0.3%	110	17.9
Netherlands	1,902	0.3%	156	12.2
Uganda	1,726	0.3%	5	323.3
Peru	1,687	0.3%	56	30.0
Afghanistan	1,534	0.3%	11	139.5
Chile	1,440	0.2%	90	16.0
Angola	1,417	0.2%	26	54.9
Romania	1,365	0.2%	79	17.4
North Korea	1,313	0.2%	42	31.1
Ghana	1,291	0.2%	17	76.7
Belgium	1,274	0.2%	104	12.2
Czechia	1,252	0.2%	106	11.8
Mozambique	1,229	0.2%	9	132.7
Nepal	1,208	0.2%	15	80.4
Yemen	1,196	0.2%	11	109.8
Côte d’Ivoire	1,086	0.2%	14	80.1
Cameroon	1,065	0.2%	10	105.4
Israel and Palestine, State of	1,060	0.2%	68	15.5
Madagascar	1,059	0.2%	4	252.2
Sri Lanka	1,031	0.2%	28	37.4

Tab. 19: National budgets - global budget 680 Gt / LUC 0 / weighting population 50%.

sorted by 'budget' - in Mill. t	budget 2020 - 2100	weighted key	emissions 2019	scope years
China	173,248	29.5%	11,535	15.0
United States	73,218	12.5%	5,107	14.3
India	50,914	8.7%	2,597	19.6
EU28	50,784	8.7%	3,304	15.4
EU27	45,051	7.7%	2,939	15.3
Russia	26,037	4.4%	1,792	14.5
Japan	17,139	2.9%	1,154	14.9
Indonesia	11,597	2.0%	626	18.5
Germany	10,509	1.8%	703	15.0
Iran	10,494	1.8%	702	14.9
South Korea	9,451	1.6%	652	14.5
Brazil	8,911	1.5%	478	18.6
Saudi Arabia	8,750	1.5%	615	14.2
Canada	8,381	1.4%	585	14.3
Mexico	8,052	1.4%	485	16.6
South Africa	7,399	1.3%	495	15.0
Turkey	6,607	1.1%	416	15.9
Australia	6,182	1.1%	433	14.3
United Kingdom	5,733	1.0%	365	15.7
Pakistan	5,512	0.9%	224	24.6
Vietnam	5,252	0.9%	305	17.2
Italy, San Marino and the Holy See	5,201	0.9%	332	15.7
France and Monaco	5,024	0.9%	315	16.0
Poland	4,753	0.8%	318	15.0
Egypt	4,618	0.8%	255	18.1
Thailand	4,535	0.8%	275	16.5
Spain and Andorra	4,061	0.7%	259	15.7
Taiwan	4,036	0.7%	277	14.6
Kazakhstan	3,984	0.7%	277	14.4
Malaysia	3,749	0.6%	249	15.1
Nigeria	3,656	0.6%	100	36.5
Bangladesh	3,358	0.6%	110	30.5
Philippines	3,282	0.6%	151	21.8
Argentina	3,223	0.5%	199	16.2
Ukraine	3,173	0.5%	196	16.2
United Arab Emirates	3,139	0.5%	223	14.1
Iraq	3,136	0.5%	198	15.9
Algeria	2,947	0.5%	181	16.3
Netherlands	2,322	0.4%	156	14.8
Venezuela	1,822	0.3%	110	16.6
Colombia	1,751	0.3%	87	20.2
Uzbekistan	1,668	0.3%	95	17.6
Czechia	1,559	0.3%	106	14.8
Belgium	1,552	0.3%	104	14.9
Ethiopia	1,527	0.3%	18	83.6
Qatar	1,481	0.3%	107	13.9
Chile	1,439	0.2%	90	16.0
Morocco	1,421	0.2%	74	19.2
Kuwait	1,394	0.2%	99	14.1
Oman	1,319	0.2%	93	14.2
Turkmenistan	1,299	0.2%	91	14.3
Romania	1,290	0.2%	79	16.4
Myanmar/Burma	1,274	0.2%	48	26.4
Peru	1,136	0.2%	56	20.2
Austria	1,086	0.2%	72	15.0
Israel and Palestine, State of	1,083	0.2%	68	15.9
Serbia and Montenegro	1,069	0.2%	71	15.1
Democratic Republic of the Congo	1,031	0.2%	3	345.4
Greece	1,011	0.2%	66	15.4
Belarus	1,010	0.2%	66	15.2

Tab. 20: National budgets - global budget 680 Gt / LUC 0 / weighting population 15%.