Calculation of Paris-compatible Emission Targets for the Six Largest Emitters with the Regensburg Model[1]

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Abstract

What are emissions targets for the world's six largest emitters that sum up to Paris-compatible emissions?

To answer this question, this paper shows top-down exemplary national emission pathways that are derived from a remaining global CO2 budget using the Regensburg Model, which is based on converging per capita emissions.

The Paris Ambition Mechanism is based on a bottom-up approach. However, if the national targets are not Paris-compatible in sum, the question arises whether national targets represent an adequate contribution to the necessary global efforts. Results in the Regensburg Model can be interpreted as a lower limit for the ambitions of industrialised countries.

A discourse on global framework data and distribution keys of a global CO2 budget can contribute to Paris-compatible NDCs in sum.

[1] This paper is also an update of a publication in "Climate Policy" (Sargl, et al., 2017) due to new data on the remaining budgets in the IPCC's AR6 WGI (IPCC, 2021) and new national emission figures (EDGAR, 2021).

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Global CO2 budgets

CO2 accumulates in the atmosphere.[2] If global warming is to keep within certain limits, the sum of CO2 emissions is therefore decisive. For the remaining global CO2 budgets, the IPCC published the figures in Tab. 1 in its Sixth Assessment Report 2021.

Warming	Remaining carbon budgets			Scenario variation	Geophysical uncertainties			
Probabilities:	*50%*	*67%*	*83%*	Non-CO2 scenario variation	Non-CO2 forcing and response uncertainty	Historical temperature uncertainty	ZEC uncertainty	Recent emissions uncertainty
[°C]	[GtCO2 from 2020 on]			[GtCO2]				
1.5	500	400	300	±220	±220	±550	±420	±20
1.6	650	550	400					
1.7	850	700	550					
1.8	1000	850	650					

Tab. 1: Remaining global CO2 budgets from 2020 onwards[3]

In the Summary for Policymakers, the IPCC states that (IPCC, 2021):

*“**D.1.1** (...) there is a near-linear relationship between cumulative anthropogenic CO2 emissions and the global warming they cause. Each 1000 GtCO2 of cumulative CO2 emissions is assessed to likely cause a 0.27°C to 0.63°C increase in global surface temperature with a best estimate of 0.45°C. (...) This quantity is referred to as the transient climate response to cumulative CO2 emissions (TCRE). This relationship implies that reaching net zero anthropogenic CO2 emissions is a requirement to stabilize human-induced global temperature increase at any level, but that limiting global temperature increase to a specific level would imply limiting cumulative CO2 emissions to within a carbon budget.*“

*“**D.1.2** (...) Remaining carbon budgets have been estimated for several global temperature limits and various levels of probability, based on the estimated value of TCRE and its uncertainty, estimates of historical warming, variations in projected warming from non-CO2 emissions, climate system feedbacks such as emissions from thawing permafrost, and the global surface temperature change after global anthropogenic CO2 emissions reach net zero.*“

The need to assess socio-economic consequences in the speed of decarbonisation, the compliance probabilities and the bandwidths of variations and uncertainties in the budgets mentioned by the IPCC require a scientifically based political decision on the global CO2 budget to which Nationally Determined Contributions (NDCs) should be oriented. The Federal Constitutional Court in Germany also emphasized this fact: National climate policy must be oriented towards remaining global CO2 budgets (cf. BVerfG, 2021).

If the parties of the Paris Agreement make the underlying global CO2 budget and its distribution transparent in their NDCs or if they are requested more to do so, this could initiate a discourse that leads to converging benchmarks for the global framework data.

[2] The subscript of 2 in CO2 is generally omitted in this work for reasons of simplification.

[3] Tab. 1 is based on the Tables SPM.2 and 5.8 in the IPCC Sixth Assessment Report (cf. IPCC, 2021). The given probabilities indicate the percentage of the examined scenarios in which the temperature target is met (cf. MCC, 2020). For further scientific background information, please refer to the IPCC report. In 2019, global emissions were around 41 GtCO2 (Global Carbon Project, 2021).

Current emission targets of the six largest emitters

Tab. 2 shows the baseline data for the six largest emitters in 2019. As an example of a country with low per capita emissions and a low share of global emissions Kenya is added for comparison.

	emissions in Gt			per capita 2019 in t	share in global emissions 2019	share in global population 2019
	1990	2010	2019			
China	2.4	9.3	11.5	8.1	31%	18%
United States	5.1	6.0	5.0	15.3	14%	4%
EU27	3.8	3.7	2.9	6.6	8%	6%
India	0.6	1.2	2.6	1.9	7%	18%
Russia	2.4	1.7	1.8	12.4	5%	2%
Japan	1.2	1.3	1.1	9.0	3%	2%
sum	15.5	23.2	25.0		68%	50%
Kenya	0.006	0.009	0.019	0.36	0.05%	0.68%
global	22.1	29.2	36.5	4.7		

Tab. 2: Baseline data of the six largest emitters plus Kenya[4]

Tab. 3 shows the currently submitted or announced NDC revisions of the six largest emitters, which sum up to about 70% of global emissions (cf. Tab. 2):

country	target year 2030	reference year	long-term goals
United States	-50%	2005	climate neutrality by 2050
EU27	-55%	1990	
Japan	-46%	2013	
India	reduce emission intensity 45% in relation to the national product	2005	net zero 2070
Russia	at least -30%	1990	net zero 2060
China	turning point of CO2 emissions before 2030	-	CO2 neutrality before 2060

Tab. 3: Current emission targets of the six largest emitters[5]

The question arises if these commitments are in line with the Paris climate targets.[6] To answer this question top-down national emission targets from different global data are calculated as reference values.

[4] These are the CO2 emissions from fossil fuel use (except international shipping and aviation; ISA) and cement production (EDGAR, 2021). CO2 emissions from land-use change (LUC) are therefore not included here (see also Footnote 13).

[5] Source and further details at Climate Action Tracker (https://climateactiontracker.org; status as of 19/11/2021).

[6] In its synthesis report the UNFCCC Secretariat stated that (UNFCCC, 2021):

"The total global GHG emission level in 2030, taking into account implementation of all the latest NDCs, is expected to be 15.9 per cent above the 2010 level. According to the SR1.5, to be consistent with global emission pathways with no or limited overshoot of the 1.5°C goal, global net anthropogenic CO2 emissions need to decline by about 45 per cent from the 2010 level by 2030, reaching net zero around 2050. For limiting global warming to below 2°C, CO2 emissions need to decrease by about 25 per cent from the 2010 level by 2030 and reach net zero around 2070."

Calculation of national emission paths with the Regensburg Model

The Regensburg Model

Resource sharing models directly address the allocation of a remaining global CO2 budget (cf. Sargl, et al., 2022b). The Regensburg Model (RM) distribute a global pathway and leads to converging per capita emissions.

The model proceeds in two steps:

(1) Determining of global emissions paths
Global emission paths in line with a global budget are derived. With the scenario types RM 1 - 6, an entire range of plausible possibilities are offed (see Excursus, p. 15). For reasons of simplification, a linear course of the global emission path (RM-6) is assumed below.[7]

(2) Derivation of national emission paths
Next national emission paths are derived from the global emission paths using the Regensburg Formula (cf. Wittmann, 2022):

$$\boldsymbol{E_t^i = (1 - C_t) * E_{BY}^i + C_t * E_{CY}^i}$$

where:

$$C_t = \frac{E_{BY} - E_t}{E_{BY} - E_{CY}} \text{ and } E_{CY}^i = \frac{E_{CY}}{P_{BY}} * P_{BY}^i$$ [8]

E_t *or* E_t^i	global emissions or emissions of country *i* in the year *t*
P_t *or* P_t^i	global population or population of country *i* in the year *t*
BY	base year; here: 2019
CY	convergence year[9]
E_{CY}/P_{BY}	convergence level - selectable parameter; here selected: **0.5 t per capita**

The national emission paths yield the same per capita emissions in the convergence year.[10] Thus the emission allocation based on the current emissions in the base year will be gradually shifted to an allocation based on equal per capita emissions (cf. Fig. 1).

[7] Due to the inclusion of actual emissions in 2020 and the consideration of a normalised value in 2020 when calculating global emissions in 2021, the global emission paths only fall on a straight line from 2022 onwards.

[8] In the Excel tool (Wolfsteiner & Wittmann, 2022c), P_{CY} *and* P_{CY}^i can also be used, which are based on estimated values of the UN.

[9] The convergence year results from the global path due to the selected convergence level.

[10] Deviations from the Regensburg Formula in the Regensburg Model:

- After the convergence period, the global path is distributed per capita.
- Global net negative emissions are distributed according to the country's share of global emissions in the base year.

With the Regensburg Formula a global monotonic path leads to national monotonic paths. This means:

- Countries that start with per capita emissions below the convergence level will never exceed this level.
- Countries that start above the convergence level with per capita emissions must reduce their emissions from the outset.

Due to these properties, the Regensburg Model is advantageous for industrialised countries in case of a low convergence level.

Determination of the global budget

An EU database provides CO2 emissions excluding emissions from land-use change (LUC) and international shipping and aviation (ISA) for all countries in the world shown in Tab. 2 for the six largest emitters (cf. EDGAR, 2021).

Before calculating a global CO2 budget to distribute here on this data basis, budgets for LUC and ISA emissions must be deducted from the global budget (see exemplary calculations in Tab. 4).[11] The derived budgets thus include emissions from fossil fuel use (except ISA) and cement production.

	Gt	Gt	Gt
LUC budget 2020 – 2100	-100	0	100
global CO2 budget 2020 - 2100	**550**	**550**	**550**
- LUC budget 2020 - 2100	-100	0	100
- ISA budget 2020 - 2100	17	17	17
= global CO2 budget 2020 - 2100 to be distributed	633	533	433

Tab. 4: Calculation scheme of the global budget to be distributed here[12]

The assumptions about the global LUC budget have a significant impact on the emission targets for countries. The illustrative model pathways P1 - P4 of the IPCC from its Special Report 2018 could be used as a reference for the LUC budget, with cumulative LUC emissions ranging from -230 Gt to +140 Gt for the period 2020 - 2100 (cf. Wolfsteiner & Wittmann, 2022b).[13] In the following calculations, an exemplary value of zero is used for the LUC budget (except in Tab. 9 and Tab. 10). This implies that until 2100 annual net positive LUC emissions occurring are compensated by annual net negative LUC emissions. Further an exemplary budget of 3% of the global budget is reserved for ISA, which corresponds roughly to its current share of global CO2 emissions.

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[11] If data were available at country level including LUC and ISA, this step would not be necessary. However, especially in the case of LUC emissions, there are still great uncertainties in determining the level of emissions.

[12] In the Excel tool used (Wolfsteiner & Wittmann, 2022c) other values can also be used for LUC or ISA emissions. Example calculation of the second column: 550 - (-100) - 17 = 633.

[13] The annual LUC emissions are currently assumed to be +4 Gt CO2 (cf. Global Carbon Project, 2021).

Since the current commitments of the six largest emitters listed in Tab. 3 refer to all greenhouse gases, but the reference values shown in the next chapter refer only to certain CO2 emissions, the reference values are only to a limited extend comparable if greenhouse gas fractions in the national targets are to be reduced at different rates.

Exemplary national emission targets

Exemplary national emission targets are calculated, with the following parameters being varied:[14]

(1) Global CO2 budget 2020 - 2100

(2) Inclusion of a national volume overshoot in the non-LUC sector

(3) Inclusion of a negative global LUC budget

Variation of the global budget

According to the IPCC, a remaining global CO2 budget of 400 Gt from 2020 onwards correlates with a probability of 67% with the 1.5°C limit (see Tab. 1). This would lead to the emission targets in Tab. 5 for 2030 and 2050.

global CO2 budget 2020 - 2100 in Gt		400		minimum annual emissions			0%
convergence level in t per capita		0.5		LUC budget 2020 - 2100 in Gt			0
reference values (linear global emissions path)				budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	year emissions neutrality
target year:	2030		2050				
reference year:	1990	2019	1990	2019			
China	129%	-52%	-100%	-100%	117	10	0	2041
United States	-54%	-53%	-100%	-100%	49	10	0	
EU27	-62%	-51%	-100%	-100%	30	10	0	
India	158%	-40%	-100%	-100%	32	12	0	
Russia	-65%	-53%	-100%	-100%	18	10	0	
Japan	-53%	-52%	-100%	-100%	11	10	0	
Kenya	267%	25%	-100%	-100%	0.5	24	0	

Tab. 5: Reference values - B400 / NNE0 / LUC0[15]

For all countries considered except India and Kenya, emissions would be well halved by 2030 compared to 2019. For China, India and Kenya, emissions in 2030 would be significantly higher compared to 1990.

Using a higher global budget of 550 Gt, leads to the results in Tab. 6.

[14] For the calculation of the exemplary results in this paper we have used the Excel tool "RM" (version 51.0), which can be downloaded from http://save-the-climate.info or from the platform zenodo (Wolfsteiner & Wittmann, 2022c).

[15] Structure of the reference value tables: For the target years, the change in emissions in percent compared to the reference years is given for a linear emissions path. The percentage given for the minimum annual emissions is applied to the global emissions in 2019. The result represents the possible minimum of global emissions until 2100. A temporary overshoot is possible if this minimum is negative (see Chapter "Inclusion of an overshoot and a negative LUC budget"). The national budget 2020 - 2100 results from the summation of the annual emissions. The scope in years is obtained by dividing the national budget by the country's emissions in 2019 (see Tab. 2). The year of emissions neutrality is the year in which global positive emissions reach their minimum respectively global emissions are zero (see also Footnote 17).

global CO2 budget 2020 - 2100 in Gt			550		minimum annual emissions			0%
convergence level in t per capita			0.5		LUC budget 2020 - 2100 in Gt			0
reference values (linear global emissions path)					budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	year emissions neutrality
target year:	2030		2050					
reference year:	1990	2019	1990	2019				
China	198%	-37%	-100%	-100%	161	14	0	2049
United States	-39%	-38%	-100%	-100%	68	13	0	
EU27	-51%	-37%	-100%	-100%	41	14	0	
India	207%	-28%	-100%	-100%	44	17	0	
Russia	-54%	-38%	-100%	-100%	24	14	0	
Japan	-39%	-37%	-100%	-100%	16	14	0	
Kenya	251%	19%	-100%	-100%	0.6	34	0.00	

Tab. 6: Reference values - B550 / NNE0 / LUC0

Fig. 1 shows the exemplary course of per capita emissions and Fig. 2 of the emission paths.

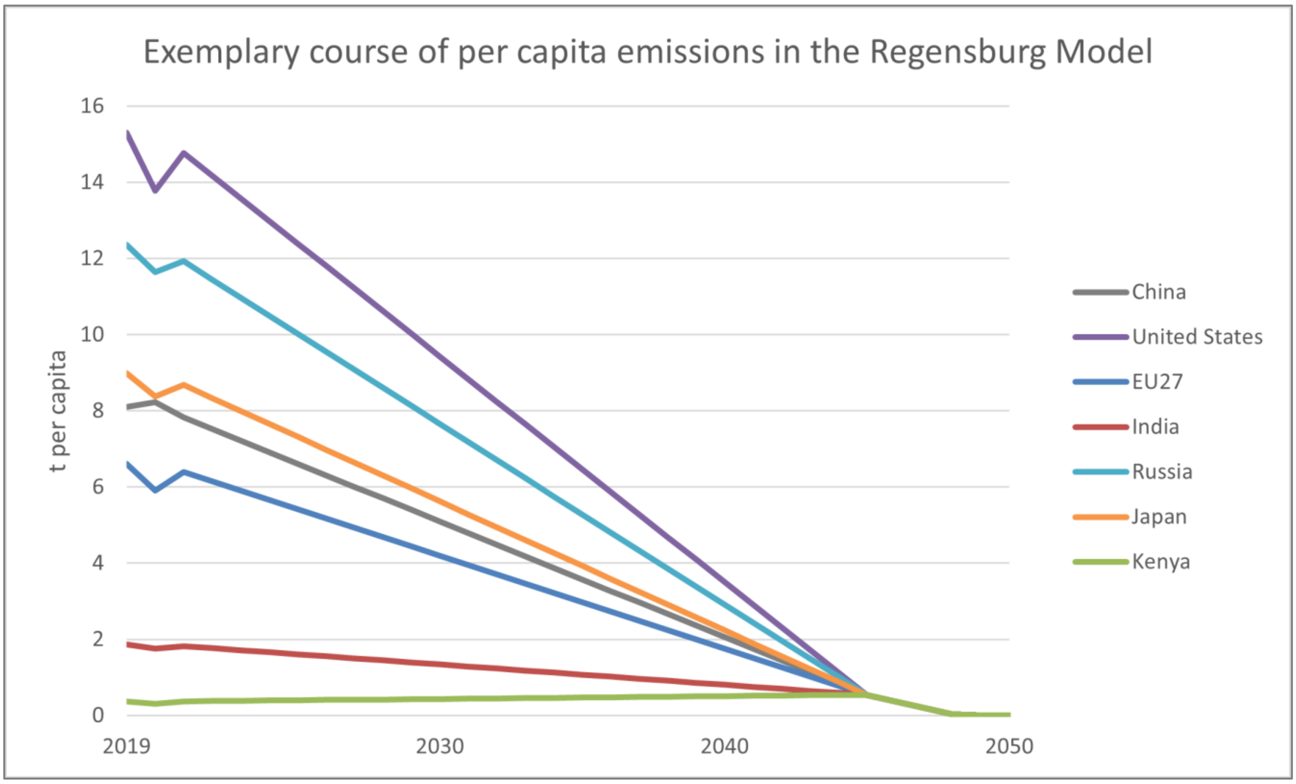

Fig. 1: Exemplary per capita emissions – B550 / NNE0 / LUC0 / convergence level: 0.5 t[16]

[16] The kinks in the paths result from actual emissions in 2020 (see also footnote 7).

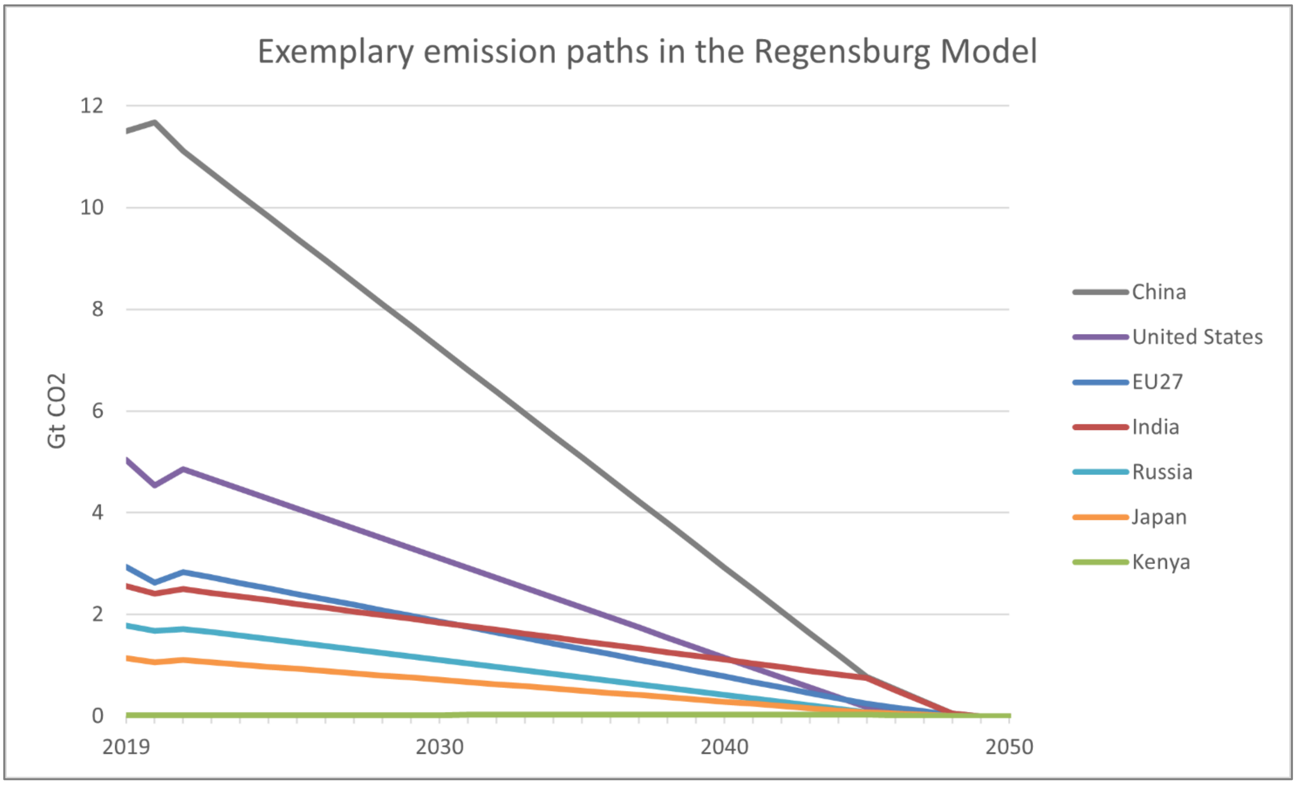

Fig. 2: Exemplary emission paths – B550 / NNE0 / LUC0 / convergence level: 0.5 t

Using this framework data to calculate the reduction from individual reference years for the countries USA, EU, Russia, and Japan and comparing it to the commitments of these countries give the results in Tab. 7:

	current targets (see Tab. 3)		framework data Tab. 6
country	target year 2030	individual reference year	change 2030 vs. individual reference year
United States	-50%	2005	**-48%**
EU27	-55%	1990	**-50%**
Russia	-30%	1990	**-54%**
Japan	-46%	2013	**-46%**

Tab. 7: Reference values - B550 / NNE0 / LUC0 - individual reference years

Disregarding the fact that the countries' targets generally refer to all greenhouse gases, the framework data used for Tab. 6 give a good representation of the current targets of the USA and Japan for 2030. The EU has set itself a more ambitious target. The target for Russia, however, is significantly lower. According to Tab. 6, China would have to reduce its emissions by 37% by 2030. So far, however, China only wants to reach its emissions peak before 2030. Even India would have to reduce its emissions significantly by 2030, although its per capita emissions are below average in 2019 (see Tab. 2). However, India's target presented means a further increase in emissions by 2030.

A further increase in the global budget to 650 Gt give the results in Tab. 8.

global CO2 budget 2020 - 2100 in Gt			650		minimum annual emissions			0%
convergence level in t per capita			0.5		LUC budget 2020 - 2100 in Gt			0
reference values (linear global emissions path)					budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	year emissions neutrality
target year:	2030		2050					
reference year:	1990	2019	1990	2019				
China	227%	-31%	-71%	-94%	191	17	0	2054
United States	-32%	-32%	-97%	-97%	81	16	0	
EU27	-47%	-31%	-94%	-92%	49	17	0	
India	224%	-24%	15%	-73%	51	20	0	
Russia	-49%	-32%	-97%	-96%	29	16	0	
Japan	-33%	-31%	-95%	-94%	19	16	0	
Kenya	230%	12%	304%	37%	0.7	38	0	

Tab. 8: Reference values - B650 / NNE0 / LUC0

Inclusion of an overshoot and a negative LUC budget

A **volume overshoot** means here a temporary exceeding of the previously defined global CO2 budget. This overshoot has to be offset until 2100 by subsequent net negative emissions.[17] The potential of net negative emissions is included in this model by a percentage of global emissions in 2019. The result represents the potential minimum of global emissions by 2100. With a negative minimum value, the lower this value, the higher the overshoot.

The following main aspects need to be considered:

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

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

(3) A potential asymmetry between CO2 emissions and removal from the atmosphere in the climate–carbon cycle is not taken into account here (IPCC, 2021, p. 5-9).

Combining a potential of net negative emissions of -2% and a global CO2 budget of 550 Gt give the following results:[18]

[17] 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.

[18] The illustrative model paths P1 - P4 of the IPCC from its Special Report 2018 could be used as a reference. However, the corresponding values show a wide range from -55% to +2% (cf. Wolfsteiner & Wittmann, 2022b).

global CO2 budget 2020 - 2100 in Gt			550		minimum annual emissions			-2%
convergence level in t per capita			0.5		LUC budget 2020 - 2100 in Gt			0
reference values (linear global emissions path)					budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	year emissions neutrality
target year:	2030		2050					
reference year:	1990	2019	1990	2019				
China	211%	-34%	-98%	-100%	161	14	11	2050
United States	-36%	-36%	-100%	-100%	68	13	5	
EU27	-49%	-34%	-100%	-99%	41	14	3	
India	213%	-27%	-91%	-98%	44	17	3	
Russia	-52%	-35%	-100%	-100%	24	14	2	
Japan	-36%	-35%	-100%	-100%	16	14	1	
Kenya	236%	14%	-73%	-91%	0.6	34	0.02	

Tab. 9: Reference values - B550 / NNE2 / LUC0

The temporary overshoot resulting from net negative emissions would roughly correspond to the current annual emissions of the major emitters (cf. Tab. 2 with Tab. 9).

The inclusion of a **negative LUC budget** would increase the global CO2 budget (see calculation logic in Tab. 4). However, it is not clear who would be responsible that this negative LUC budget is realised. Moreover, there are major doubts about the permanence of negative LUC emissions.[19] If, despite these concerns, a LUC budget of -100 Gt is added to a global budget, we get these results:

global CO2 budget 2020 - 2100 in Gt			400		minimum annual emissions			-2%
convergence level in t per capita			0.5		LUC budget 2020 - 2100 in Gt			-100
reference values (linear global emissions path)					budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	year emissions neutrality
target year:	2030		2050					
reference year:	1990	2019	1990	2019				
China	193%	-38%	-109%	-102%	145	13	12	2047
United States	-40%	-40%	-102%	-102%	60	12	5	
EU27	-52%	-37%	-102%	-102%	37	13	3	
India	212%	-27%	-109%	-102%	42	16	3	
Russia	-55%	-39%	-101%	-102%	22	12	2	
Japan	-40%	-38%	-102%	-102%	14	12	1	
Kenya	291%	33%	-106%	-102%	0.7	36	0.02	

Tab. 10: Reference values - B400 / NNE2 / LUC100

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

Implicit weighting population

A national budget can be determined directly with the following weighting formula:

$$B^i = \left((1 - \check{C}) * \frac{E_{BY}^i}{E_{BY}} + \check{C} * \frac{P_{BY}^i}{P_{BY}} \right) * B$$

where

B global CO2 budget; here from 2020 onwards

B^i national CO2 budget of the country i; here from 2020 onwards

$\check{C}$ weighting of population

Convergence models have an implicit weighting of the population (cf. Wittmann, 2022). This means: If $\check{C}$ is determined so that the same B^i results as in the Regensburg Model, the weighting is the same for all countries. Tab. 11 shows the implicit weighting for the framework data used here.[20]

global CO2 budget 2020 - 2100 in Gt	specified	400	550	650	550	400
selected scenario type		RM-6 (linear global emissions path)				
minimum annual emissions		0%			-2%	
LUC budget 2020 - 2100 in Gt		0				-100
convergence level in t per capita	0.50	0.53	0.54	0.50	0.51	0.65
implicit weighting population		12%	12%	11%	12%	15%

Tab. 11: Implicit weighting population[21]

With our Extended Smooth Pathway Model (ESPM), the population can be explicitly weighted and plausible national emission paths can be derived using the RM Scenario Types from the resulting national budgets (cf. Sargl, et al., 2022a).

[20] With the same global budget, the implicit weighting only depends on the chosen global path and the chosen convergence level. With a global budget of 550 Gt and otherwise identical parameters, the scenario type RM-5 (cf. Excursus: Regensburg Model Scenario Types) results in an implicit weighting of 17% instead of 12% (cf. Tab. 11).

[21] The implicit weighting was calculated for the period 2021 - 2100, as current emissions were included for 2020. The convergence year is chosen as the year in which global per capita emissions are closest to the specified convergence level. Therefore, the actual convergence level may deviate slightly from the specified value.

Conclusions

Reference values based on the Regensburg Model represent a "moral floor" for industrialised countries if the convergence level is chosen relatively low, since the emission paths of countries that start below the chosen convergence level never exceed it. Industrialised countries whose targets fall short of even these reference values run into explanatory problems when justifying their NDCs.

The presented emission targets for the six largest emitters should be seen as exemplary, as important global framework data and distribution keys must be discussed in depth and decided politically. For this discourse with ultimate political decisions, the following agenda emerges:

Agenda:

1. Concretise science based global framework data, especially with regard to the global CO2 budget and the scope of net negative emissions.
2. Derive politically national CO2 budgets that ensure a fair and economically sensible distribution of a global CO2 budget.[22]
3. Align emission targets with a climate policy-sensible course of annual rates of change.[23]
4. Adjust the framework data and reduction targets regularly on the basis of new scientific findings and technical/real developments.

The annual revision of the NDCs now foreseen is a major step forward towards the necessary reductions in global emissions already by 2030 to keep compliance with the 1.5°C limit within reach.[24]

[22] See e. g. Excursus “Allocation of a global CO2 budget” in (Sargl, et al., 2022a).

[23] See Excursus “Regensburg Model Scenario Types”, p. 15.

[24] At the UN Climate Change Conference in Glasgow 2021 (COP26), the following decisions were taken concerning the Paris Ambition Mechanism (CMA.3/-Decision, 2021):

„*29. Recalls Article 3 and Article 4, paragraphs 3, 4, 5 and 11, of the Paris Agreement and requests Parties to revisit and strengthen the 2030 targets in their nationally determined contributions as necessary to align with the Paris Agreement temperature goal by the end of 2022, taking into account different national circumstances;*

30. Also requests the secretariat to annually update the synthesis report on nationally determined contributions under the Paris Agreement, referred to in decision 1/CMA.2, paragraph 10, to be made available to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at each of its sessions;“.

Excursus: Regensburg Model Scenario Types

From an overall perspective of climate policy, scenarios with a non-linear emissions path may be useful.

The Regensburg Model Scenario Types RM 1 - 5 are based on the course of the annual reduction rates. 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-2, RM-4)

(4) Convex: initially over-proportional increase (RM-5)

In addition, the scenario type RM-6 uses linear emission paths. Accordingly, the annual reduction rates for RM-6 have a concave course and the annual reduction amount is constant.

With our **web app** http://espm.climate-calculator.info the different scenario types can be graphically traced. For a comprehensive mathematical description, we refer to (Wolfsteiner & Wittmann, 2022a).

The following questions should be considered, when assessing a scenario type:

(1) Which reduction rates are realistic and when?

(2) Do initially slowly increasing reduction rates (RM-2/4 and RM-6) imply an unjustifiable duty for future, as they imply higher reduction rates later?

(3) Do high later reduction rates make sense, if they provide a longer lead time for the necessary investments and the investments could then rather be made within the framework of normal investment cycles? However, this requires a very credible climate policy backed by 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 refraining from linear emission paths (RM-6): "*A slow start, hoping for steep emission reductions in later years, jeopardises compliance with the budget and climate targets*" (SRU, 2020, p. 56). This argument would also apply to the RM-2/4 scenario types.

The decision of the German Federal Constitutional Court on the Climate Protection Act also implicitly poses the question of what annual reduction rates we must accept today so that the freedom of future generations is not unduly restricted [see Excursus: „German Federal Constitutional Court on freedom opportunities for future generations“ in (Sargl, et al., 2022a)].

To avoid very high annual reduction rates in later years, the scenario types RM-3 and RM-5 are suitable.

Nevertheless, linear global emission paths are used here for the comparison of emission targets for the six largest emitters for reasons of simplification, as the differences between the scenario types are not the focus of this work. If the scenario types RM-3 or RM-5 were applied, the emission targets for 2030 would be more ambitious for the six largest emitters.

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