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Paris-compatible emissions targets for the six largest emitters

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Prof. Manfred Sargl

M.Sc. M.A. Dr Daniel Wiegand

Graduate mathematician Günter Wittmann

Graduate economist Andreas Wolfsteiner

www.save-the-climate.info

save-the-climate@online.ms

Abstract

What are realistic emissions targets for the world's six largest emitters that are Paris-compatible in total? To explore this question, this paper varies key framework data on the available budget and its sharing mechanism and calculates top-down national emissions targets using the Extended Smooth Pathway Model (ESPM). The Paris ambition mechanism1 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.

[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 amendments does not lead to Paris-compatible targets, the second round of amendments scheduled for 2025 seems late in view of the reductions already needed by 2030. In 2023, the Paris Agreement stipulates a global stocktake on the progress made towards achieving the Paris climate goals.

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1 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]

The need to assess socio-economic consequences in the speed 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 oriented. The German Federal Constitutional Court made this clear in its landmark ruling in 2021: Climate policy must be oriented towards remaining CO2 residual budgets. (vgl. BVerfG, 2021).[4]

[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.

[4] Excerpt from the main considerations of the Federal Constitutional Court:

"*The constitutionally relevant temperature threshold of well below 2 °C and preferably 1.5 °C can in principle be converted into a global CO2 residual budget, which can then be distributed among the states. The Intergovernmental Panel on Climate Change (IPCC) has named concrete global CO2 residual budgets for various temperature thresholds and various probabilities of occurrence on the basis of a quality-assurance procedure, disclosing the remaining uncertainty. On this basis, the German Advisory Council on the Environment (Sachverständigenrat für Umweltfragen) has also determined a concrete national residual budget for Germany from 2020 that would be compatible with the Paris target. Due to the uncertainties and evaluations contained therein, the budget size determined cannot currently provide a numerically accurate measure for constitutional court review. The legislature still has room for manoeuvre. However, it may not fill this space at its political discretion. If there is scientific uncertainty about environmentally relevant causal relationships, Article 20a of the Basic Law imposes a special duty of care on the legislature. According to this, already reliable indications of the possibility of serious or irreversible impairments must be taken into account. At present, a violation of this duty of care cannot be established. It follows that estimates by the IPCC on the size of the remaining global CO2*

If the Parties make transparent an underlying global CO_2 budget and its distribution in their NDCs, this could also initiate a discourse that eventually leads to converging global benchmarks.

residual budget must be taken into account, even though they contain uncertainties. The emission levels regulated in Article 4 para. 1 sentence 3 KSG in conjunction with Annex 2 would largely exhaust the residual budget determined by the German Advisory Council on the Environment (Sachverständigenrat für Umweltfragen) on the basis of the IPCC estimates until the year 2030. However, compared to the uncertainties currently included in the calculation of the residual budget, the degree of shortfall did not form a sufficient basis for a constitutional court challenge" (BVerfG, 2021).

2 Principles used here to calculate national emission targets

For the calculation of concrete national emission targets based on global framework data for the six largest emitters, the following Extended Smooth Pathway Model (ESPM) is used, 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* and the issue of climate justice with *population* (cf. Raupach, et al., 2014).[6] In our tools (see Chapter 6), in some cases national budgets calculated in a different way can also be used as a basis.

(2) Derivation of national emission paths

Plausible emission paths are derived that adhere to the national budget. With the Regensburg Model Scenario Types (see Excursus 1), we offer the entire range of plausible possibilities. For reasons of simplification, a linear progression of the **emission paths** is assumed below.

The EU database EDGAR 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. 2).

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. 4 refer to all greenhouse gases, the reference values shown in the next chapter are only directly comparable to a limited extent.

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 IPCC's illustrative model pathways P1

[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).

[6] Other criteria that could be considered include: 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.

- P4 from its 2018 Special Report 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. 15 and Tab. 16). This implies that annual net positive LUC emissions occurring until 2100 are compensated by corresponding 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), however, 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 the years 2018 and 2019 still have to be subtracted from the total global budget as of 2018 (cf. EDGAR, 2020).

	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. 2: Calculation scheme of the global budget to be distributed here [8]

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

[8] Example calculation for column 2: 680 - (-100) - 20 - 73 = 687.

3 Current emission targets and baseline data of the six largest emitters

Tab. 3 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. 3: Baseline data of the six largest emitters plus Nigeria

These are the CO2 emissions due to the use of fossil fuels (except international shipping and aviation; ISA) and cement production. The corresponding global per capita emissions in 2019 were 4.8 t (cf. EDGAR, 2020).

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

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

Tab. 4: Current emission targets of the six largest emitters [9]

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.

[9] Sources: Climate Action Tracker (https://climateactiontracker.org) and current reporting. These targets generally refer to all greenhouse gases.

4 Exemplary national emission targets for the six largest emitters

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

(1) Global CO2 budget 2018 - 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

4.1 Variation of the global budget and population weighting

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%). This would lead to the following emission targets for 2030 and 2050:

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:

[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 2019. The result represents the national annual minimum emissions until 2100. A temporary overshoot occurs if this minimum is negative until 2100. The budget for the period 2020 - 2100 is obtained by applying the weighted distribution key to the global budget to be distributed (see calculation logic Tab. 2). The range in years is obtained by dividing the national budget by the national emissions in 2019 (see Tab. 3). 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				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:

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:

[11] Tab. 17 in the annex also shows the 60 highest national budgets resulting from these framework data by way of example.

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 individual reference years named by the USA, the EU, Russia and Japan respectively:

	Current goals (see Tab. 4)		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 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:

[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				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:

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. 12: Reference values - B680 / LUC0 / P15 / NNE0

Tab. 17 in the appendix shows the 60 highest country budgets with a global budget of 680 Gt and a weighting of the population with 50% or 15% (see also Excursus 2: Relationship between population weighting and potential for generating certificates).

4.2 Calculation of a quantity overshoot

A **volume overshoot** in the ESPM means a temporary exceeding of a predefined CO2 budget. This overshoot (column "temporary overshoot" in the reference value tables) is compensated by corresponding net negative emissions until 2100.[13] The potential for net negative emissions is expressed below by a percentage applied to the country's emissions in 2019.[14] The result represents the minimum emissions until 2100. Depending on the given potential for net negative emissions, the volume overshoot is higher or lower.

However, two aspects need to be considered:

(1) Currently, the potential of negative emissions is still technically and economically very uncertain (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.

[13] 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.

[14] 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.

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:[15]

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. 13: Reference values - B570 / LUC0 / P50 / NNE2

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

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. 14: Reference values - B570 / LUC0 / P15 / NNE2

The temporary volume overshoot to be offset by net negative emissions would roughly correspond to the current annual emissions of the major emitters (cf. Tab. 3 with Tab. 13 and Tab. 14).

4.3 Calculation of a negative LUC budget

The inclusion of a **negative LUC budget** would increase the global CO2 budget to be distributed here (see calculation logic in Tab. 2). However, it is questionable who would then have to ensure

[15] 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).

that this negative LUC budget is actually realised. Moreover, there are major doubts about the permanence of negative LUC emissions.[16] If, despite these concerns, 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. 15: Reference values - B420 / LUC100 / P50 / NNE2

Weighting the population by 15% yields the following results:

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. 16: Reference values - B420 / LUC100 / P15 / NNE2

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

5 Conclusions

Only exemplary emission targets for the world's six largest emitters could and should be shown here, as important framework data still need to be discussed and decided in more detail 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.
- Orient emissions targets towards 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 new 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. 3) 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 specific scientific, economic and technical assumptions. Consequently, on the one hand, their results have a wide range of variation and, on the other hand, their occurrence is a kind of "black box" for society and decision-makers. 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 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).

6 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.

7 Digressions

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 start with 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 monotonic 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 disproportionate 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 (SRU) 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). In addition to RM-6, this would also apply to the scenario types RM-2/4.

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 greenhouse gas reductions be 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 and RM3 are suitable -(the graphics in our web application should make this clear: http://eu.climate-calculator.info).

For the comparisons of emission targets for the six largest emitters in this paper, linear emission paths (RM-6) 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

Excursus:

Relationship between weighting of population and potential for generating certificates

The exemplary 60 country budgets that result from a global budget of 680 Gt and a weighting of the population with 50% or with 15% (see Tab. 17 in the Annex) show: The lower the weighting of the population, the smaller the scope for newly industrialising and developing countries to generate certificates within the framework of international emissions trading according to Article 6 (2) of the Paris Agreement. The stated ranges of the country 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.

The status of negotiations and implementation of Article 6 of the Paris Agreement and the flexible mechanisms of the Kyoto Protocol will not be discussed 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 emissions trading between states be permitted. 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.

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

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Appendix: Exemplary national budgets with different global framework data

global budget 2018 - 2100 in Gt	570	LUC budget	0	
weighting population	50%			
sorted by national budget	national budget 2020 - 2100	weighted key	emissions 2019	scope years
	Gt		Gt	
China	120,1	25,0%	11,535	10
India	59,5	12,4%	2,597	23
United States	43,7	9,1%	5,107	9
EU27	33,1	6,9%	2,939	11
Russia	16,3	3,4%	1,792	9
Indonesia	12,5	2,6%	0,626	20
Japan	11,5	2,4%	1,154	10
Brazil	9,7	2,0%	0,478	20
Pakistan	8,2	1,7%	0,224	37
Germany	7,2	1,5%	0,703	10
Iran	7,2	1,5%	0,702	10
Mexico	7,1	1,5%	0,485	15
Nigeria	6,9	1,4%	0,100	69
South Korea	5,9	1,2%	0,652	9
Bangladesh	5,8	1,2%	0,110	53
Turkey	5,3	1,1%	0,416	13
Saudi Arabia	5,1	1,1%	0,615	8
South Africa	5,1	1,1%	0,495	10
Vietnam	5,0	1,0%	0,305	16
Canada	5,0	1,0%	0,585	9
Egypt	4,8	1,0%	0,255	19
United Kingdom	4,5	0,9%	0,365	12
Philippines	4,3	0,9%	0,151	29
France and Monaco	4,1	0,9%	0,315	13
Italy, San M. a. t. H. S.	4,1	0,8%	0,332	12
Thailand	4,0	0,8%	0,275	14
Australia	3,6	0,8%	0,433	8
Ethiopia	3,6	0,8%	0,018	198
Poland	3,3	0,7%	0,318	10
Spain and Andorra	3,2	0,7%	0,259	12
Dem. Rep. of the Congo	2,7	0,6%	0,003	911
Argentina	2,7	0,6%	0,199	14
Ukraine	2,7	0,6%	0,196	14
Malaysia	2,6	0,5%	0,249	11
Taiwan	2,6	0,5%	0,277	9
Algeria	2,5	0,5%	0,181	14
Iraq	2,5	0,5%	0,198	13
Kazakhstan	2,4	0,5%	0,277	9
Colombia	2,1	0,4%	0,087	25
Myanmar/Burma	2,0	0,4%	0,048	41
Tanzania	1,9	0,4%	0,013	142
Sudan and South Sudan	1,8	0,4%	0,023	81
Kenya	1,8	0,4%	0,020	89
United Arab Emirates	1,8	0,4%	0,223	8
Uzbekistan	1,6	0,3%	0,095	17
Morocco	1,6	0,3%	0,074	22
Venezuela	1,6	0,3%	0,110	15
Netherlands	1,6	0,3%	0,156	10
Uganda	1,4	0,3%	0,005	264
Peru	1,4	0,3%	0,056	25
Afghanistan	1,3	0,3%	0,011	114
Chile	1,2	0,2%	0,090	13
Angola	1,2	0,2%	0,026	45
Romania	1,1	0,2%	0,079	14
North Korea	1,1	0,2%	0,042	25
Ghana	1,1	0,2%	0,017	63
Belgium	1,0	0,2%	0,104	10
Czechia	1,0	0,2%	0,106	10
Mozambique	1,0	0,2%	0,009	109
Nepal	1,0	0,2%	0,015	66
sum without EU	439		34	

global budget 2018 - 2100 in Gt	680	LUC budget	0	
weighting population	50%			
sorted by national budget	national budget 2020 - 2100	weighted key	emissions 2019	scope years
	Gt		Gt	
China	146,8	25,0%	11,535	13
India	72,7	12,4%	2,597	28
United States	53,4	9,1%	5,107	10
EU27	40,4	6,9%	2,939	14
Russia	19,9	3,4%	1,792	11
Indonesia	15,3	2,6%	0,626	24
Japan	14,1	2,4%	1,154	12
Brazil	11,9	2,0%	0,478	25
Pakistan	10,0	1,7%	0,224	45
Germany	8,8	1,5%	0,703	13
Iran	8,8	1,5%	0,702	12
Mexico	8,7	1,5%	0,485	18
Nigeria	8,4	1,4%	0,100	84
South Korea	7,2	1,2%	0,652	11
Bangladesh	7,1	1,2%	0,110	64
Turkey	6,5	1,1%	0,416	16
Saudi Arabia	6,2	1,1%	0,615	10
South Africa	6,2	1,1%	0,495	13
Vietnam	6,1	1,0%	0,305	20
Canada	6,1	1,0%	0,585	10
Egypt	5,9	1,0%	0,255	23
United Kingdom	5,5	0,9%	0,365	15
Philippines	5,3	0,9%	0,151	35
France and Monaco	5,0	0,9%	0,315	16
Italy, San M. a. t. H. S.	5,0	0,8%	0,332	15
Thailand	4,8	0,8%	0,275	18
Australia	4,4	0,8%	0,433	10
Ethiopia	4,4	0,8%	0,018	241
Poland	4,0	0,7%	0,318	13
Spain and Andorra	3,9	0,7%	0,259	15
Dem. Rep. of the Congo	3,3	0,6%	0,003	1.114
Argentina	3,3	0,6%	0,199	17
Ukraine	3,2	0,6%	0,196	17
Malaysia	3,2	0,5%	0,249	13
Taiwan	3,1	0,5%	0,277	11
Algeria	3,1	0,5%	0,181	17
Iraq	3,1	0,5%	0,198	16
Kazakhstan	2,9	0,5%	0,277	11
Colombia	2,6	0,4%	0,087	30
Myanmar/Burma	2,4	0,4%	0,048	51
Tanzania	2,3	0,4%	0,013	173
Sudan and South Sudan	2,2	0,4%	0,023	99
Kenya	2,2	0,4%	0,020	109
United Arab Emirates	2,2	0,4%	0,223	10
Uzbekistan	2,0	0,3%	0,095	21
Morocco	2,0	0,3%	0,074	27
Venezuela	2,0	0,3%	0,110	18
Netherlands	1,9	0,3%	0,156	12
Uganda	1,7	0,3%	0,005	323
Peru	1,7	0,3%	0,056	30
Afghanistan	1,5	0,3%	0,011	140
Chile	1,4	0,2%	0,090	16
Angola	1,4	0,2%	0,026	55
Romania	1,4	0,2%	0,079	17
North Korea	1,3	0,2%	0,042	31
Ghana	1,3	0,2%	0,017	77
Belgium	1,3	0,2%	0,104	12
Czechia	1,3	0,2%	0,106	12
Mozambique	1,2	0,2%	0,009	133
Nepal	1,2	0,2%	0,015	80
sum without EU	536		34	

global budget 2018 - 2100 in Gt	680	LUC budget	0	
weighting population	15%			
sorted by national budget	national budget 2020 - 2100	weighted key	emissions 2019	scope years
	Gt		Gt	
China	173,2	29,5%	11,535	15
United States	73,2	12,5%	5,107	14
India	50,9	8,7%	2,597	20
EU27	45,1	7,7%	2,939	15
Russia	26,0	4,4%	1,792	15
Japan	17,1	2,9%	1,154	15
Indonesia	11,6	2,0%	0,626	19
Germany	10,5	1,8%	0,703	15
Iran	10,5	1,8%	0,702	15
South Korea	9,5	1,6%	0,652	14
Brazil	8,9	1,5%	0,478	19
Saudi Arabia	8,8	1,5%	0,615	14
Canada	8,4	1,4%	0,585	14
Mexico	8,1	1,4%	0,485	17
South Africa	7,4	1,3%	0,495	15
Turkey	6,6	1,1%	0,416	16
Australia	6,2	1,1%	0,433	14
United Kingdom	5,7	1,0%	0,365	16
Pakistan	5,5	0,9%	0,224	25
Vietnam	5,3	0,9%	0,305	17
Italy, San M. a. t. H. S.	5,2	0,9%	0,332	16
France and Monaco	5,0	0,9%	0,315	16
Poland	4,8	0,8%	0,318	15
Egypt	4,6	0,8%	0,255	18
Thailand	4,5	0,8%	0,275	16
Spain and Andorra	4,1	0,7%	0,259	16
Taiwan	4,0	0,7%	0,277	15
Kazakhstan	4,0	0,7%	0,277	14
Malaysia	3,7	0,6%	0,249	15
Nigeria	3,7	0,6%	0,100	36
Bangladesh	3,4	0,6%	0,110	30
Philippines	3,3	0,6%	0,151	22
Argentina	3,2	0,5%	0,199	16
Ukraine	3,2	0,5%	0,196	16
United Arab Emirates	3,1	0,5%	0,223	14
Iraq	3,1	0,5%	0,198	16
Algeria	2,9	0,5%	0,181	16
Netherlands	2,3	0,4%	0,156	15
Venezuela	1,8	0,3%	0,110	17
Colombia	1,8	0,3%	0,087	20
Uzbekistan	1,7	0,3%	0,095	18
Czechia	1,6	0,3%	0,106	15
Belgium	1,6	0,3%	0,104	15
Ethiopia	1,5	0,3%	0,018	84
Qatar	1,5	0,3%	0,107	14
Chile	1,4	0,2%	0,090	16
Morocco	1,4	0,2%	0,074	19
Kuwait	1,4	0,2%	0,099	14
Oman	1,3	0,2%	0,093	14
Turkmenistan	1,3	0,2%	0,091	14
Romania	1,3	0,2%	0,079	16
Myanmar/Burma	1,3	0,2%	0,048	26
Peru	1,1	0,2%	0,056	20
Austria	1,1	0,2%	0,072	15
Israel and Palestine, S. of	1,1	0,2%	0,068	16
Serbia and Montenegro	1,1	0,2%	0,071	15
Dem. Rep. of the Congo	1,0	0,2%	0,003	345
Greece	1,0	0,2%	0,066	15
Belarus	1,0	0,2%	0,066	15
Sudan and South Sudan	0,9	0,2%	0,023	41
sum without EU	551		35	

Tab. 17: National budgets with different global framework data [17]

[17] 59 countries plus the EU with the highest resulting budgets.