Working paper

Calculation of Paris-compatible Emission Targets and CO2 Budgets for the Six Largest Emitters with the Regensburg Model[1]

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Abstract

What are achievable emission targets and CO2 budgets for the world's six major emitters that are Paris-compatible in total?

To answer this question, this paper shows top-down exemplary national emission paths 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.

The results of the Regensburg Model can be interpreted as a lower limit for the ambitions of the industrial 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, 2023).

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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.

<table>
<tr><td rowspan="2">Warm-ing</td><td colspan="3" rowspan="2">Remaining carbon budgets</td><td>Scenario variation</td><td colspan="4">Geophysical uncertainties</td></tr>
<tr><td rowspan="2">Non-CO2 scenario variation</td><td rowspan="2">Non-CO2 forc-ing and response uncertainty</td><td rowspan="2">Historical temperature uncertainty</td><td rowspan="2">ZEC uncer-tainty</td><td rowspan="2">Recent emissions uncertainty</td></tr>
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<tr><td>[°C]</td><td colspan="3">[GtCO2 from 2020 on]</td><td colspan="5">[GtCO2]</td></tr>
<tr><td>1.5</td><td>500</td><td>400</td><td>300</td><td rowspan="4">±220</td><td rowspan="4">±220</td><td rowspan="4">±550</td><td rowspan="4">±420</td><td rowspan="4">±20</td></tr>
<tr><td>1.6</td><td>650</td><td>550</td><td>400</td></tr>
<tr><td>1.7</td><td>850</td><td>700</td><td>550</td></tr>
<tr><td>1.8</td><td>1000</td><td>850</td><td>650</td></tr>
</table>

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.*"

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. The Federal Constitutional Court in Germany also emphasized this fact: National climate policy must be oriented towards remaining global CO2 budgets (cf. BVerfG, 2021). This results from the physically given budget property of CO2.

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.

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

[3] Tab. 1 based on Tables SPM.2 and 5.8 in the IPCC Sixth Assessment Report (cf. IPCC, 2021). Regarding probabilities, the IPCC notes: "*This likelihood is based on the uncertainty in transient climate response to cumulative CO2 emissions (TCRE) and additional Earth system feedbacks and provides the probability that global warming will not exceed the temperature levels provided in the [left column]. Uncertainties related to historical warming (±550 GtCO2) and non-CO2 forcing and response (±220 GtCO2) are partially addressed by the assessed uncertainty in TCRE, but uncertainties in recent emissions since 2015 (±20 GtCO2) and the climate response after net zero CO2 emissions are reached (±420 GtCO2) are separate*" (IPCC, 2021, p. 29 SPM).

For further scientific background information, we refer to the IPCC report.

In 2019, global emissions were around 40.9 GtCO2 (GCP, 2023).

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	9.1	11.8	8.3	32%	18%
United States	5.0	5.9	5.0	15.1	14%	4%
EU27	3.8	3.7	2.9	6.5	8%	6%
India	0.6	1.2	2.5	1.9	7%	18%
Russia	2.4	1.7	1.9	13.0	5%	2%
Japan	1.2	1.3	1.1	8.9	3%	2%
sum	15.3	22.9	25.2		69%	50%
Kenya	0.01	0.01	0.02	0.4	0.05%	0.68%
global	21.9	32.7	36.5	4.7	100%	

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

Tab. 3 shows the currently submitted NDCs 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% to -52%	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 is to what extent these commitments are in line with the Paris climate targets. To answer this question, top-down national emission paths are derived here based on different global framework data as a reference.

[4] These are the CO2 emissions from fossil fuel use (except international shipping and aviation; ISA) and cement production (EDGAR, 2023). CO2 emissions from land-use change (LUC) are therefore not included here (see also Footnote 11).

[5] Source and further details at Climate Action Tracker (https://climateactiontracker.org; status as of 08/11/2022).

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., 2023). The resource sharing approach used here, the Regensburg Model (RM), distributes a global path that adheres to a predefined global CO2 budget and results in converging per capita emissions.[6]

The model proceeds in two steps:

(1) Determining of global emission paths
Global emission paths in line with a global CO2 budget are derived. With the scenario types RM 1 - 6, an entire range of plausible possibilities are offed (see Excursus, p. 18). For reasons of simplification, a linear course of the global emission path (RM-6) is used in the Chapter “Exemplary national CO2 emission targets and budgets”.

(2) Derivation of national emission paths
Next national emission paths are derived from the global emission paths using the Regensburg Formula (cf. Wittmann & Wolfsteiner, 2023):

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

where:

$$C_t = \frac{E_{BY} - E_t}{E_{BY} - E_{CY}} \text{ and } E_{CY}^i = \frac{E_{CY}}{P_{BY}} * P_{BY}^i \; ^7$$

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[8]
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.[9] 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).

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[6] In contrast, in our Extended Smooth Pathway Model (ESPM), a global CO2 budget is allocated directly (cf. Sargl, et al., 2024b).

[7] In the Excel tool (Wolfsteiner & Wittmann, 2024) to calculate E_{CY}^i, P_{CY} and P_{CY}^i can also be used based on estimated values of the UN.

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

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

- After the convergence period, the global path is distributed per capita (basis here: population figures 2019).
- 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 (also emerging countries).

The national CO2 budgets that result from the national emission paths have for all countries the characteristic of an equal implicit weighting of the population (see Chapter “Implicit Weighting Population”). Due to the characteristics of the Regensburg Model, its implicit weighting is rather low, so that it can be considered advantageous for industrialised countries.

Determination of the global budget to be distributed here

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 and Kenya (cf. EDGAR, 2023).

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). 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[10]

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, 2023b) and (Wolfsteiner & Wittmann, 2023c)]. In the following calculations, an exemplary value of zero is used for the LUC budget (except in Tab. 10 and Tab. 11). This implies that until 2100 annual net positive LUC emissions occurring are compensated by annual net negative LUC emissions.[11]

[10] In the Excel tool used (Wolfsteiner & Wittmann, 2024) other values can also be used for LUC or ISA budgets. Example calculation of the second column: 550 - (-100) - 17 = 633.

[11] The annual global LUC emissions are assumed to be around +4.6 Gt CO2 in 2019 (cf. GCP, 2023).

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.

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.

Leaving aside the fact that the NDCs may refer to different greenhouse gas fractions, the targets there for some countries can be converted into the change in CO2 emissions in 2030 compared to 2019 considered here, which allows for better comparability (see Tab. 5).

country	target year 2030	reference year	change 2030 vs. 2019
	see Tab. 3		
United States	-50%	2005	**-41%**
EU27	-55%	1990	**-41%**
Russia	-30%	1990	**-12%**
Japan	-46%	2013	**-37%**

Tab. 5: Conversion of emission targets to the change in 2030 compared to 2019

Exemplary national CO2 emission targets and budgets

Exemplary national emission paths are calculated, with the following parameters being varied:[12]

(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

Already known actual CO2 emissions after the base year 2019 are not taken into account in the emission paths, as the primary aim here is to determine the national CO2 budgets that result in the Regensburg Model in the case of a distribution of a global CO2 budget from 2020.

These national CO2 budgets or the implicit weighting of the population (see Chapter “Implicit Weighting Population (IWP)”) can be the basis for deriving plausible national emission paths in our Extended Smooth Pathway Model, which also take actual emissions after 2019 into account [cf. (Sargl, et al., 2024b) and (Sargl, et al., 2024a)].

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. 6.

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	130%	-53%	-100%	-100%	**117**	10	0	
United States	-55%	-55%	-100%	-100%	**47**	10	0	
EU27	-63%	-52%	-100%	-100%	**30**	10	0	
India	169%	-36%	-100%	-100%	**33**	13	0	2042
Russia	-64%	-55%	-100%	-100%	**18**	10	0	
Japan	-55%	-53%	-100%	-100%	**11**	10	0	
Kenya	347%	49%	-100%	-100%	**0.6**	30	0.00	

Tab. 6: Reference values - B400 / NNE0 / LUC0[13]

[12] For the calculation of the exemplary results in this paper we have used the Excel tool "RM" (version 58.2), which can be downloaded from the platform zenodo (Wolfsteiner & Wittmann, 2024). Here is a **simplified web app**: http://RM.climate-calculator.info.

[13] 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.

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

Using a higher global budget of 550 Gt, leads to the results in Tab. 7.

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	203%	-38%	-100%	-100%	**165**	14	0	2050
United States	-40%	-39%	-100%	-100%	**67**	14	0	
EU27	-52%	-38%	-100%	-100%	**41**	14	0	
India	198%	-30%	-100%	-100%	**44**	17	0	
Russia	-51%	-39%	-100%	-100%	**26**	14	0	
Japan	-40%	-38%	-100%	-100%	**16**	14	0	
Kenya	246%	15%	-100%	-100%	**0.7**	34	0.00	

Tab. 7: Reference values - B550 / NNE0 / LUC0

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

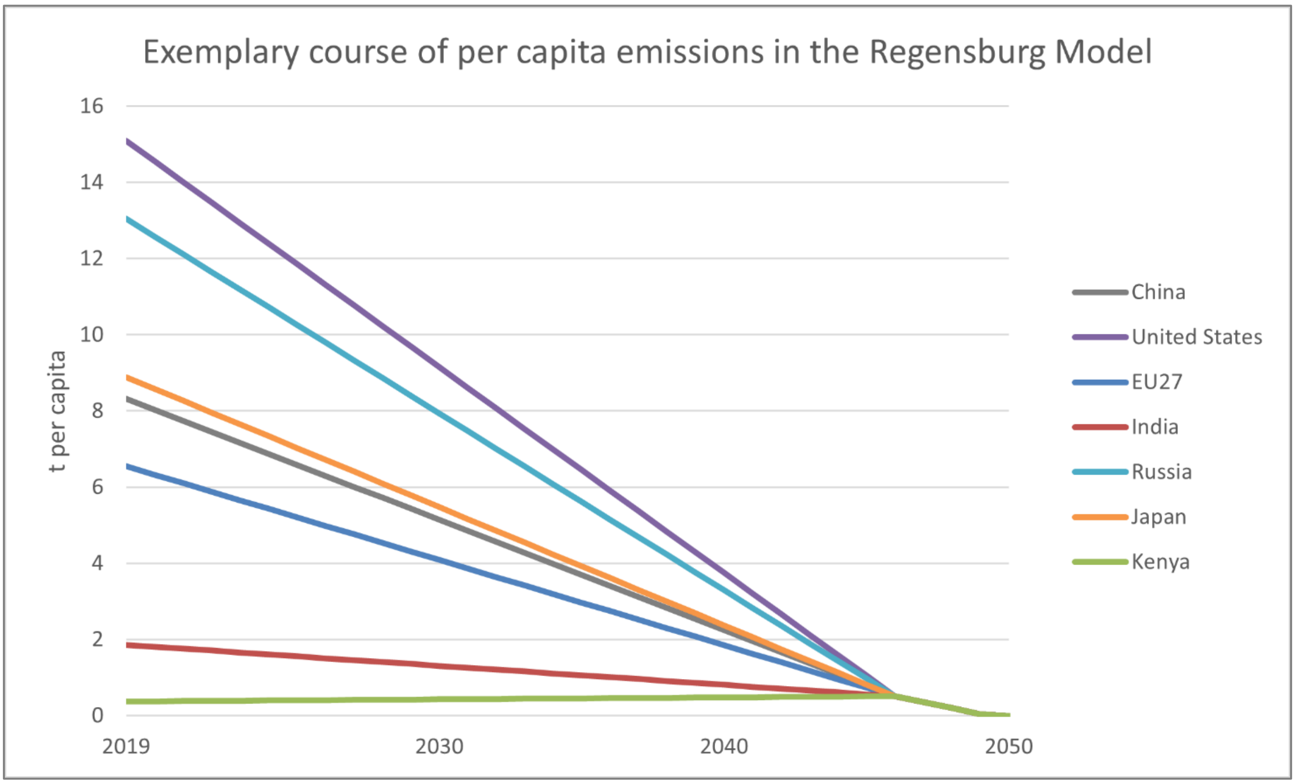

Fig. 1: Exemplary per capita emissions – B550 / NNE0 / LUC0 / convergence level: 0.5 t

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 first year with global negative emissions or global emissions are zero (see also Footnote 15).

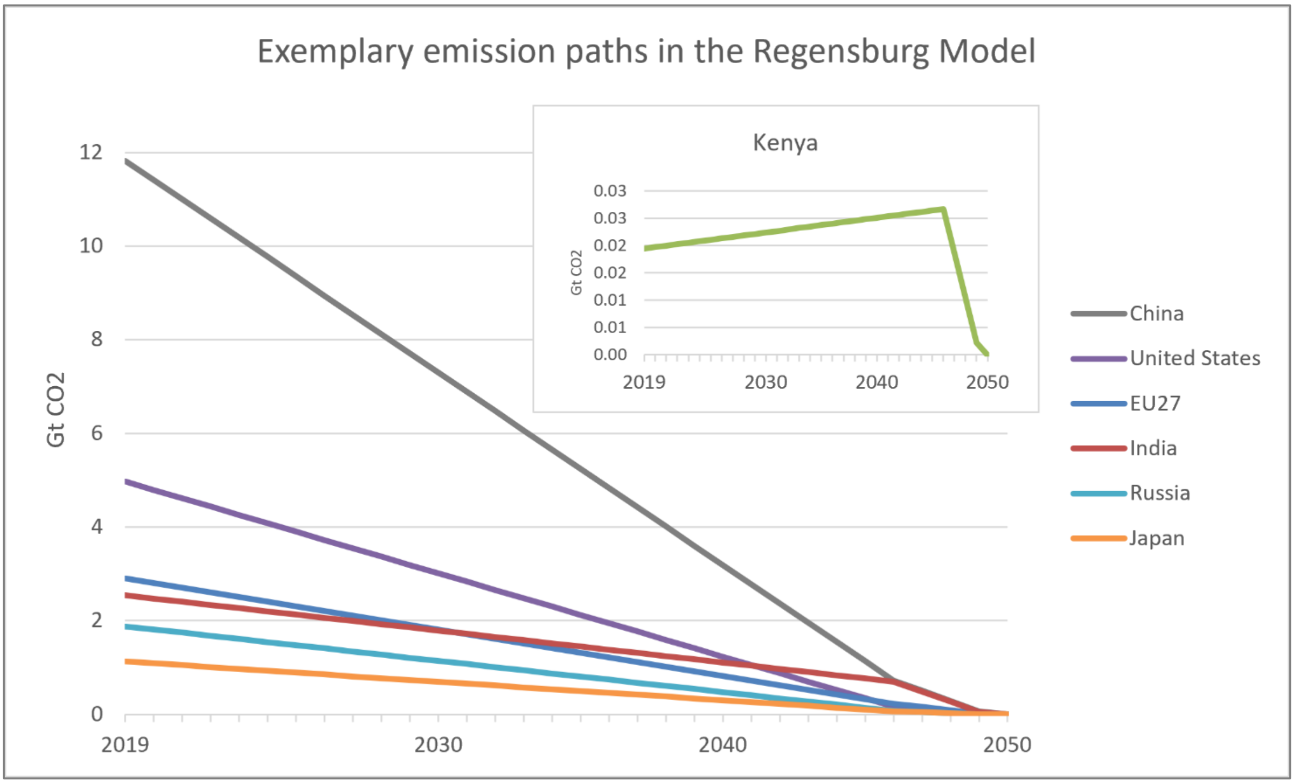

Fig. 2: Exemplary national emission paths – B550 / NNE0 / LUC0 / convergence level: 0.5 t[14]

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. 8:

	current targets (see Tab. 3)		framework data Tab. 7
country	target year 2030	individual reference year	change 2030 vs. individual reference year
United States	-50%	2005	**-49%**
EU27	-55%	1990	**-52%**
Russia	-30%	1990	**-51%**
Japan	-46%	2013	**-48%**

Tab. 8: Reference values - B550 / NNE0 / LUC0 - individual reference years

Disregarding the fact that the countries' targets generally refer to all greenhouse gases and that the actual emissions after 2019 were not taken into account here, the framework data used for Tab. 7 give a good representation of the current targets of the USA, EU27 and Japan for 2030. The target for Russia, however, is significantly lower. According to Tab. 7, China would have to reduce its emissions by 38% by 2030 vs. 2019. 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

[14] As Fig. 2 shows with the example of Kenya, countries that start with per capita emissions far below the convergence level experience a clear kink in the emission path at the end of the convergence period. As this is not a meaningful emission path, the resulting national budget should be used as a basis in the Extended Smooth Pathway Model (ESPM) to derive a plausible emission path (cf. Sargl, et al., 2021).

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. 9.

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	230%	-33%	-64%	-93%	**193**	16	0	2055
United States	-34%	-34%	-96%	-96%	**78**	16	0	
EU27	-48%	-32%	-93%	-91%	**48**	17	0	
India	222%	-24%	38%	-67%	**53**	21	0	
Russia	-47%	-34%	-96%	-95%	**30**	16	0	
Japan	-35%	-33%	-93%	-93%	**18**	16	0	
Kenya	268%	22%	390%	63%	**0.9**	44	0.00	

Tab. 9: 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.[15] 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 (cf. Wolfsteiner & Wittmann, 2023c):

(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 possible 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:[16]

[15] 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.

[16] 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, 2023b) and (Wolfsteiner & Wittmann, 2023c)].

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	213%	-36%	-89%	-98%	**162**	14	12	2052
United States	-38%	-38%	-99%	-99%	**65**	13	5	
EU27	-51%	-36%	-98%	-97%	**41**	14	3	
India	212%	-26%	-59%	-90%	**46**	18	2	
Russia	-50%	-37%	-99%	-99%	**25**	13	2	
Japan	-39%	-37%	-98%	-98%	**15**	14	1	
Kenya	279%	26%	45%	-52%	**0.8**	39	0.02	

Tab. 10: 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. 10).

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.[17] If, despite these concerns, a LUC budget of -100 Gt is added to a global budget, we get these results with a global budget of 400 Gt:

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	198%	-39%	-110%	-102%	**148**	13	12	2049
United States	-41%	-41%	-102%	-102%	**60**	12	5	
EU27	-53%	-38%	-102%	-102%	**37**	13	3	
India	202%	-29%	-108%	-102%	**41**	16	3	
Russia	-52%	-40%	-102%	-102%	**23**	12	2	
Japan	-41%	-39%	-102%	-102%	**14**	12	1	
Kenya	279%	26%	-106%	-102%	**0.7**	36	0.02	

Tab. 11: Reference values - B400 / NNE2 / LUC100

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

Implicit Weighting Population (IWP)

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

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

where

B	global CO2 budget; here from 2020 onwards
B^i	national CO2 budget of the country i; here from 2020 onwards
C	weighting of population

Convergence models have an implicit weighting of the population (cf. Wittmann & Wolfsteiner, 2023). This means: If C is determined so that the same B^i results as in the Regensburg Model, the weighting is the same for all countries.

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

Tab. 12 shows the implicit weighting for the framework data used here.

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**	0.69	**0.50**	0.61	0.62	0.60
Implicit Weighting Population (IWP)		15%	**11%**	13%	14%	14%

Tab. 12: Implicit Weighting Population

This shows that the Regensburg Model has a relatively low implicit weighting of the population.

In principle, the implicit weighting is also independent of the selected global budget (cf. Wittmann & Wolfsteiner, 2023). The slightly different weightings in Tab. 12 result from the fact that the year in which the per capita emissions are closest to the specified value is chosen as the convergence year. As Tab. 12 shows, with an actual convergence level of 0.5 t and a linear global emission path (RM-6), the implicit weighting is 11%.

The implicit weighting only depends on the chosen global path and the chosen convergence level. When using, for example, the scenario type RM-5 (cf. Excursus: The Regensburg Model Scenario Types) results in an implicit weighting of 16% instead of 11% (see Tab. 13).[18] Basically, scenario

[18] If IWP in RM-5 is determined in such a way that exactly the specified convergence level of 0.5 is adhered to, this amounts to 15%.

types that are more ambitious at the beginning have a higher implicit population weighting (cf. Wittmann & Wolfsteiner, 2023).

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., 2024b).

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. Every country that starts above the convergence level has to reduce from the beginning (also emerging countries). Industrialised countries whose targets fall short of even these reference values run into explanatory problems when justifying their NDCs.[19]

It could be shown that under certain global framework data, it can be said that the NDCs for the target year 2030 of the USA, the EU and Japan comply with this moral lower limit (cf. Tab. 8). Whereby actual target compliance is not yet assured and the strict orientation towards the 1.5°C limit would have to be abandoned.

In the case of India and China, there is a gap in ambition by 2030, which is unlikely to be compensated by others, especially in the case of China due to its major share in current global emissions.

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. For this discourse with ultimately transparent political decisions, the following agenda emerges for each Party under the Paris Ambition Mechanism:

Political 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.[20]
3. Align emission targets with a climate policy-sensible course of **annual rates of change**.[21]
4. **Adjust** the framework data and reduction targets regularly on the basis of new scientific findings and technical/real developments.

[19] If not only a "moral lower limit" is to be shown, approaches are more purposeful that, instead of dividing up a global path, directly distribute a global CO2 budget (cf. Sargl, et al., 2024b).

[20] See e. g. Excursus “Allocation of a global CO2 budget” in (Sargl, et al., 2024b).

[21] See Excursus “Regensburg Model Scenario Types” p. 18 and (Wolfsteiner & Wittmann, 2023a).

However, the bottom-up approach of the Paris Agreement will not be sufficient to meet the Paris climate targets. We also need a global discourse on adequate national contributions and more global cooperation, taking into account the following points:

- Due to the budgetary nature of CO2, the 2030 targets are crucial to keep the Paris Agreement targets still within reach.
- 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 climate justice distribution of a remaining global CO2 budget.
- The 2025 NDCs review round based on the first Global Stocktake (GST) must be used to keep the Paris goals within reach (cf. UNFCCC, 2023).
- Major emitters need to find a negotiating format to agree on Paris-compatible and binding targets. The UN climate conferences are not the place to do this because of their unanimity rule for over 190 countries (cf. Edenhofer, 2022).

Excursus: The 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.

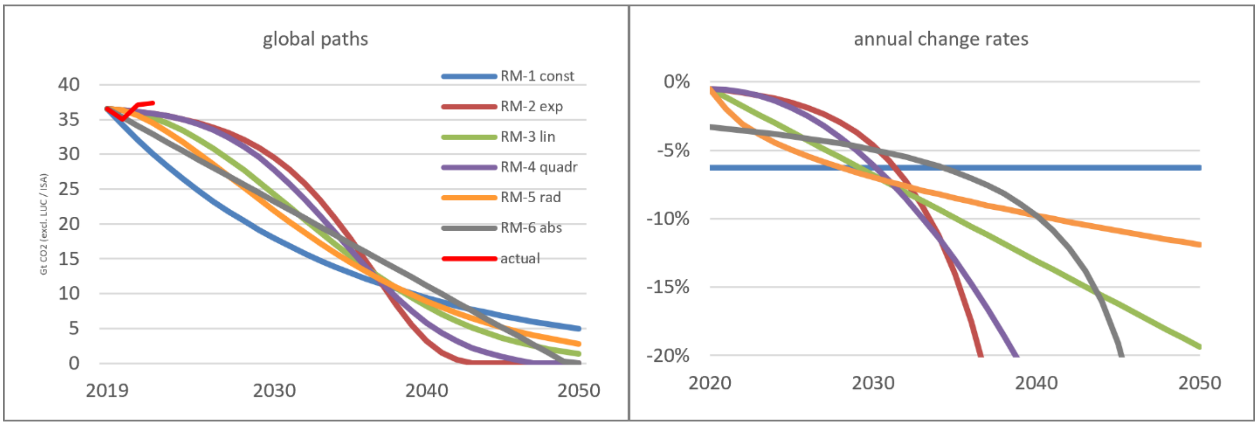

Fig. 3: Exemplary global paths – B550 / NNE 0 / LUC 0

With our web app http://paths.climate-calculator.info/ the different scenario types can also be graphically traced. For a comprehensive mathematical description, we refer to (Wolfsteiner & Wittmann, 2023a).

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 scenario types RM-2 und RM-4.

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., 2024b)].

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

Overall, in many cases, scenario types RM-2 and RM-4 are likely to be the most realistic. However, these scenario types require a high level of credibility of climate policy or climate policy instruments so that investments in a fossil-free future are made in the right time.

Nevertheless, linear global emission paths (RM-6) 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.

In Tab. 13, the differences in the scenario types are shown using China as an example (cf. Tab. 7):

global CO2 budget 2020 - 2100 in Gt		550	minimum emissions		0%
convergence level in t per capita		0.5	LUC budget in Gt		0
scenario type:	RM-1 const	RM-5-rad	RM-6-abs	RM-3-lin	RM-4-quadr
target year	changes versus 2019				
2030	**-53%**	**-42%**	**-38%**	**-36%**	**-25%**
2040	-78%	-80%	-73%	-82%	-89%
2050	-91%	-96%	-100%	-98%	-100%
year emissions neutrality	**2081**	**2063**	**2050**	**2056**	**2047**
overshoot in Gt	0.0	0.0	0.0	0.0	0.0
national budget 2020 - 2100 in Gt	**153**	**161**	**165**	**163**	**166**
Implicit Weighting Population	**27%**	**16%**	**11%**	**13%**	**9%**

Tab. 13: Exemplary reference values China RM Scenario Types – B5550 / NNE0 / LUC0

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