Paris-compatible Emission Targets for the Six Major Emitters based on the Extended Smooth Pathway Model (ESPM)[1]

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Web apps for this paper:

- Paris-compatible national CO2 budgets: https://national-budgets.climate-calculator.info
- Emission paths: https://paths.climate-calculator.info
- National CO2 budgets derived from NDCs: https://ib-iwp.climate-calculator.info

Abstract

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

To answer this question, this paper varies key global framework data on the available budget and the sharing mechanism to calculate top-down national emissions targets using the Extended Smooth Pathway Model (ESPM).

The Paris Ratchet Mechanism is based on a bottom-up approach. However, if the national targets are not Paris-compatible in sum, the question arises whether they represent an adequate contribution to the necessary global efforts. An open and transparent discussion of this issue can contribute to NDCs that, in sum, are once compatible with the Paris Agreement.

[1] This paper is also an update of a publication in the "Zeitschrift für Umweltpolitik & Umweltrecht" (Sargl, et al., 2021) due to the publication of new data on the remaining global budgets in the Sixth Assessment Report of the IPCC (IPCC, 2021) and emissions data (EDGAR, 2025). See also our corresponding paper for Germany and the EU (Sargl, et al., 2025).

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1 Global CO2 budgets and their relevance for national targets

CO2 accumulates in the atmosphere.[2] If global warming is to keep within certain limits, the sum of CO2 emissions is therefore decisive (budget property of CO2). Fig. 1 makes clear what also results from the budget property: the later we act, the earlier we have to achieve emission neutrality and the more we depend on net negative emissions.

Overarching goal in the Paris Agreement is to hold "the increase in the global average temperature to **well below 2°C** above pre-industrial levels" and **pursue efforts** "to limit the temperature increase to **1.5°C** above pre-industrial levels".

For the remaining global CO2 budgets, the IPCC published the figures in Tab. 1 in its Sixth Assessment Report 2021:

Warming	Remaining carbon budgets
[°C]	[GtCO2 from 2020 on]
1.5	300
1.6	400
1.7	550
1.8	650

Tab. 1: Remaining global CO2 budgets from 2020 onwards with a compliance probability of 83%[3]

In 2024, global emissions were estimated at around 42 GtCO2 (GCP, 2024).

The need to take into account the socio-economic consequences of the pace of decarbonisation, the likelihood of compliance and other uncertainties requires a science-based but ultimately policy decision on the global carbon budget against which nationally determined contributions (NDCs) are set.

If the Parties make transparent an underlying global CO2 budget and its distribution in their NDCs, or if they are more encouraged to do so, this can initiate a discourse that ultimately leads to converging benchmarks for the global framework data that contributes to Paris-compatible NDCs in sum.[4]

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

[3] Tab. 1 based on Table SPM.2 in the IPCC Sixth Assessment Report (cf. IPCC, 2021). The key statements of the IPCC on remaining CO2 budgets are summarised here: (Wolfsteiner, 2025c). New data on the remaining CO2 budget will also be presented there. For further background information, we refer to the IPCC report.

[4] In a landmark decision in 2021 the Federal Constitutional Court in Germany made this clear: Climate policy must be oriented towards remaining CO2 budgets (cf. BVerfG, 2021). This results from the physically given budget property of CO2. See also Excursus 1: German Federal Constitutional Court on CO2 budgets.

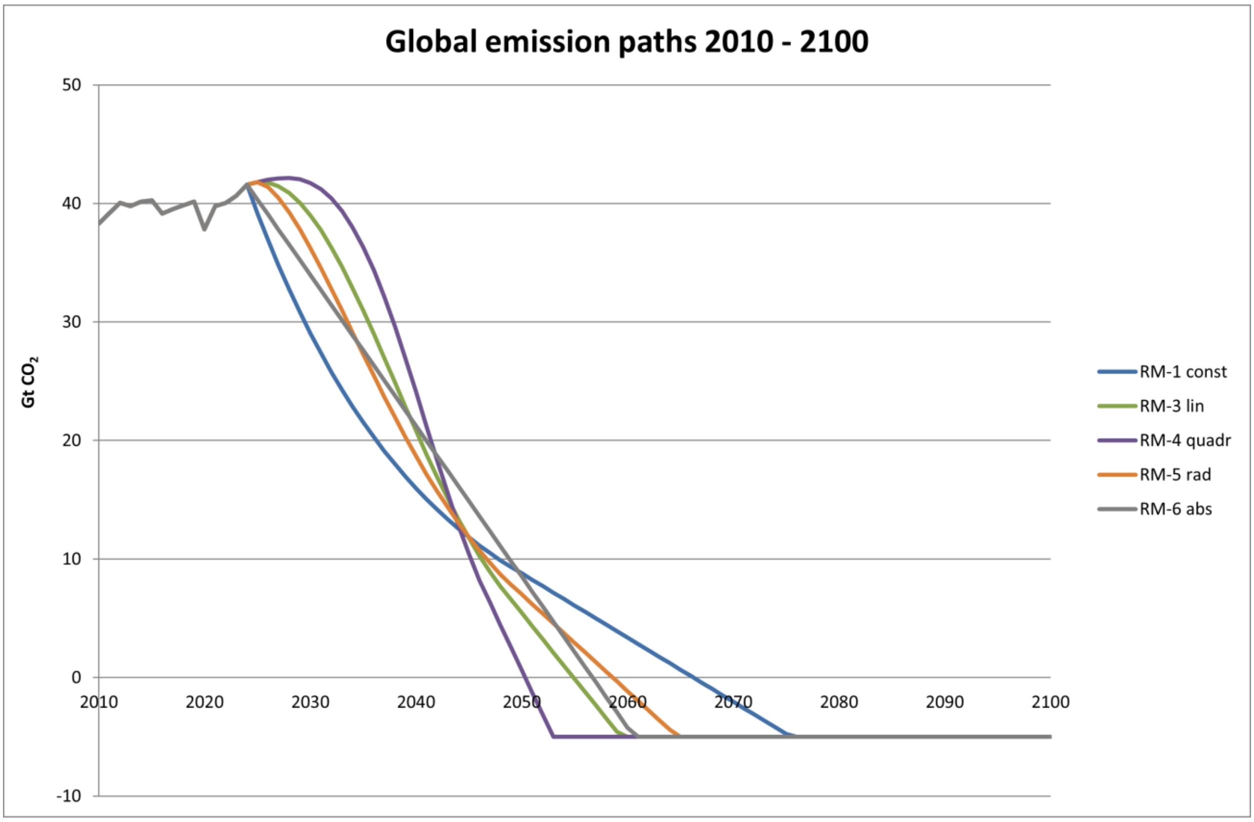

Fig. 1: Paris-compatible global emission paths – B650[5]

[5] All paths adhere to a CO2 budget of 650 Gt in the period 2020 – 2100. -5 Gt was specified as the possible minimum for emissions. A starting change rate of 0.5% was selected in the RM Scenario Types 3 – 5. For the scenario types used, see Excursus 5. The paths were calculated with this tool: (Wolfsteiner & Wittmann, 2025c). This refers to total CO2 emissions, including land use change (actual values according to (GCP, 2024)).

Here are simplified web apps:

- RM Scenario Types (see Excursus 5): https://paths.climate-calculator.info
- Linear global emission paths: http://global-paths.climate-calculator.info

2 Calculation of national emission paths with the ESPM

2.1 The Extended Smooth Pathway Model (ESPM)

In order to calculate national emission targets based on global framework data, the Extended Smooth Pathway Model (ESPM) is used. The ESPM proceeds in two steps (cf. Wiegand, et al., 2021; Sargl, et al., 2021):

1. Determining of national budgets
2. Derivation of national emission paths

2.1.1 Determining of national budgets

In order to derive national budgets from a global budget, an allocation key is needed. In determining the following exemplary national emissions targets, a weighted distribution key was used that takes into account a country's share of global emissions and its share of the world's population in 2019 (cf. Raupach, et al., 2014).[6] With this two-dimensional distribution key, the current emissions reflect the **current reality** and the population shares address the issue of **climate justice**. This leads to the following weighting formula:

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

where

E_{BY} *or* E_{BY}^i	global emissions or emissions of country *i* in the base year; here: BY = 2019
P_{BY} *or* P_{BY}^i	global population or population of country *i* in the base year
B or B^i	global CO2 budget or national CO2 budget of the country *i*; here from 2020 on
C	weighting of population[7]

There are many possible approaches to allocating a global budget to countries (cf. van der Wijst, et al., 2025). In our view, this distribution key represents the most important factors and makes it possible in particular to identify feasible national targets. Other criteria seem to us to make more sense in other contexts (see Excursus 3: Allocation of a global CO2 budget). A two-dimensional distribution key also has the advantage that only one factor has to be determined.

[6] In some of our tools, it is also possible to specify national budgets that have been determined in a different way (see Chapter "Tools and further exemplary results ").

[7] Based on converging per capita emissions, an implicit weighting of the population can be determined in the Regensburg Model (cf. Sargl, et al., 2017; Sargl, et al., 2024a). This is one way to identify a traceable value (cf. Wolfsteiner & Wittmann, 2024b).

2.1.2 *Derivation of national emission paths*

With the help of the **Regensburg Model Scenario Types** RM 1 – 6, plausible emission paths are derived that comply with the national CO2 budget. With these scenario types, we offer the entire range of plausible possibilities (see Excursus 5).

A **volume overshoot** can be taken into account in the RM Scenario Types. This means a temporary exceeding of the previously defined CO2 budget. This overshoot is offset by subsequent net negative emissions until 2100.[8]

The potential for net negative emissions is included in the model by a percentage of a country's emissions in 2019.[9] The result represents the potential minimum emissions by 2100. If this value is negative, then a volume overshoot is possible. Thereby, the lower this negative value, the higher the overshoot.

The illustrative model pathways P1 – P4 of the IPCC from its 2018 special report can be used as a reference for the potential for a volume overshoot. However, the corresponding values show a wide range. CO2 emissions in 2100 excluding land use (AFOLU) relative to corresponding emissions in 2019 range from -55% to +2% (cf. Wolfsteiner & Wittmann, 2025e; Wolfsteiner & Wittmann, 2025c).[10]

2.1.3 *NDC indicator: Implicit weighting of the population (IWP)*

Countries indirectly point out with their NDC which national CO2 budget they are claiming for themselves in the future.

The implicit weighting of the population (IWP) is a helpful measure for assessing this claim (cf. Sargl, et al., 2024a; Wolfsteiner & Wittmann, 2024b; Wolfsteiner, 2025b). If this national budget

[8] The following main aspects need to be considered (cf. Wolfsteiner & Wittmann, 2025e):

(1) 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.

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

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

(4) According to recent findings, "*the century-scale climate–carbon cycle response to a CO2 removal from the atmosphere is not always equal and opposite to the response to a CO2 emission*" (IPCC, 2021, p. 9 chapter 5). This potential asymmetry is not taken into account here.

[9] This means that **countries with high current emissions** would have to realise or finance **high net negative CO2 emissions**. Since a budget for LUC is provided here at global level, negative CO2 emissions at national level refer to the non-LUC sector.

[10] It should be expressly noted that **net negative emissions** in the IPCC illustrative model paths can also serve to **offset positive emissions of other greenhouse gases** such as methane and nitrous oxide, and not just to offset past CO2 overshoot.

can be estimated (cf. Wolfsteiner, 2025a) or, at best, is even directly specified, the implicit weighting of the population depending on a global CO2 budget is given by

$$\mathrm{C} = \frac{B^i - B * E^i_{BY}/E_{BY}}{B * (P^i_{BY}/P_{BY} - E^i_{BY}/E_{BY})} = IWP$$

after transforming the above weighting formula.

See Tab. 6 for the IWP for the six major emitters based on their NDCs.

2.2 Data basis used

The EU database EDGAR provides CO2 emissions excluding CO2 emissions from land-use (**LUC**) and international shipping and aviation (**ISA**) for all countries in the world which are shown in Tab. 2 for the six largest emitters plus Nigeria (cf. EDGAR, 2025).[11] For comparison Nigeria is added as an example of a country with low per capita emissions and a low share of global emissions.

	emissions in Gt				per capita 2019 in t	share in global emissions 2019	share in global population 2019
	1990	2010	2019	2024			
China	2.4	9.1	11.8	13.1	8.3	32%	18%
United States	5.0	5.5	5.0	4.6	15.1	14%	4%
EU27	3.8	3.4	2.9	2.5	6.6	8%	6%
India	0.6	1.7	2.6	3.2	1.9	7%	18%
Russia	2.4	1.7	1.9	2.0	12.9	5%	2%
Japan	1.2	1.2	1.1	1.0	8.9	3%	2%
Sum	15.4	22.7	25.2	26.4		69%	50%
Nigeria	0.08	0.09	0.13	0.13	0.6	0.3%	2.6%
Global	22.0	32.8	36.7	39.6	4.8	100%	

Tab. 2: Baseline data of the six largest emitters plus Nigeria[12]

[11] Brief description of different concepts CO2 emission from land use: GCP LUC = CO2 from land use changes, IPCC AFOLU = agriculture + forestry + land use, UNFCCC/EU LULUCF = essentially CO2 from land use & forests. AFOLU and LULUCF are almost identical in regard to CO2 in theory, as agriculture almost exclusively involves CH_4/N_2O.

When using the remaining carbon budgets presented by the IPCC, it is important to offset all anthropogenic CO2 emissions. This includes not only emissions from fossil fuels and industrial processes (EFOS), but also emissions from land use changes.

The Global Carbon Project (GCP) LUC category is the appropriate measure to be used here (GCP, 2024), because AFOLU-CO2 (IPCC) and LULUCF (UNFCCC/EU) include not only land use changes but also management-related sinks (e.g. forest management, wood products). These sinks are already accounted for in the IPCC budget framework as part of the natural land sink.

However, in the IPCC illustrative model paths, AFOLU CO2 emissions only reflect sources from land use changes (cf. IPCC, 2019, sec. 2.3.1.2). Management-related sinks (forests, soils, HWP) are reported separately as land sinks. Therefore, LUC according to GCP largely corresponds to AFOLU emissions in the IPCC illustrative model paths.

The following are the estimated emissions for 2010:

concept	model path IPCC SR15	GtCO2	source
LUC		+5.5	(GCP, 2024)
LULUCF		-2.6	(EDGAR, 2025)
AFOLU IPCC SR15	P1	+5.4	(Wolfsteiner & Wittmann, 2025c)
	P2	+4.6	
	P3	+7.2	
	P4	+4.2	

[12] These are the CO2 emissions from fossil fuel use (except international shipping and aviation; ISA) and cement production (EDGAR, 2025). CO2 emissions from land-use change (LUC) are therefore not included here (see also Chapter 2.2 Data basis used). Remark: The countries (excluding the EU) that account for less than 2% of global CO2 emissions are together responsible for around 39% of global emissions. This means that even countries with a small share of global emissions cannot escape responsibility.

Before calculating national budgets on this data basis, global budgets for LUC and ISA emissions must be deducted from the global budget (see exemplary calculations in Tab. 3).[13] The national budgets derived from this global CO2 budget thus cover CO2 emissions from fossil fuel use (except ISA) and cement production.

For the LUC budget, the illustrative model paths P1 - P4 of the IPCC from its Special Report 2018 could be used as a reference. However, the cumulative AFOLU emissions there range from -230 Gt to +140 Gt for the period 2020 - 2100 (cf. Wolfsteiner & Wittmann, 2025c; Wolfsteiner & Wittmann, 2025e).[14]

However, it is problematic when it is not clear who is responsible for ensuring that the LUC budget is actually adhered to. Moreover, there are major doubts about the permanence of negative LUC emissions.[15]

Further a budget of 3.3% of the global budget is reserved for ISA, which corresponds roughly to its current share of global CO2 emissions.[16]

	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	18	18	18
= global CO2 budget 2020 - 2100 to be distributed	632	532	432

Tab. 3: Calculation scheme of the global budget to be distributed here[17]

[13] If country level data including LUC and ISA are available, this step is not necessary (cf. Sargl, et al., 2025). However, especially in the case of LUC emissions, there are still great uncertainties in determining the level of emissions. If estimates were used here, with a wide range in accuracy, this could significantly distort the results.

[14] See **limitations** described in footnotes 10 and 11.

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

[16] Global ISA emissions are estimated at 1.3 GtCO2 in 2019 (EDGAR, 2025). In the Excel tool used (Wolfsteiner & Wittmann, 2025b), other values for ISA emissions can also be taken.

[17] Example calculation of the second column: 550 – (-100) – (+18) = 632.

3 Current emission targets of the six largest emitters

Tab. 4 shows the current status of already submitted NDCs of the six largest emitters, which together account for about 70% of global emissions (cf. Tab. 2).

country	emissions	target year 2030	target year 2035	target year 2040	reference year	long-term goals
United States[18]	all sectors and all gases	*−50% to -52%*	*−61% to −66%*	-	2005	climate neutrality by 2050
EU27	including LULUCF and international aviation	−55%	−66% to −72%[19]	−90%[20]	1990	
Japan	including land use & forests	−46%	*−60%[21]*	-	2013	
India	excluding LULUCF	reduce emission intensity 45% in relation to the national product	-	-	2005	net zero 2070
Russia	GHG, taking into account the maximum possible absorptive capacity of forests.	−30%	-	-	1990	net zero 2060
China	carbon dioxide emissions	turning point of CO2 emissions before 2030	−7% to −10% compared with the peak[22]	-	-	CO2 neutrality before 2060

Tab. 4: Current emission targets of the six largest emitters[23]

For the purpose of comparison, Tab. 5 shows the targets converted into the change in emissions in 2030 compared to 2019. However, this neglects the fact that NDCs can refer to different greenhouse gas fractions (see Chapter 2.2 Data basis used).

[18] The Trump administration's renewed withdrawal of the United States from the Paris Agreement will take effect on 27 January 2026.

[19] Commission's letter of intent dated 18/09/2025.

[20] Proposal by the European Commission February 2024. A decision is to be made before COP30.

[21] Japanese government is thinking about raising this (source: https://www.japantimes.co.jp/news/2024/11/26/japan/japan-emission-reduction-target/).

[22] Announcement by the Chinese President at the UN General Assembly on 24/09/2025.

[23] Source and further details at Climate Action Tracker (https://climateactiontracker.org; the status used here is: 28/08/2025).

country	target year 2030	reference year	change 2030 vs. 2019
China	see assumption footnote 24		**+11%**
United States	-50%	2005	**-41%**
EU27	-55%	1990	**-41%**
India	see assumption footnote 24		**+18%**
Russia	-30%	1990	**-8%**
Japan	-46%	2013	**-36%**

Tab. 5: Conversion NDCs to the change in 2030 compared to 2019[24]

The question arises, if these commitments are sufficient to meet the Paris climate targets, especially for the target years 2030 and 2035. Due to the budgetary nature of CO2, the coming years are crucial to keeping the Paris climate targets within reach. Our way to answer to this question is to calculate national emission targets as reference values that arise top-down given different global framework data.

An initial impression can be gained by looking at the implicit weighting of the population (see Chapter 2.1.3 NDC indicator: Implicit weighting of the population (IWP)).

Tab. 6 shows the implicit weighting of the population (IWP) based on an estimated implicit national emission budget. For the estimation of the implicit budget, linear emission paths from 2025 to 2030 and from 2031 to the year of emissions neutrality were assumed.[25] Our web app http://ib-iwp.climate-calculator.info can perform this calculation for any country in the world, provided that the necessary data can be derived from the NDC.

[24] Assumptions:

- China:
    - Emissions increase by 0.8% p.a. in the years 2025, 2026, …, 2030. 0.8% is the actual value in 2024.
    - The resulting figure for 2030 has been reduced by 5% because China wants to reach its peak before 2030.
- India:
    - GDP will increase by 6% p.a. in the years 2024, 2025, …, 2030. Actual value 2024: 6.5%.
    - India's GDP was derived from the “CO2 emissions per GDP” according to (EDGAR, 2025).

The assumptions can be changed in the web apps http://national-budgets.climate-calculator.info and http://ib-iwp.climate-calculator.info.

Note: The NDCs in Tab. 4 refer in part to different greenhouse gas fractions. For the sake of simplicity, it is assumed here that all greenhouse gas fractions are to be reduced equally.

[25] The two linear emission pathways represent a significant simplification. For example, they do not take into account whether net negative emissions are planned after emissions neutrality in order to compensate for a previous overshoot. In addition, other scenario types (see Excursus 5: Regensburg Model Scenario Types) would lead to slightly different budgets.

	target 2030 vs. 2019	net zero target	implicit budget	IWP	IWP
				BY: 2019	*BY*: 2019
				GB: 650 Gt	GB: 550 Gt
			Gt	*B*: 629 Gt	*B*: 532 Gt
China	11%	2060	332	-150%	-219%
United States	-41%	2050	73	21%	-2%
EU27	-41%	2050	42	60%	4%
India	18%	2070	91	70%	94%
Russia	-8%	2060	45	-67%	-108%
Japan	-36%	2050	17	26%	-9%
sum			600		

Tab. 6: Implicit budgets and weightings population (IWP)[26]

Tab. 6 shows that even grandfathering is not sufficient to reflect the NDCs for China and Russia in this framework. With a remaining global budget (GB) of 650 Gt from 2020 onwards, China's current emissions should be weighted at 250% and its population at -150%.

[26] For ISA emission, 3.3% was reserved, and a zero budget was assumed for LUC.

4 Exemplary national emission targets for the six largest emitters plus Nigeria

Exemplary national emission targets are calculated, with the following global framework data being varied:

(1) Global CO2 budget 2020 - 2100

(2) Weighting of the population in the determination of national CO2 budgets

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

(4) Inclusion of a negative global LUC budget

The following results can be reproduced with our web apps:

- Determination of national CO2 budgets: http://national-budgets.climate-calculator.info. Many other combinations of global framework data can also be specified there. The tool also provides the results for a linear emission path.
- Determining emission paths using the RM Scenario Types: https://paths.climate-calculator.info.

The following results were determined using this detailed Excel tool: (Wolfsteiner & Wittmann, 2025b).

Note: The NDCs in Tab. 4 refer in part to different greenhouse gas fractions. Therefore, the reference values calculated in this chapter are only comparable to a limited extent if the greenhouse gas fractions are to be reduced to varying degrees.

4.1 Overview of results for extreme and mean values in the global framework data

The following results are based on a linear course of the emission paths (scenario type: RM-6).[27]

A zero LUC budget and 0% potential for net negative emissions are assumed at the start.[28]

According to the IPCC report, 300 GtCO2 from 2020 onwards corresponds with a probability of 83% with compliance with the 1.5°C limit (see Tab. 1). Due to the historical responsibility of the "old" industrialised countries for past emissions, much can be said for dividing a remaining global

[27] Due to the inclusion of actual emissions in the years 2020 - 2024, the emission paths only fall on a straight line from 2025 onwards (see Fig. 2).

[28] A LUC budget of zero means that annual positive net LUC emissions are fully compensated by annual negative net LUC emissions by 2100. A potential of 0% for net negative emissions means that the minimum value of the emission fade is zero. This does not take into account whether a negative LUC-CO2 budget or net negative CO2 emissions without land use are also required to offset other positive greenhouse gas emissions (see also footnote 10).

In the Excel tool used (Wolfsteiner & Wittmann, 2025b), other values also be taken.

CO_2 budget among the countries according to their population size respectively per capita (weighting population: 100%). This would lead to the emission targets in Tab. 7. Using a global CO_2 budget of 650 Gt, which corresponds to keeping warming to 1.8°C, leads to the results in Tab. 8.

global CO2 budget 2020 - 2100 in Gt				300	minimum annual emissions			0%
weighting population				100%	LUC budget 2020 - 2100 in Gt			0
reference values (linear emission paths, RM-6)					budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	year emissions neutrality
target year:	2030	2030	2035	2040				
reference year:	1990	2019						
China	-	-	-	-	53	5	-	-
United States	-	-	-	-	12	2	-	-
EU27	-100%	-100%	-100%	-100%	17	6	0.0	2028
India	298%	-6%	-31%	-56%	51	20	0.0	2049
Russia	-	-	-	-	5	3	-	-
Japan	-	-	-	-	5	4	-	-
Nigeria	67%	0%	-5%	-9%	8	60	0.0	-

Tab. 7: Linear emission paths - reference values big six - B300 / P100 / NNE0 / LUC0[29]

global CO2 budget 2020 - 2100 in Gt				650	minimum annual emissions			0%
weighting population				100%	LUC budget 2020 - 2100 in Gt			0
reference values (linear emission paths, RM-6)					budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	year emissions neutrality
target year:	2030	2030	2035	2040				
reference year:	1990	2019						
China	82%	-63%	-100%	-100%	116	10	0.0	2034
United States	-100%	-100%	-100%	-100%	27	5	0.0	2027
EU27	-55%	-41%	-63%	-84%	36	12	0.0	2044
India	375%	12%	2%	-8%	112	44	0.0	2087
Russia	-100%	-100%	-100%	-100%	12	6	0.0	2028
Japan	-59%	-58%	-95%	-100%	10	9	0.0	2036
Nigeria	91%	14%	22%	29%	16	130	0.0	-

Tab. 8: Linear emission paths - reference values big six - B650 / P100 / NNE0 / LUC0

The framework data used, and in particular the 100% population weighting, obviously no longer lead to realisable targets for the territorial emissions of China, the USA, Russia and Japan, even if

[29] **Structure of the reference value tables with linear emission paths:**

For the target years, the change in emissions in percent compared to the reference years is given for a linear emission path.

The percentage given for the minimum annual emissions is applied to the country's emissions in 2019. The result represents the possible minimum of the country's emissions until 2100. A temporary overshoot is possible if this minimum is negative.

The national CO_2 budget for the period 2020 - 2100 results from applying the weighted distribution key to the global CO_2 budget to be distributed here (see calculation logic Tab. 3).

The scope in years is obtained by dividing the national CO_2 budget by the country's emissions in 2019 (see Tab. 2).

The year of emissions neutrality is the first year with negative emissions or emissions are zero. If no year is specified, then emissions neutrality will not be achieved by 2100 or it can no longer be achieved in compliance with the specified framework data due to the actual emissions after 2019.

the target is reduced to 1.8°C, which can be understood as the lower limit of the Paris Agreement. With a global CO2 budget that is seriously geared towards limiting global warming to 1.5°C, China, USA, Russia and Japan would no longer be able to meet their budget due to their actual emissions since 2019 (see Tab. 7).

Weighting the factors *population* and *emissions* equally leads to the results in Tab. 9 and the results of a population weighting of 0% (grandfathering) are shown in Tab. 10.

global CO2 budget 2020 - 2100 in Gt				650	minimum annual emissions			0%
weighting population				50%	LUC budget 2020 - 2100 in Gt			0
reference values (linear emission paths, RM-6)					budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	year emissions neutrality
target year:	2030	2030	2035	2040				
reference year:	1990	2019						
China	235%	-32%	-67%	-100%	159	13	0.0	2040
United States	-44%	-44%	-75%	-100%	56	11	0.0	2040
EU27	-51%	-35%	-52%	-69%	43	15	0.0	2050
India	349%	6%	-9%	-24%	78	30	0.0	2066
Russia	-55%	-41%	-82%	-100%	22	12	0.0	2038
Japan	-40%	-38%	-59%	-80%	15	13	0.0	2045
Nigeria	72%	2%	0%	-1%	9	74	0.0	-

Tab. 9: Linear emission paths - reference values big six - B650 / P50 / NNE0 / LUC0[30]

global CO2 budget 2020 - 2100 in Gt				650	minimum annual emissions			0%
weighting population				0%	LUC budget 2020 - 2100 in Gt			0
reference values (linear emission paths, RM-6)					budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	year emissions neutrality
target year:	2030	2030	2035	2040				
reference year:	1990	2019						
China	297%	-19%	-44%	-69%	203	17	0.0	2047
United States	-27%	-27%	-44%	-61%	85	17	0.0	2052
EU27	-48%	-32%	-46%	-59%	50	17	0.0	2055
India	267%	-14%	-45%	-76%	44	17	0.0	2044
Russia	-39%	-20%	-43%	-67%	32	17	0.0	2048
Japan	-33%	-31%	-45%	-60%	19	17	0.0	2055
Nigeria	32%	-21%	-43%	-65%	2	17	0.0	2049

Tab. 10: Linear emission paths - reference values big six - B650 / P0 / NNE0 / LUC0[31]

Weighting the population with 50% instead of 100% would mean a higher ambition level for India, since among the six largest emitters, only India's per capita emissions in the base year 2019 are below the global average (see Tab. 2). For the other five, however, the requirements are reduced (see also Fig. 3).

[30] Tab. 27 in the appendix shows by way of example the 60 highest national CO2 budgets resulting from these framework data.

[31] Remark: If the population share is neglected and actual emissions were not considered for the years 2020 - 2024 (see footnote 27), grandfathering would result in the same targets for all countries.

Fig. 2 shows the emission paths for the six largest emitters with a global CO2 budget of 650 Gt and a population weighting of 50%. The figure also illustrates that if China does not reduce its emissions by 2030, it will create an ambition gap that others cannot easily fill.

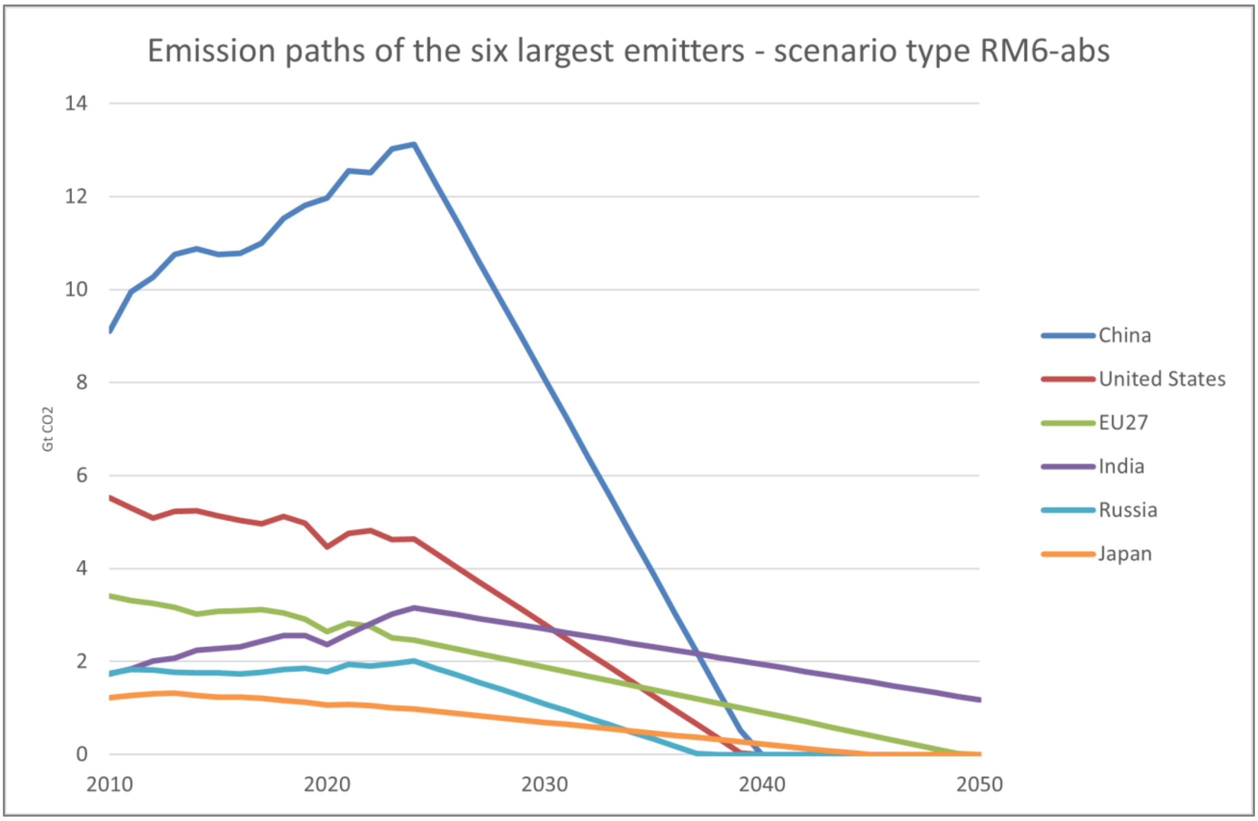

Fig. 2: Emission paths major emitters (RM-6-abs) – B650 / P50 / NNE0 / LUC0[32]

Fig. 3 shows the course of the reference values 2030 to 2019 depending on the weighting of the population with a global CO2 budget of 650 Gt.

[32] Actual emissions 2010 - 2024 (see also footnote 27).

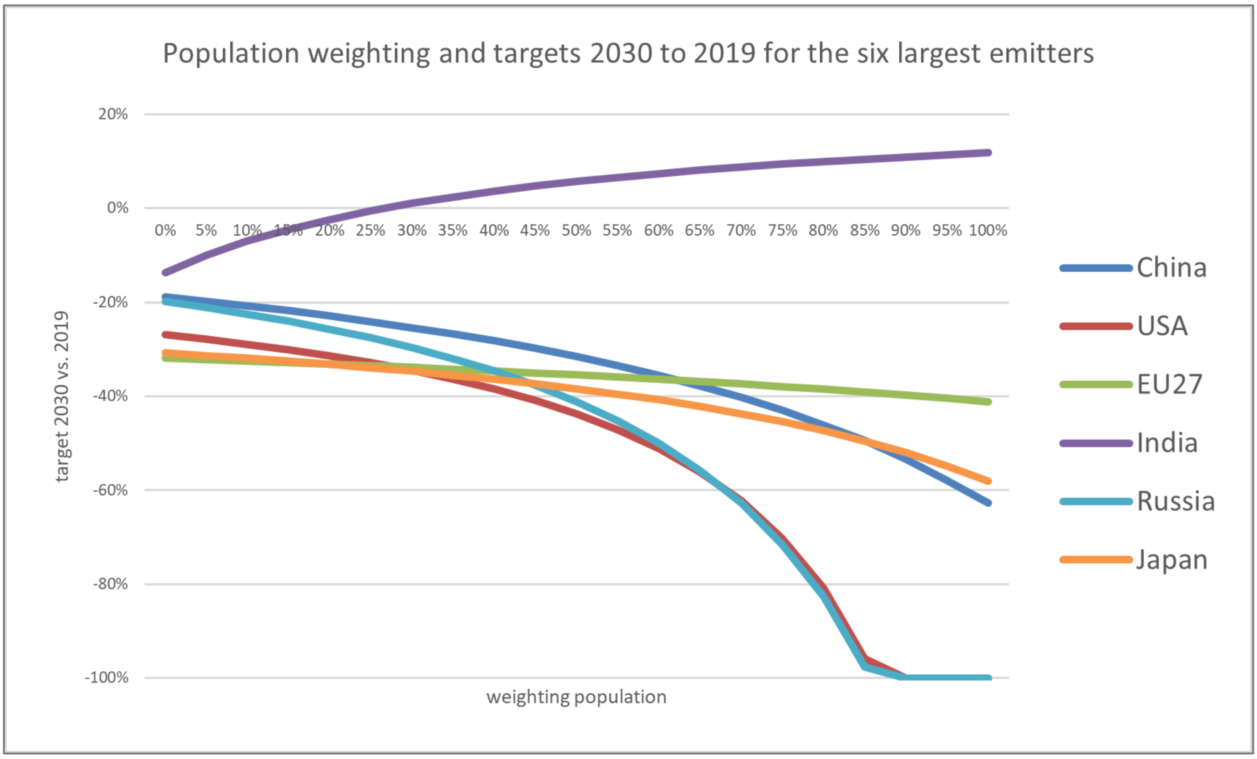

Fig. 3: Weighting population vs. targets 2030/2019 major emitters – B650 / NNE0 / LUC0[33]

Tab. 11 considers a potential for net negative emissions (and thus for an overshoot) of -25% and a LUC budget of -180 Gt. These figures are based on the illustrative model path P3 from the IPCC Special Report 2018 (cf. Wolfsteiner & Wittmann, 2025e).[34] However, relying so heavily on negative CO2 emissions harbours massive risks.[35]

global CO2 budget 2020 - 2100 in Gt				650	minimum annual emissions			-25%
weighting population				50%	LUC budget 2020 - 2100 in Gt			-180
reference values (linear emission paths, RM-6)					budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	year emissions neutrality
target year:	2030	2030	2035	2040				
reference year:	1990	2019						
China	358%	-6%	-21%	-36%	205	17	101.1	2062
United States	-21%	-21%	-33%	-45%	72	14	39.8	2064
EU27	-43%	-26%	-35%	-44%	55	19	15.6	2072
India	372%	11%	1%	-9%	100	39	6.8	2084
Russia	-31%	-10%	-25%	-40%	28	15	16.8	2061
Japan	-28%	-25%	-35%	-45%	19	17	7.2	2069
Nigeria	79%	7%	8%	10%	12	95	0.0	-

Tab. 11: Linear emission paths - reference values big six - B650 / P50 / NNE25 / LUC180

[33] Without taking actual emissions after 2019 into account, all countries would start at the same value with a population weighting of 0% (grandfathering).

[34] See **limitation** described in footnote 10.

[35] See footnote 8 and (Wolfsteiner & Wittmann, 2025e).

4.2 Exemplary global framework data reflect the NDCs of USA, EU and Japan

The following exemplary combinations of the global framework data in Tab. 12 lead to results that come close to the targets in the NDCs of the USA, the EU and Japan for 2030 (see Tab. 13). Due to the limitations associated with negative CO2 emissions, conservative assumptions were made for the LUC budget and potential of net negative emissions (cf. Wolfsteiner & Wittmann, 2025e). Population weighting was used as a free parameter to map the NDCs for 2030 of the countries considered here as closely as possible.

global CO2 budget 2020 - 2100 in Gt				550	minimum annual emissions			-2%
weighting population				15%	LUC budget 2020 - 2100 in Gt			0
reference values (linear emission paths, RM-6)					budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	year emissions neutrality
target year:	2030	2030	2035	2040				
reference year:	1990	2019						
China	261%	-26%	-57%	-88%	160	14	13.8	2042
United States	-33%	-33%	-55%	-77%	65	13	5.5	2046
EU27	-51%	-35%	-52%	-68%	40	14	3.0	2050
India	287%	-9%	-36%	-63%	46	18	2.7	2047
Russia	-45%	-28%	-58%	-89%	24	13	2.2	2042
Japan	-37%	-35%	-53%	-71%	15	13	1.2	2048
Nigeria	53%	-9%	-20%	-31%	4	29	0.1	2072

Tab. 12: Linear emission paths - reference values big six – B550 / P15 / NNE2 / LUC0

Using the framework data from Tab. 12 and comparing the results with the countries' commitments leads to the following results (see Tab. 13):

country	framework data Tab. 12	NDC (see Tab. 5)	deviation % points
China	-26%	+11%	-37%
United States	-33%	-41%	8%
EU27	-35%	-41%	6%
India	-9%	+18%	-26%
Russia	-28%	-8%	-20%
Japan	-35%	-36%	1%

Tab. 13: Comparison with NDCs (change 2030 vs. 2019) - B550 / P15 / NNE2 / LUC0

Disregarding the fact that the countries' targets generally refer to all greenhouse gases, the framework data used for Tab. 12 are a good representation of the current targets of the EU, USA and Japan for 2030.

The resulting national budgets based on the framework data in Tab. 12 also correspond to the implicit CO2 budgets for these countries based on their NDCs (see Tab. 14):

Gt	national budget (Tab. 12)	implicit budget[36] (Tab. 6)	devia-tion in %
China	160	332	108%
United States	65	73	12%
EU27	40	42	4%
India	46	91	98%
Russia	24	45	89%
Japan	15	17	13%
sum	350	600	71%

Tab. 14: Comparison with NDCs (budgets) - B550 / P15 / NNE2 / LUC0

However, the results for China, India and Russia are far apart. Even India and Nigeria, would have to reduce their emissions significantly by 2030, despite far below-average per capita emissions in 2019 (see Tab. 2).[37]

The question arises as to whether, for example, China and India could achieve the targets for 2030 according to Tab. 12 by taking a different emissions pathway. The framework data from Tab. 12 is used below to show the entire range of plausible emission paths (see Tab. 15):[38]

China					
global CO2 budget 2020 - 2100 in Gt		550	minimum emissions		-2%
weighting population		15%	LUC budget in Gt		0
scenario type:	RM-1-const	RM-5-rad	RM-3-lin	RM-4-quadr	RM-6-abs
target year	changes versus 2019				
2025	-1%	12%	12%	12%	5%
2030	**-44%**	**-26%**	**-18%**	**-5%**	**-26%**
2035	-68%	-68%	-68%	-74%	-57%
2040	-82%	-89%	-94%	-102%	-88%
2045	-90%	-97%	-102%	-102%	-102%
2050	-94%	-102%	-102%	-102%	-102%
year emissions neutrality	**2061**	**2048**	**2044**	**2039**	**2042**
overshoot in Gt	9.1	12.1	13.3	14.6	13.8
start change rate 2025	-10.8%	0.8%	0.8%	0.8%	-5.6%
national budget in Gt	**160**				

Tab. 15: RM Scenario Types - reference values China - B550 / P15 / NNE2 / LUC0[39]

In scenario type RM-4, China would only have to reduce its emissions by 5% by 2030 compared to 2019. However, this has the price that emission neutrality must then be achieved earlier and more

[36] See footnote 25 for the limitations.

[37] Our web app can also be used to check whether a country is on the right track: http://national-budgets.climate-calculator.info.

[38] In scenario types RM 3 - 5, the rate of change for the starting year (here: 2025) can be specified on the basis of a realistic estimate. Since this rate of change is the basis for the entire course of the following rates of change, a normalised value must be used that is not influenced by temporary effects such as the pandemic. For the reference values shown here, the actual rates for 2024 was used as the starting rate of change in scenario types RM 3 - 5. In order to find a solution in the respective scenario type, this starting value may have been changed slightly.

[39] Structure of the tables with the RM Scenario Types: The emission targets of scenario types RM 3 - 5 for 2030 are less ambitious from left to right.

net negative emissions must be realised. But even this scenario type is still far from China's 2030 target in its NDC (see Tab. 13).

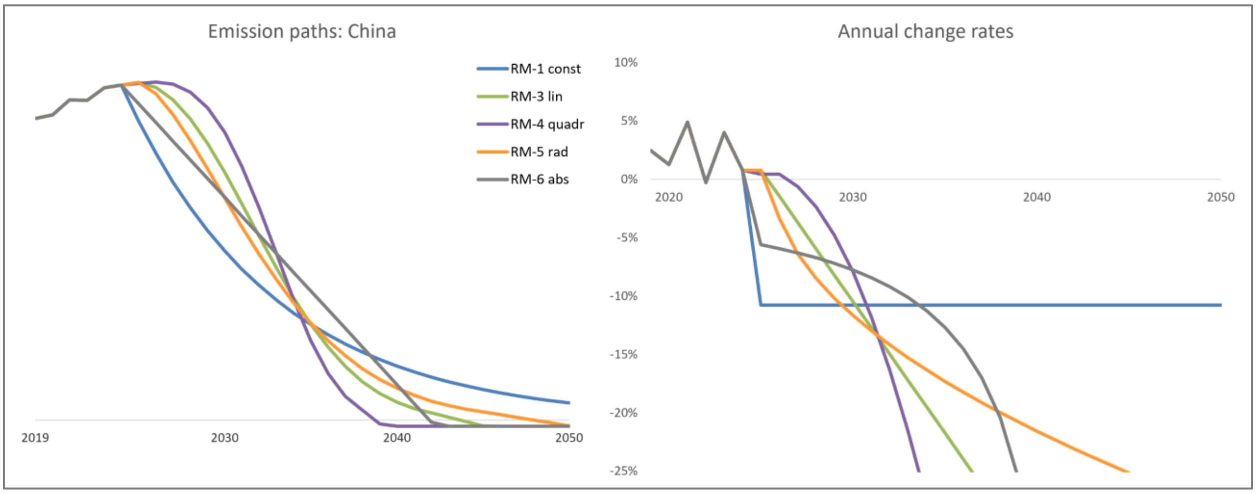

Fig. 4: RM Scenario Types – emission paths and annual change rates China – B550 / P15 / NNE2 / LUC0[40]

The results for the scenario types are also shown below for the other countries analysed:

United States					
global CO2 budget 2020 - 2100 in Gt		550	minimum emissions		-2%
weighting population		15%	LUC budget in Gt		0
scenario type:	RM-1-const	RM-5-rad	RM-3-lin	RM-4-quadr	RM-6-abs
target year	changes versus 2019				
2025	-15%	-6%	-6%	-7%	-11%
2030	**-48%**	**-32%**	**-25%**	**-15%**	**-33%**
2035	-68%	-63%	-60%	-57%	-55%
2040	-80%	-83%	-86%	-94%	-77%
2045	-88%	-94%	-97%	-102%	-99%
2050	-92%	-98%	-102%	-102%	-102%
year emissions neutrality	**2066**	**2053**	**2048**	**2043**	**2046**
overshoot in Gt	3.2	4.7	5.2	5.8	5.5
start change rate 2025	-9.2%	0.3%	0.3%	0.3%	-4.7%
national budget in Gt	**65**				

Tab. 16: RM Scenario Types - reference values USA - B550 / P15 / NNE2 / LUC0

40 Actual change rates in these graphics: 2019 - 2024.

EU27					
global CO2 budget 2020 - 2100 in Gt		550	minimum emissions		-2%
weighting population		15%	LUC budget in Gt		0
scenario type:	RM-1-const	RM-5-rad	RM-3-lin	RM-4-quadr	RM-6-abs
target year	changes versus 2019				
2025	-22%	-17%	-17%	-17%	-19%
2030	**-48%**	**-37%**	**-32%**	**-28%**	**-35%**
2035	-65%	-59%	-54%	-47%	-52%
2040	-77%	-75%	-74%	-74%	-68%
2045	-84%	-86%	-88%	-93%	-85%
2050	-89%	-93%	-96%	-102%	-102%
year emissions neutrality	**2073**	**2062**	**2056**	**2050**	**2050**
overshoot in Gt	1.4	2.2	2.5	3.0	3.0
start change rate 2025	-7.7%	-2.0%	-2.0%	-2.0%	-3.9%
national budget in Gt	**40**				

Tab. 17: RM Scenario Types - reference values EU - B550 / P15 / NNE2 / LUC0

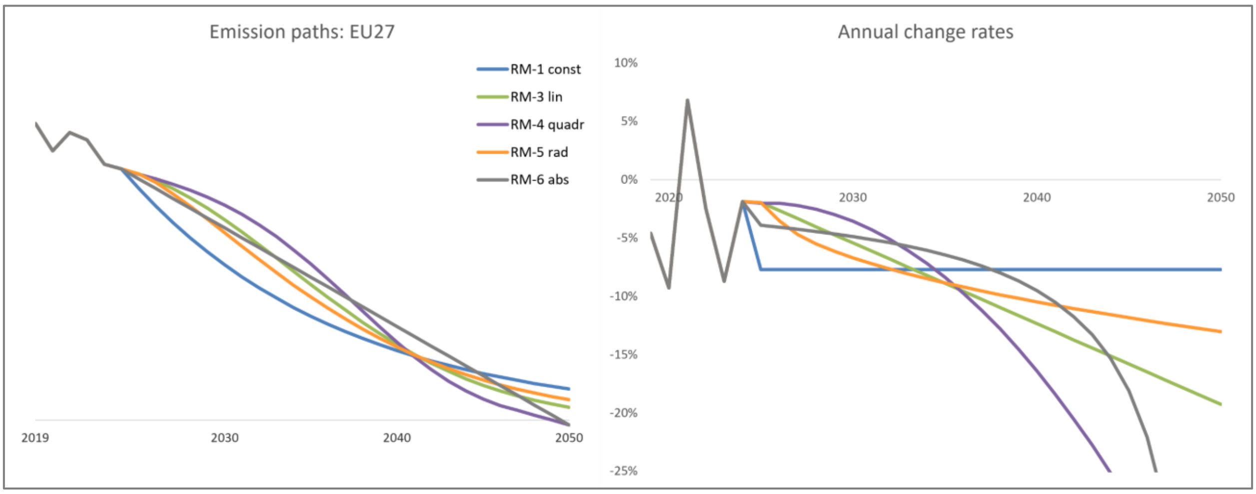

Fig. 5: RM Scenario Types – emission paths and annual change rates EU – B550 / P15 / NNE2 / LUC0

India					
global CO2 budget 2020 - 2100 in Gt		550	minimum emissions		-2%
weighting population		15%	LUC budget in Gt		0
scenario type:	RM-1-const	RM-5-rad	RM-3-lin	RM-4-quadr	RM-6-abs
target year	changes versus 2019				
2025	13%	29%	29%	29%	18%
2030	**-28%**	**3%**	**17%**	**36%**	**-9%**
2035	-54%	-45%	-42%	-45%	-36%
2040	-70%	-78%	-85%	-98%	-63%
2045	-81%	-93%	-99%	-102%	-90%
2050	-88%	-99%	-102%	-102%	-102%
year emissions neutrality	**2072**	**2052**	**2046**	**2041**	**2047**
overshoot in Gt	1.3	2.5	2.8	3.0	2.7
start change rate 2025	-8.6%	4.6%	4.6%	4.6%	-4.4%
national budget in Gt	**46**				

Tab. 18: RM Scenario Types - reference values India - B550 / P15 / NNE2 / LUC0

The target value in scenario type RM-3 for 2030 could be compatible with India's NDC (cf. Tab. 4 and Tab. 13). But in this scenario type and with the assumptions made here about the global framework data, India would have to achieve emission neutrality as early as 2046 instead of 2070 as set out in its NDC.

Russia					
global CO2 budget 2020 - 2100 in Gt		550	minimum emissions		-2%
weighting population		15%	LUC budget in Gt		0
scenario type:	RM-1-const	RM-5-rad	RM-3-lin	RM-4-quadr	RM-6-abs
target year	changes versus 2019				
2025	-4%	11%	11%	11%	2%
2030	**-45%**	**-26%**	**-16%**	**-1%**	**-28%**
2035	-69%	-70%	-72%	-82%	-58%
2040	-83%	-91%	-96%	-102%	-89%
2045	-90%	-98%	-102%	-102%	-102%
2050	-94%	-102%	-102%	-102%	-102%
year emissions neutrality	**2061**	**2047**	**2043**	**2038**	**2042**
overshoot in Gt	1.4	2.0	2.1	2.3	2.2
start change rate 2025	-10.8%	2.9%	3.0%	3.0%	-5.6%
national budget in Gt	**24**				

Tab. 19: RM Scenario Types - reference values Russia - B550 / P15 / NNE2 / LUC0

Japan					
global CO2 budget 2020 - 2100 in Gt		550	minimum emissions		-2%
weighting population		15%	LUC budget in Gt		0
scenario type:	RM-1-const	RM-5-rad	RM-3-lin	RM-4-quadr	RM-6-abs
target year	changes versus 2019				
2025	-21%	-16%	-16%	-16%	-17%
2030	**-48%**	**-39%**	**-35%**	**-30%**	**-35%**
2035	-66%	-61%	-57%	-51%	-53%
2040	-78%	-77%	-77%	-76%	-71%
2045	-86%	-88%	-89%	-93%	-89%
2050	-91%	-94%	-96%	-101%	-102%
year emissions neutrality	**2071**	**2061**	**2056**	**2050**	**2048**
overshoot in Gt	0.6	0.9	1.0	1.1	1.2
start change rate 2025	-8.2%	-3.0%	-3.0%	-3.0%	-4.2%
national budget in Gt	**15**				

Tab. 20: RM Scenario Types - reference values Japan - B550 / P15 / NNE2 / LUC0

Nigeria					
global CO2 budget 2020 - 2100 in Gt		550	minimum emissions		-2%
weighting population		15%	LUC budget in Gt		0
scenario type:	RM-1-const	RM-5-rad	RM-3-lin	RM-4-quadr	RM-6-abs
target year	changes versus 2019				
2025	1%	10%	10%	10%	2%
2030	**-18%**	**13%**	**24%**	**34%**	**-9%**
2035	-32%	-2%	15%	38%	-20%
2040	-45%	-24%	-12%	2%	-31%
2045	-55%	-46%	-46%	-56%	-42%
2050	-63%	-65%	-73%	-92%	-53%
year emissions neutrality	**2097**	**2076**	**2064**	**2054**	**2072**
overshoot in Gt	0.0	0.1	0.1	0.1	0.1
start change rate 2025	-3.9%	4.8%	4.8%	4.8%	-2.1%
national budget in Gt	**4**				

Tab. 21: RM Scenario Types - reference values Nigeria - B550 / P15 / NNE2 / LUC0

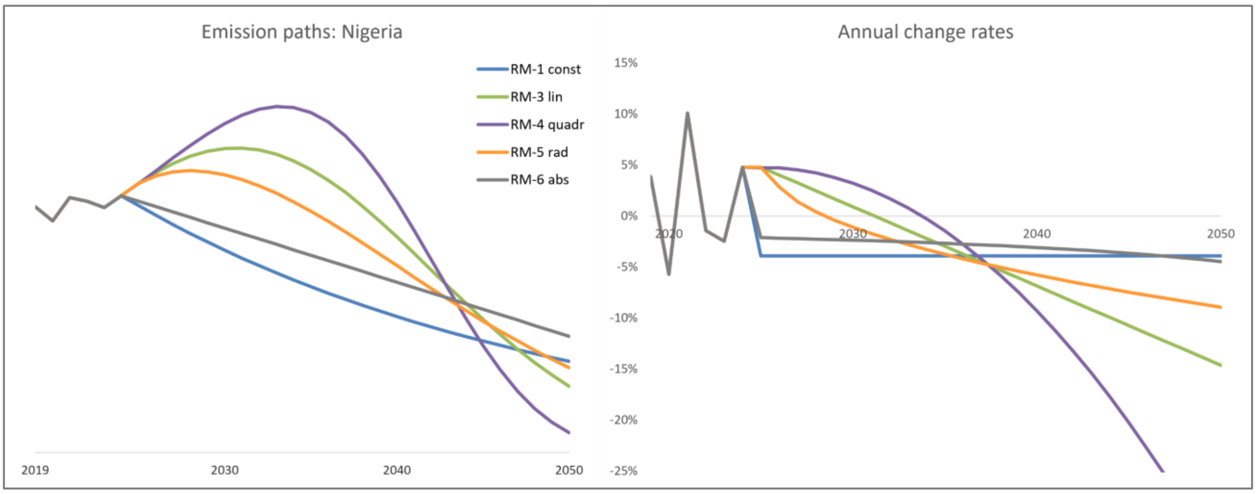

Fig. 6: RM Scenario Types – emission paths and annual change rates Nigeria – B550 / P15 / NNE2 / LUC0

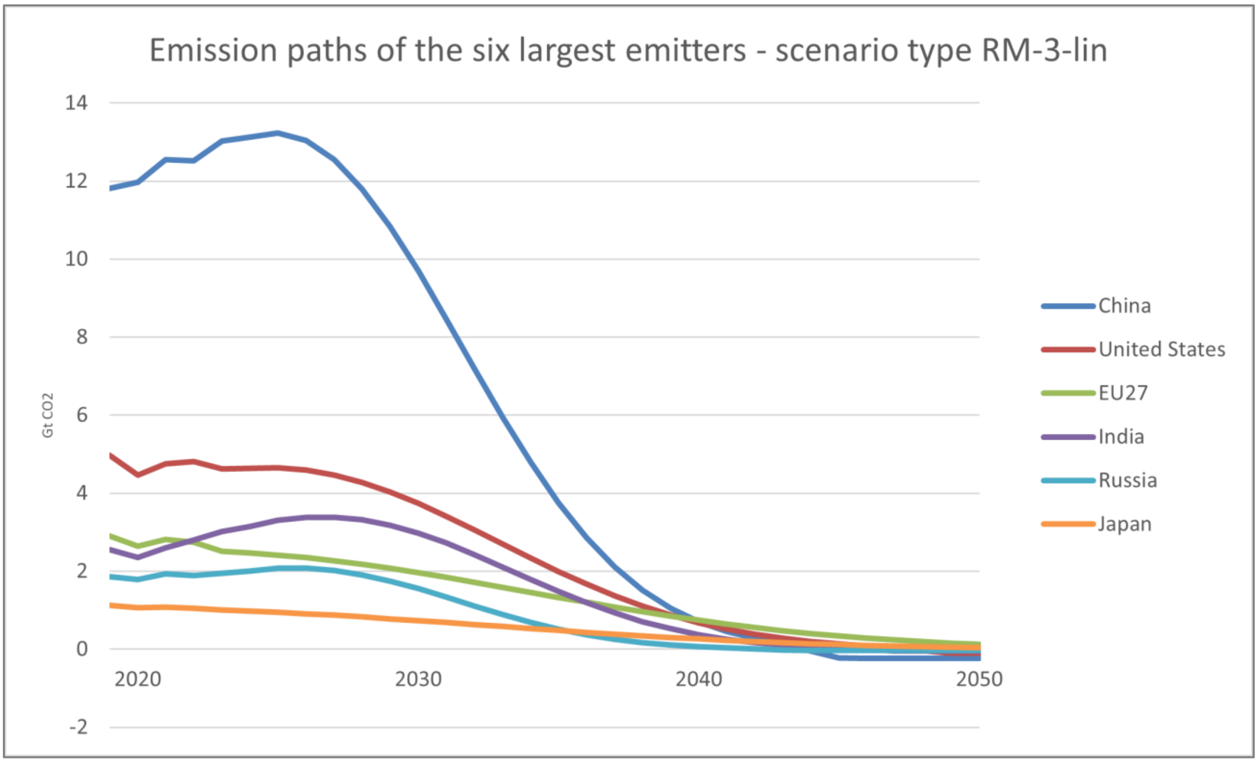

Fig. 7: Emission paths major emitters (RM-3-lin) – B550 / P15 / NNE2 / LUC0

4.3 Exemplary global framework data reflect the NDCs of China and India

In order to obtain targets for China and India that move in the direction of their NDCs, the global budget, the LUC budget and the potential for net negative emissions would each have to be changed in a direction and to an extent that would significantly increase the risk of not successfully limiting global warming (see Tab. 22 and Tab. 23). In particular, the risks of such a massive negative LUC budget and such a high potential for net negative emissions are hardly acceptable.[41]

On the other hand, there would then be a scope for the EU and Japan to provide budgets to India and China. For example, with the framework data from Tab. 12, the EU would receive a budget of around 40 Gt; in Tab. 24 it would be around 61 Gt. However, due to the small share of the EU and Japan in global emissions, the resulting scope is small.

[41] See footnote 8 and (Wolfsteiner & Wittmann, 2025e).

China					
global CO2 budget 2020 - 2100 in Gt		650	minimum emissions		-25%
weighting population		15%	LUC budget in Gt		-180
scenario type:	RM-1-const	RM-5-rad	RM-3-lin	RM-4-quadr	RM-6-abs
target year	changes versus 2019				
2025	7%	12%	12%	12%	8%
2030	**-13%**	**4%**	**10%**	**15%**	**-5%**
2035	-29%	-12%	-1%	12%	-18%
2040	-42%	-30%	-19%	-4%	-31%
2045	-52%	-47%	-40%	-30%	-45%
2050	-62%	-62%	-60%	-60%	-58%
year emissions neutrality	**2071**	**2065**	**2062**	**2058**	**2066**
overshoot in Gt	69.7	91.0	105.1	121.0	88.1
start change rate 2025	-4.0%	0.8%	0.8%	0.8%	-2.4%
national budget in Gt	**244**				

Tab. 22: RM Scenario Types - reference values China – B650 / P15 / NNE25 / LUC180

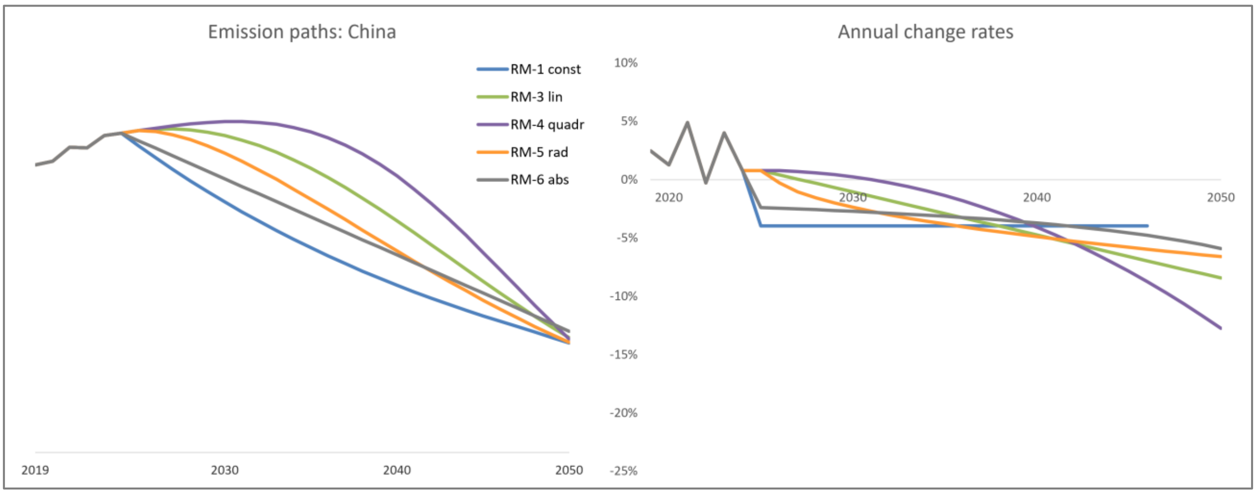

Fig. 8: RM Scenario Types – emission paths and annual change rates China – B650 / P15 / NNE25 / LUC180

India					
global CO2 budget 2020 - 2100 in Gt		650	minimum emissions		-25%
weighting population		15%	LUC budget in Gt		-180
scenario type:	RM-1-const	RM-5-rad	RM-3-lin	RM-4-quadr	RM-6-abs
target year	changes versus 2019				
2025	19%	29%	29%	29%	21%
2030	**-1%**	**34%**	**47%**	**57%**	**8%**
2035	-18%	20%	43%	70%	-6%
2040	-32%	-4%	17%	45%	-19%
2045	-44%	-29%	-20%	-15%	-32%
2050	-53%	-51%	-54%	-71%	-46%
year emissions neutrality	**2077**	**2065**	**2059**	**2054**	**2071**
overshoot in Gt	11.0	20.6	25.2	29.3	16.2
start change rate 2025	-3.7%	4.5%	4.6%	4.5%	-2.2%
national budget in Gt	**69**				

Tab. 23: RM Scenario Types - reference values India – B650 / P15 / NNE25 / LUC180

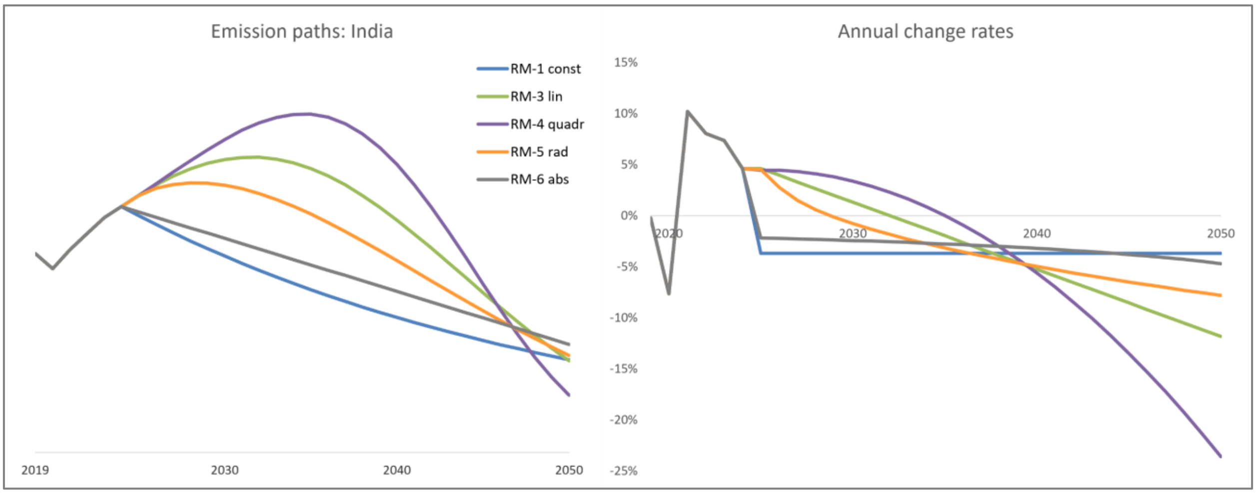

Fig. 9: RM Scenario Types – emission paths and annual change rates India – B650 / P15 / NNE25 / LUC180

global CO2 budget 2020 - 2100 in Gt				650	minimum annual emissions			-25%
weighting population				15%	LUC budget 2020 - 2100 in Gt			-180
reference values (linear emission paths. RM-6)					budget 2020 - 2100 in Gt	scope years	temporary overshoot in Gt	year emissions neutrality
target year:	2030	2030	2035	2040				
reference year:	1990	2019						
China	366%	-5%	-18%	-31%	244	21	88.1	2066
United States	-19%	-19%	-29%	-39%	98	20	29.8	2071
EU27	-43%	-25%	-34%	-42%	61	21	13.1	2075
India	357%	8%	-6%	-19%	69	27	16.2	2071
Russia	-29%	-7%	-20%	-33%	37	20	13.7	2067
Japan	-27%	-24%	-33%	-42%	23	21	5.6	2074
Nigeria	62%	-4%	-11%	-18%	6	44	0.0	-

Tab. 24: Linear emission paths - reference values big six – B650 / P15 / NNE25 / LUC180

Gt	national budget (Tab. 24)	implicit budget[42] (Tab. 6)	devia-tion in %
China	244	332	36%
United States	98	73	-26%
EU27	61	42	-32%
India	69	91	32%
Russia	37	45	23%
Japan	23	17	-26%
sum	532	600	13%

Tab. 25: Comparison with NDCs (budgets) – B650 / P15 / NNE25 / LUC180

[42] See footnote 25 for the limitations.

5 Conclusions

The ESPM is a helpful tool for making comprehensible science-based policy decisions and for presenting meaningful reference values in the Paris Ratchet Mechanism:

- The ESPM approach is open to the question of how a national CO2 budget is determined. The weighted distribution key used here for a global CO2 budget with the two components "emissions share" and "population share" in a base year represents a pragmatic approach that can map the two most important factors “current reality” and “equity” (see Excursus 3).
- With the RM Scenario Types offered in the ESPM (see Excursus 5), national paths can be derived that adhere to a predefined budget and take socio-economic factors into account. The scenario types ultimately enable a transparent political decision on emission paths.

The emission targets for the world's six major emitters presented here are only examples, as important framework data need to be decided politically.[43] This results in the following political agenda for each Party to the Paris Agreement:[44]

Political agenda:

1. Concretise global framework data based on the state of scientific knowledge, especially with regard to the global CO2 budget and the scope of net negative emissions.
2. Derive a national CO2 budget on this base that ensure a fair and economically sensible distribution of a global CO2 budget.[45]
3. Align emission targets with a climate policy-sensible course of annual rates of change.[46]
4. Adjust the framework data and reduction targets regularly on the basis of new scientific findings and technical/real developments.

Despite the exemplary nature of the results shown here, they provide important indications of which scenarios/framework data lead to realistic national emission targets that sum up to a Paris-compatible global emissions budget.

[43] This web app can be used to specify a variety of global framework data.: http://national-budgets.climate-calculator.info.

[44] At present, a corresponding global agreement would not be realistic. Therefore, in the sense of the bottom-up approach of the Paris Ratchet Mechanism, each country is to answer the points of the following agenda for itself. However, this can initiate a global discourse that contributes to Paris-compatible NDCs in sum. In addition, the major emitters need to find a binding negotiation format (cf. Edenhofer, 2022).

[45] See Excursus 3: Allocation of a global CO2 budget.

[46] See Excursus 5: Regensburg Model Scenario Types.

An important finding is that there is a trade-off between realisable national emission paths for major emitters in line with the 1.5°C limit and climate justice.

The following is now crucial:

- We have to face the difficult task of identifying achievable national targets that are consistent with the Paris Agreement and adequately address climate justice. In doing so, concessions will be necessary, both in terms of orientation towards the 1.5°C limit and in terms of the per capita distribution of a remaining global CO2 budget.
- Major emitters should find a negotiating format to agree on Paris-compatible and binding targets. The UN climate conferences are not the appropriate format for such negotiations because of the unanimity rule of over 190 countries (cf. Edenhofer, 2022).
- The figures show that we urgently need a solution to China's looming ambition gap (cf. for example: Tab. 6, Tab. 13 and Fig. 2). This ambition gap is particularly critical for achieving the Paris climate targets, firstly because of China's high share of global emissions and secondly because the rapid reduction in emissions that is actually necessary may not seem feasible.
- But the emissions of emerging nations such as India must also fall soon. If emissions continue to rise in these countries, as they have in recent years, then the Paris climate targets will also not be achievable. The decarbonisation of the Global South must be financially supported. On its path to greater prosperity, the Global South must leapfrog the high-carbon era of the old industrialised countries.
- However, all parties to the Paris Agreement are required to submit NDCs by 2025 reflecting the global reduction needs according to the Global Stocktake (GST). The NDCs are still a long way from being Paris-compatible in total.[47]
- Paris-compatible NDCs are the first step. The second, equally important step is to ensure that these targets are actually met. Hard emission caps in emissions trading systems could ensure this, for example (cf. Expertenrat für Klimafragen, 2022, p. 17). As long as there are no NDCs that are Paris-compatible in total and that are also adhered to, further forms of cooperation must be found, as the room for manoeuvre of individual countries is limited by the risk of carbon leakage if climate protection at the corporate level means higher costs.

[47] (cf. UNFCCC, 2023; UNFCCC, 2024; UNEP, 2024).

Tools and further exemplary results

For the calculation of the exemplary results in this paper we have used the Excel tool "ESPM" (version 79.0), which can be downloaded from the zenodo platform (Wolfsteiner & Wittmann, 2025b).

Further exemplary results for the six largest emitters with different framework data and RM Scenario Types are shown at http://espm.save-the-climate.info.

The web app http://national-budgets.climate-calculator.info can be used to calculate Paris-compatible CO2 budgets for all countries in the world (corresponding detailed Excel tool: (Wolfsteiner & Wittmann, 2025d)). This web app also shows the emission targets for a linear emission path. This allows the results shown here to be reproducible. Minor deviations may occur due to a different mathematical approach (cf. Wittmann & Wolfsteiner, 2023).

The web app http://paths.climate-calculator.info can be used to calculate emission paths that comply with a predefined CO2 budget (corresponding detailed Excel tool: (Wolfsteiner & Wittmann, 2025a). In addition to linear emission paths, other scenario types are offered there (see Excursus 5: Regensburg Model Scenario Types).

The web app http://ib-iwp.climate-calculator.info can be used to calculate implicit emission budgets derived from an NDC and to calculate the implicit weighting of the population (see Chapter 2.1.3 NDC indicator: Implicit weighting of the population (IWP)).

At https://climate-calculator.info we provide an overview of the tools we offer.

Excursuses

Excursus 1: German Federal Constitutional Court on CO2 budgets 32
Excursus 2: German Federal Constitutional Court on freedom opportunities for future generations 32
Excursus 3: Allocation of a global CO2 budget 35
Excursus 4: Potential for emissions trading between countries 36
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German Federal Constitutional Court on CO2 budgets

Excerpt from the main considerations of the Federal Constitutional Court (BVerfG, 2021):

"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 [(SRU, 2020)], note by the authors] 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 residual budget must be taken into account, even though they contain uncertainties. The emission levels regulated in Article 4 para. 1 sentence 3 KSG [Climate Protection Act, note by the authors] in conjunction with Annex 2 would largely exhaust the residual budget determined by the German Advisory Council on the Environment 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."

Excursus 1: German Federal Constitutional Court on CO2 budgets

German Federal Constitutional Court on freedom opportunities for future generations

Excerpt from the guiding principles of the decision of the Federal Constitutional Court (BVerfG, 2021):

"Under certain conditions, the Basic Law obliges the safeguarding of freedom protected by fundamental rights over time and the proportionate distribution of opportunities for freedom over the generations. In terms of subjective law, fundamental rights, as an intertemporal safeguard of freedom, protect against a unilateral shifting of the greenhouse gas reduction burden imposed by Article 20a GG [Basic Law, note by the authors] to 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 the early formulation of transparent targets for further greenhouse gas reductions that provide orientation for the necessary development and implementation processes and give them a sufficient degree of development pressure and planning certainty."

Excursus 2: German Federal Constitutional Court on freedom opportunities for future generations

Allocation of a global CO2 budget

The global community has set itself the following framework:

"*Acknowledging that the global nature of climate change calls for the widest possible cooperation by all countries and their participation in an effective and appropriate international response, in accordance with their common but differentiated responsibilities and respective capabilities and their social and economic conditions.*"

United Nations Climate Change Framework Convention of 1992

Five basic allocation approaches can be distinguished:[48]

(1) Grandfathering

(2) Equality

(3) Responsibility

(4) Capability

(5) Cost efficiency

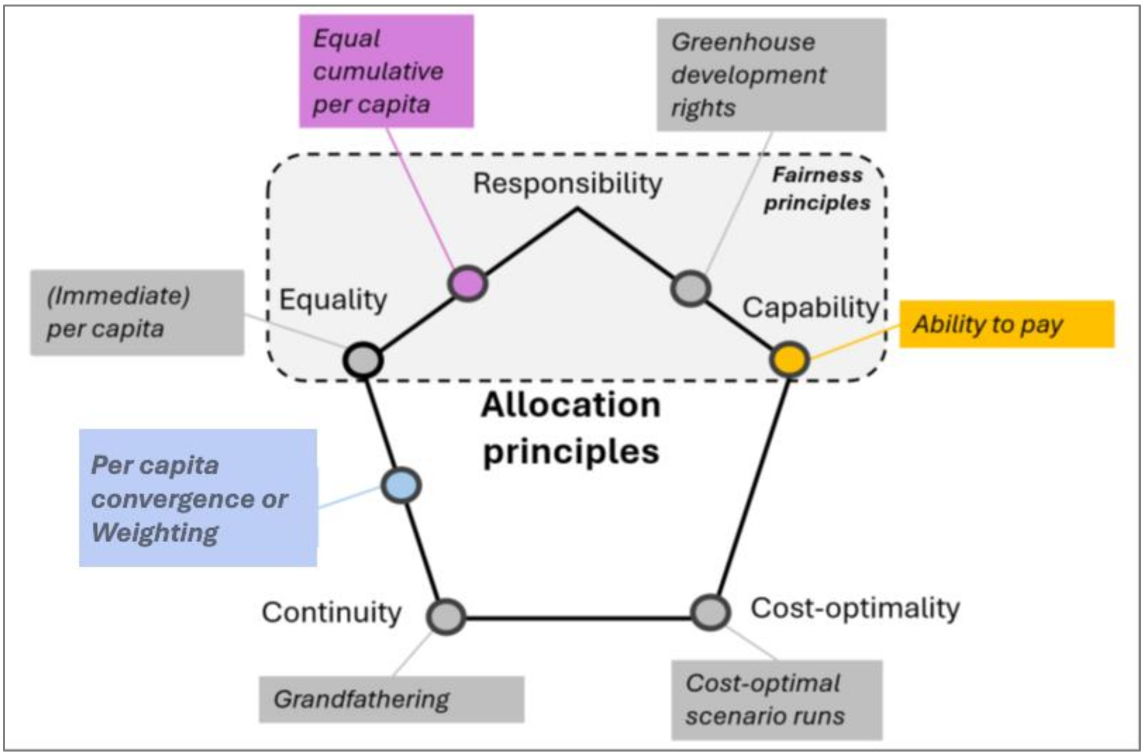

Fig. 10: Allocation principles for the distribution of a remaining global CO2 budget[49]

[48] See (Dekker, et al., 2025) for a comprehensive classification of effort-sharing approaches and an assessment of their influence on national targets under different equity, strategic, and scientific assumptions. See also: (Robiou du Pont, et al., 2017, p. 40; Robiou du Pont, et al., 2025).

[49] „Allocation and fairness principles (corners of the pentagon, in black) and methods to quantify these principles or combinations thereof (in coloured or grey text boxes)" (Dekker, et al., 2025, Supplementary information). Source of the figure: (Dekker, et al., 2025, Supplementary information: Figure SI.3). Original figure concept based on (Höhne, et al., 2014).

In the field labelled 'Per capita convergence', 'or Weighting' has been added to reflect the approach used in this paper.

In addition to the allocation keys "current emissions share" (1) and "current population share" (2) used here, other criteria may therefore be taken into account such as historical emissions (3) or GDP per capita (4).

Including historical emissions highlights the responsibility of the "old" industrialised countries for the decarbonisation process, but results in unrealistic territorial emission targets. However, historical emissions could play a significant role, especially in compensating for Loss and Damage.

The idea behind "capability" is that wealthier countries should set themselves more ambitious goals. Since there is a correlation between emissions per capita and GDP per capita for the six largest emitters (cf. Tab. 26), the GDP per capita criterion is already indirectly mapped via the weighting of the population. However, the correlation coefficient of 0.7 is clearly below 1, so that this mapping is not perfect. In principle, it might make more sense to use criteria based on economic performance for direct financial issues such as contributions to Climate Finance.

correlation	per capita	
	emissions in t	GDP in TUSD
India	2	7
EU27	7	45
China	8	16
Japan	9	41
Russia	13	28
United States	15	62
correlation coefficient	0.68	

Tab. 26: GDP per capita of the six largest emitters

Instead of allocating a global budget, a global path can be allocated by using a convergence model [also a combination of the approaches (1) and (2)] (cf. Sargl, et al., 2024a). Using a convergence model implies an implicit weighting of the population that is the same for all countries (cf. Wittmann & Wolfsteiner, 2023). In the Regensburg Model convergence approach, this implicit weighting is around 12% with a linear emission path and a per capita emissions convergence at 0.5 t (cf. Wolfsteiner & Wittmann, 2024b; Sargl, et al., 2024b). Due to its characteristics, the Regensburg Model can be described as a kind of "moral floor" for the industrialised countries.

Another approach (5) are Integrated Assessment Models (IAMs), which can be used to identify globally cost-efficient national emission paths (cf. van Soest, et al., 2021).[50] But the results of IAMs are a "black box" for policy makers. For the ESPM approach, on the other hand, only a few framework data need to be specified politically and equity aspects can be explicitly considered. This means that emissions paths can ultimately be determined politically in a transparent manner in the ESPM, taking socio-economic factors into account.

In convergence models and IAMs, the national budgets and thus the distribution of a global CO2 budget result indirectly.

A distinction can be made whether the allocation of a global CO2 budget refers to the actual territorial emissions of a country or to tradable emission rights. If allocation is based on emission rights, the scope for climate justice can be considered even greater (Rajamani, et al., 2021; Robiou du Pont, et al., 2025). However, it is important to keep in mind that the resulting potential financial flows in a subsequent emissions trading should be realistic. The potential to generate certificates with different weightings of the population is discussed in Excursus 4.

[50] For a recent approach that derives nationally consistent emission targets from global welfare-optimizing IAM scenarios, see (van der Wijst, et al., 2025).

If the allocation is based on territorial emissions, it would have to be examined whether it makes sense for countries with low per capita emissions today to build up an economy that is more fossil fuel-based and has to decarbonise again soon afterwards.

When allocating a global CO2 budget, it should be taken into account that it must also work for countries with currently high per capita emissions or high per capita incomes.

There are two aspects to consider:

Territorial emission targets or payments within the framework of global emission trading

(1) must also be politically enforceable at national level.

(2) should also be economically viable in the sense that the global economy is not unduly affected. This would otherwise also have a considerable negative impact on countries with low economic power.

An ethical justification for these aspects can be found in **Rawls' "Theory of Justice"**.

Excursus 3: Allocation of a global CO2 budget

Potential for emissions trading between countries

The exemplary national CO2 budgets in Tab. 27 in the appendix, which are derived from various global framework data, show that:

- The lower the weighting of the population, the smaller the scope for newly industrialising and developing countries to generate certificates within the framework Article 6 (2) of the Paris Agreement. The stated scopes of the national budgets can serve as a measure of this leeway.
- A higher the weighting of the population, would result in a higher demand for certificates of the industrialised countries plus China.
- Ambitious targets, for example those of the EU, only allow limited scope for compensating for the lack of ambition of emerging countries such as China and India.

Emissions trading therefore does not solve the fundamental problem of a tight global CO2 budget.

For a further development of the Cooperative Mechanisms under Article 6 of the Paris Agreement with regard to a global remaining CO2 budget, it would make sense that the NDCs must state the CO2 budget that a country will claim for itself through the NDC in the future. Such explicit national CO2 budgets could also facilitate emissions trading between countries, especially if the NDCs are Paris-compatible in sum. However, the integrity of emissions trading on this basis is undermined if NDCs are not met.

Excursus 4: Potential for emissions trading between countries

Regensburg Model Scenario Types

From an overall perspective of climate policy, scenarios with a nonlinear emissions path may be useful. Additional scenario types also offer the possibility of taking country-specific features into account.

The Regensburg Model Scenario Types RM 1 - 5 are based on the course of the annual change rates. Annual rates of change are used in many areas and are particularly suitable for describing a meaningful course of emission paths.

Four basic types can be distinguished in a monotonically decreasing progression of the annual rates of change:

(1) Constant: constant annual reduction rates (RM-1, straight line)

(2) Linear: linearly monotonically decreasing (RM-3; straight line)

(3) Concave: initially under-proportional monotonically decreasing (RM-2, RM-4)

(4) Convex: initially over-proportional monotonically decreasing (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://paths.climate-calculator.info the different scenario types can be graphically traced (see also Fig. 1and e.g. Fig. 4).

For a comprehensive mathematical description, we refer to: (Wolfsteiner & Wittmann, 2024a).

The advantage of scenario types RM 3 - 5 is that the start change rate can be specified on the basis of the real circumstances and that increasing emissions can also be mapped by specifying a positive start change rate.

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

(1) Which annual change rates are when realistic?

(2) Does an initially slowly rising level of ambition (RM-2/4 and RM-6) imply an unjustifiable burden for the future, since this later implies very high reduction rates?

(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) Does an initially rapidly rising level of ambition (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 to refrain 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 scenario types RM-2 and RM-4.

The decision of the German Federal Constitutional Court on the Climate Protection Act also implicitly poses the question of what annual change rates we must accept today so that the freedom of future generations is not unduly restricted (see Excursus 2: German Federal Constitutional Court on freedom opportunities for future generations).

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

Excursus 5: Regensburg Model Scenario Types

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Appendix: Exemplary national budgets with different global framework data

global budget 2020 - 2100 in Gt	550	LUC budget	0	
weighting population	50%			
sorted by national budget	national budget 2020 - 2100	weighted key	emissions 2019	scope years
	Gt		Gt	
China	134,6	25,3%	11,81	11
India	65,7	12,4%	2,55	26
United States	47,4	8,9%	4,97	10
EU27	36,4	6,8%	2,91	13
Russia	18,4	3,5%	1,86	10
Indonesia	13,9	2,6%	0,64	22
Japan	12,5	2,4%	1,12	11
Brazil	10,7	2,0%	0,47	23
Pakistan	8,5	1,6%	0,20	43
Mexico	8,1	1,5%	0,49	16
Iran	8,0	1,5%	0,71	11
Germany	7,9	1,5%	0,70	11
Nigeria	7,8	1,5%	0,13	62
Bangladesh	6,6	1,2%	0,11	60
South Korea	6,5	1,2%	0,65	10
Türkiye	5,9	1,1%	0,41	14
Viet Nam	5,8	1,1%	0,34	17
Canada	5,7	1,1%	0,61	9
South Africa	5,5	1,0%	0,48	11
Saudi Arabia	5,4	1,0%	0,58	9
Egypt	5,2	1,0%	0,24	22
United Kingdom	4,9	0,9%	0,36	14
Philippines	4,8	0,9%	0,15	32
France and Monaco	4,6	0,9%	0,32	14
Thailand	4,5	0,8%	0,29	16
Italy, S. Mar., Holy See	4,5	0,8%	0,33	13
Ethiopia	3,9	0,7%	0,02	213
Australia	3,8	0,7%	0,41	9
Poland	3,6	0,7%	0,31	11
Spain and Andorra	3,4	0,6%	0,25	14
Dem. Rep. of the Congo	3,0	0,6%	0,00	680
Ukraine	3,0	0,6%	0,21	15
Malaysia	3,0	0,6%	0,26	12
Taiwan	2,9	0,5%	0,29	10
Argentina	2,9	0,5%	0,18	16
Iraq	2,8	0,5%	0,19	14
Algeria	2,8	0,5%	0,18	15
Colombia	2,3	0,4%	0,09	27
Kazakhstan	2,2	0,4%	0,22	10
Tanzania	2,2	0,4%	0,02	131
Myanmar/Burma	2,1	0,4%	0,03	62
Sudan and South Sudan	2,0	0,4%	0,02	87
Venezuela	2,0	0,4%	0,12	17
Uzbekistan	2,0	0,4%	0,12	17
Kenya	1,9	0,4%	0,02	100
Morocco	1,8	0,3%	0,07	25
United Arab Emirates	1,8	0,3%	0,20	9
Netherlands	1,7	0,3%	0,16	11
Uganda	1,6	0,3%	0,01	230
Peru	1,6	0,3%	0,06	27
North Korea	1,4	0,3%	0,07	19
Afghanistan	1,4	0,3%	0,01	113
Chile	1,3	0,2%	0,10	14
Angola	1,3	0,2%	0,03	48
Romania	1,3	0,2%	0,08	16
Ghana	1,2	0,2%	0,02	58
Mozambique	1,1	0,2%	0,01	133
Nepal	1,1	0,2%	0,01	84
Belgium	1,1	0,2%	0,10	11
Czechia	1,1	0,2%	0,10	11
Yemen	1,1	0,2%	0,01	90
sum without EU	487		35	

global budget 2020 - 2100 in Gt	650	LUC budget	0	
weighting population	50%			
sorted by national budget	national budget 2020 - 2100	weighted key	emissions 2019	scope years
	Gt		Gt	
China	159,2	25,3%	11,81	13
India	77,7	12,4%	2,55	30
United States	56,0	8,9%	4,97	11
EU27	43,0	6,8%	2,91	15
Russia	21,8	3,5%	1,86	12
Indonesia	16,5	2,6%	0,64	26
Japan	14,8	2,4%	1,12	13
Brazil	12,7	2,0%	0,47	27
Pakistan	10,0	1,6%	0,20	51
Mexico	9,6	1,5%	0,49	20
Iran	9,5	1,5%	0,71	13
Germany	9,3	1,5%	0,70	13
Nigeria	9,3	1,5%	0,13	74
Bangladesh	7,8	1,2%	0,11	71
South Korea	7,7	1,2%	0,65	12
Türkiye	6,9	1,1%	0,41	17
Viet Nam	6,9	1,1%	0,34	20
Canada	6,7	1,1%	0,61	11
South Africa	6,5	1,0%	0,48	14
Saudi Arabia	6,4	1,0%	0,58	11
Egypt	6,2	1,0%	0,24	26
United Kingdom	5,8	0,9%	0,36	16
Philippines	5,7	0,9%	0,15	38
France and Monaco	5,4	0,9%	0,32	17
Thailand	5,3	0,8%	0,29	18
Italy, S. Mar., Holy See	5,3	0,8%	0,33	16
Ethiopia	4,6	0,7%	0,02	252
Australia	4,5	0,7%	0,41	11
Poland	4,2	0,7%	0,31	14
Spain and Andorra	4,1	0,6%	0,25	16
Dem. Rep. of the Congo	3,6	0,6%	0,00	804
Ukraine	3,6	0,6%	0,21	17
Malaysia	3,5	0,6%	0,26	14
Taiwan	3,5	0,5%	0,29	12
Argentina	3,4	0,5%	0,18	19
Iraq	3,3	0,5%	0,19	17
Algeria	3,3	0,5%	0,18	18
Colombia	2,8	0,4%	0,09	32
Kazakhstan	2,6	0,4%	0,22	12
Tanzania	2,6	0,4%	0,02	155
Myanmar/Burma	2,5	0,4%	0,03	73
Sudan and South Sudan	2,4	0,4%	0,02	103
Venezuela	2,4	0,4%	0,12	20
Uzbekistan	2,3	0,4%	0,12	20
Kenya	2,3	0,4%	0,02	118
Morocco	2,1	0,3%	0,07	29
United Arab Emirates	2,1	0,3%	0,20	11
Netherlands	2,1	0,3%	0,16	13
Uganda	1,9	0,3%	0,01	272
Peru	1,8	0,3%	0,06	32
North Korea	1,7	0,3%	0,07	23
Afghanistan	1,6	0,3%	0,01	134
Chile	1,6	0,2%	0,10	16
Angola	1,5	0,2%	0,03	57
Romania	1,5	0,2%	0,08	18
Ghana	1,4	0,2%	0,02	69
Mozambique	1,4	0,2%	0,01	157
Nepal	1,3	0,2%	0,01	99
Belgium	1,3	0,2%	0,10	13
Czechia	1,3	0,2%	0,10	13
Yemen	1,3	0,2%	0,01	106
sum without EU	576		35	

global budget 2020 - 2100 in Gt	650	LUC budget	0	
weighting population	15%			
sorted by national budget	national budget 2020 - 2100	weighted key	emissions 2019	scope years
	Gt		Gt	
China	189,5	30,1%	11,81	16
United States	76,4	12,1%	4,97	15
India	53,9	8,6%	2,55	21
EU27	47,8	7,6%	2,91	16
Russia	28,8	4,6%	1,86	16
Japan	17,9	2,9%	1,12	16
Indonesia	12,6	2,0%	0,64	20
Iran	11,4	1,8%	0,71	16
Germany	11,2	1,8%	0,70	16
South Korea	10,2	1,6%	0,65	16
Brazil	9,4	1,5%	0,47	20
Canada	9,3	1,5%	0,61	15
Saudi Arabia	8,9	1,4%	0,58	15
Mexico	8,8	1,4%	0,49	18
South Africa	7,7	1,2%	0,48	16
Türkiye	7,1	1,1%	0,41	17
Australia	6,3	1,0%	0,41	15
Viet Nam	6,1	1,0%	0,34	18
United Kingdom	6,1	1,0%	0,36	17
Italy, San Marino and the H	5,6	0,9%	0,33	17
France and Monaco	5,5	0,9%	0,32	17
Pakistan	5,4	0,9%	0,20	27
Thailand	5,0	0,8%	0,29	18
Poland	5,0	0,8%	0,31	16
Egypt	4,7	0,7%	0,24	20
Taiwan	4,5	0,7%	0,29	16
Nigeria	4,3	0,7%	0,13	34
Spain and Andorra	4,3	0,7%	0,25	17
Malaysia	4,1	0,7%	0,26	16
Bangladesh	3,6	0,6%	0,11	33
Ukraine	3,6	0,6%	0,21	17
Philippines	3,5	0,6%	0,15	24
Kazakhstan	3,4	0,5%	0,22	16
Iraq	3,3	0,5%	0,19	17
Argentina	3,2	0,5%	0,18	18
Algeria	3,2	0,5%	0,18	17
United Arab Emirates	3,0	0,5%	0,20	15
Netherlands	2,5	0,4%	0,16	16
Venezuela	2,2	0,3%	0,12	18
Uzbekistan	2,1	0,3%	0,12	18
Colombia	1,9	0,3%	0,09	22
Qatar	1,7	0,3%	0,12	15
Czechia	1,6	0,3%	0,10	16
Ethiopia	1,6	0,3%	0,02	87
Chile	1,6	0,3%	0,10	17
Belgium	1,6	0,3%	0,10	16
Morocco	1,5	0,2%	0,07	21
Kuwait	1,5	0,2%	0,10	15
Romania	1,4	0,2%	0,08	18
North Korea	1,4	0,2%	0,07	19
Oman	1,3	0,2%	0,09	15
Peru	1,3	0,2%	0,06	21
Myanmar/Burma	1,2	0,2%	0,03	34
Turkmenistan	1,1	0,2%	0,07	16
Dem. Rep. of the Congo	1,1	0,2%	0,00	253
Israel a. Palest., State o.	1,1	0,2%	0,07	17
Austria	1,1	0,2%	0,07	16
Greece	1,0	0,2%	0,06	17
Belarus	1,0	0,2%	0,06	16
Sudan and South Sudan	1,0	0,2%	0,02	43
Tanzania	1,0	0,2%	0,02	58
sum without EU	592		35	

Tab. 27: Exemplary national budgets with different global framework data [51]

[51] 59 countries plus the EU with the highest resulting national CO2 budgets.