Paris-compatible National CO2 Budgets for the Six Major Emitters Based on the Regensburg Model with Converging Per Capita Emissions

Implicit weighting of the population depending on the selected convergence level as a result of the Regensburg Model applicable to all countries

DOI 10.5281/zenodo.13992460
Published on zenodo

Version: 25/10/2024
Data status EDGAR: September 2024

Andreas Wolfsteiner ▪ Günter Wittmann ▪ www.save-the-climate.info ▪ save-the-climate@online.ms

Web apps:

- http://RM.climate-calculator.info
- http://national-budgets.climate-calculator.info

Abstract

CO2 accumulates in the atmosphere. Therefore, the sum of future emissions is crucial for meeting Paris climate targets. This inevitably raises the question: what are Paris-compatible national CO2 budgets, especially for the major emitters?

This paper gives an answer to this question by showing exemplary national CO2 budgets for the major emitters. The national CO2 budgets are derived top-down from a globally remaining CO2 budget with the help of the Regensburg Model, which is based on converging per capita emissions. In addition, the Regensburg Model provides an implicit weighting of the population depending on the chosen convergence level, which can be used for any country in the world.

The results of the Regensburg Model are highly significant if converging per capita emissions are generally recognised as a target.

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.

We expect that the discussion of Paris-compatible global framework data and different distribution keys for a remaining global CO2 budget can make a significant contribution to achieving overall Paris-compatible NDCs.

Content

List of Tables

List of Figures

Global CO2 budgets

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

Warming	Remaining carbon budgets
[°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%[2]

In «YearactualGCP», global emissions were estimated at around «actualGCP» GtCO2 (GCP, 2023).

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 of the Paris Agreement 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.

---

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

[2] Tab. 1 based on Table SPM.2 in the IPCC Sixth Assessment Report (cf. IPCC, 2021). The key statements of the IPCC on the remaining CO2 budget are summarised here: (Wolfsteiner, 2024b). For further background information, we refer to the IPCC report.

Current emission targets of the six major emitters

Tab. 2 shows the baseline data for the six major 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	2023			
China	2.4	9.1	11.9	13.3	8.3	32%	18%
United States	5.0	5.9	5.0	4.7	15.1	14%	4%
EU27	3.8	3.7	2.9	2.5	6.6	8%	6%
India	0.6	1.2	2.5	3.0	1.9	7%	18%
Russia	2.4	1.7	1.9	2.1	13.3	5%	2%
Japan	1.2	1.3	1.1	0.9	9.0	3%	2%
sum	15.4	23.0	25.3	26.4		69%	50%
Kenya	0.01	0.01	0.02	0.02	0.4	0.05%	0.68%
global	22.0	32.9	36.7	37.8	4.8	100%	

Tab. 2: Baseline data of the six major emitters plus Kenya

These are the CO2 emissions from fossil fuel use (except international shipping and aviation; ISA) and cement production (EDGAR, 2024). CO2 emissions from land use, which must also be offset against the budgets in Tab. 1, are therefore not taken into account.

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 major emitters[3]

To make the NDCs more comparable, Tab. 4 converts the targets into the change in emissions in 2030 compared to 2019. This neglects the fact that the targets in the NDCS partly refer to different greenhouse gas fractions. If greenhouse gas fractions are to be reduced at different rates, the results are only comparable to a limited extent.

---

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

country	target year 2030	reference year	change 2030 vs. 2019
China	see assumption footnote 4		**+38%**
United States	-50%	2005	**-41%**
EU27	-55%	1990	**-41%**
India	see assumption footnote 4		**+16%**
Russia	-30%	1990	**-11%**
Japan	-46%	2013	**-37%**

Tab. 4: Conversion NDCs to the change in 2030 compared to 2019[4]

The question is to what extent these commitments are in line with the Paris climate targets. As an indication of how to answer this question, this paper uses the Regensburg Model to derive national CO2 budgets from a globally remaining CO2 budget. However, the six major emitters have not yet commented on a national CO2 budget, as can be seen in Tab. 3. Therefore, a direct comparison with the national CO2 budgets determined here is not possible.[5] But, the national CO2 budgets, or the implicit weighting of the population that can be derived from it (see Chapter “Implicit Weighting Population (IWP)”, can be used in our Extended Smooth Pathway Model (ESPM) to determine national emission paths, which can then be compared with national emission targets from the NDCs (cf. Sargl, et al., 2024b). The following web app is a simplified implementation of the ESPM with linear emission paths: http://national-budgets.climate-calculator.info. The web app also includes a sheet comparing the results in the ESPM with the NDCs of the six major emitters.

---

[4] Assumptions:

- China: Emissions increase by 3% p.a. in the years 2024, 2025, …, 2030.
- India: GDP will increase by 6% p.a. in the years 2024, 2025, …, 2030. India's GDP was derived here from the “CO2 emissions per GDP” according to (EDGAR, 2024).

The assumptions can be changed in the web app http://national-budgets.climate-calculator.info.

[5] One way can also be to derive an implicit CO2 budget from an NDC (cf. Wolfsteiner, 2024a).

Calculation of national CO2 budgets with the Regensburg Model

Procedure in the Regensburg Model

Resource sharing models directly address the distribution of a remaining global CO2 budget (cf. Sargl, et al., 2024c).[6] 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 (see Fig. 1).[7]

The RM proceeds in two steps:

(1) Determination of **global emission paths**, that meet a specified budget (see Fig. 3)

For this purpose, we offer the Regensburg Model Scenario Types RM 1 - 6, which cover the entire range of plausible possibilities (see Appendix, p. 19).

(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:

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

E_t or E_t^i	global emissions or emissions of country *i* in the year *t*
P_t or P_t^i	global population or population of country *i* in the year *t*
BY	base year; here: 2019
CY	convergence year[9]

The national emission paths (see Fig. 2) yield the same predefined convergence level, i. e. the same per capita emissions in the convergence year (E_{CY}/P_{BY}, see Fig. 1). 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.

---

[6] On the general question of distribution keys for a global CO2 budget, see the corresponding excursus in: (Sargl, et al., 2024b).

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

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

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

The Regensburg Formula transforms a global monotonic path into 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).

Deviations from the Regensburg Formula in the Regensburg Model:

- If emissions continue to rise globally at the beginning, the increase is distributed using the following weighted distribution key:[10]

  $$E_t^i = E_{t-1}^i + \left((1 - C_t) * \frac{E_{t-1}^i}{E_{t-1}} + C_t * \frac{P_{BY}^i}{P_{BY}} \right) * (E_t - E_{t-1})$$

  where: $C_t = C_{t-1} * (1 + ER)$

  The starting value C_{BY} was set at 10% for the calculations here, and the escalation rate (ER) was set at 10%.

- 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 (here: 2019).

These additional distribution rules for a global path lead to national emission paths not being continuous (kinks in the emission path; see Fig. 2). The extent of this depends on the basic data of the individual country. This means that the Regensburg Model is not suitable for every country to describe a meaningful national emissions path.[11] However, with the Regensburg Model, Paris-compatible national CO2 budgets and, in particular, the implicit weighting of the population (see chapter "Implicit Weighting Population (IWP)" can be determined for certain global framework data.

It can be shown that, among the resource sharing models that take into account per capita emissions in one way or another, the Regensburg Model is generally the most favourable for industrialised countries (cf. Sargl, et al., 2024c). The Regensburg Model can thus be regarded as the moral floor for industrialised countries if they fundamentally recognise an approximation of per capita emissions as a goal.

---

[10] The Regensburg Formula cannot be used if global emissions are increasing (cf. Wittmann & Wolfsteiner, 2023).

[11] Neglecting this, we determine linear national emission paths (RM-6) for the six major emitters in this paper within the framework of the Regensburg Model at a convergence level of 0.5 t: (Sargl, et al., 2024d).

Implicit Weighting Population (IWP)

National budgets 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 or B^i	global CO2 budget or national CO2 budget of the country *i*; here from the beginning of 2020 to the end of 2100
C	weighting of population

Solving this equation for *C* results in:

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

The Regensburg Model has the following properties (cf. Wittmann & Wolfsteiner, 2023):

(1) If C is determined for one country *i* so that the same B^i results as in the Regensburg Model, this weighting C applies for all countries. We refer to this as the **implicit weighting of the population** (IWP).

(2) In principle, the IWP is also independent of the selected global budget.[12]

(3) The IWP only depends on the chosen:

  a. Convergence level

  b. Global path

  The following applies:

    i. Scenario types that are more ambitious at the beginning have a higher IWP.[13]

    ii. The IWP decreases with a lower overshoot.

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 (see Appendix, p.

---

[12] A small difference may result from the fact that the year in which the per capita emissions come closest to the specified value is selected as the convergence year.

[13] This applies in particular to the RM-1 and RM-5 scenario types (see Appendix: The Regensburg Model Scenario Types).

19). This means that the ESPM can be used to determine national emission paths based on the results of the Regensburg Model.

The following web app can be used to calculate national CO2 budgets for all countries in the world by using the IWP resulting from the Regensburg Model as an explicit weighting of the population:

http://national-budgets.climate-calculator.info.

It also shows the results for a linear emission path (RM-6) for a country of your choice. The "big six fig" sheet there shows the results for the six major emitters. The "big six NDCs" sheet contains a comparison with the current NDCs of the six major emitters.

With our corresponding Excel tools and web apps, the RM Scenario Types can also be used to determine national emission paths. The scenario types cover the full range of plausible possibilities (see Appendix, p. 19).

Here is an overview of the tools: https://climate-calculator.info.

Exemplary national CO2 budgets and Implicit Weighting Population

Determination of the global budget to be distributed here

The EU database EDGAR provides CO2 emissions excluding emissions from land-use change (LUC resp. LULUCF) and international shipping and aviation (ISA) for all countries in the world (cf. EDGAR, 2024). Before calculating a global CO2 budget to distribute here on this data basis, budgets for LUC[14] and ISA emissions must be deducted from the global CO2 budget. The derived CO2 budgets thus include CO2 emissions from fossil fuel use (except ISA) and cement production.

In the following calculations, an exemplary value of -100 Gt is used for the LUC budget.[15] This means that the current positive LUC emissions will be overcompensated by 2100.[16]

Further an exemplary budget of 3.2% of the global budget is reserved for ISA, which corresponds roughly to its current share of global CO2 emissions.[17]

In the following, we assume a **global CO2 budget of 650 Gt** from 2020 as an example. According to the IPCC, this remaining budget corresponds with a probability of 83% to limiting global warming by 1.8°C (see Tab. 1).[18]

Exemplary results

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 on.

As the IWP is independent of the selected global budget, these can also be applied to other global budgets in the web app http://national-budgets.climate-calculator.info. The national budgets and other key figures indicated, however, refer to the **global remaining CO2 budget of 650 Gt** applied here.

---

[14] LUC here refers to CO2 emissions from the use of land, which are to be offset against the CO2 budgets according to Tab. 1.

[15] A different value can also be specified in the Excel tool used (Wolfsteiner & Wittmann, 2024c). 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, 2024a) and (Wolfsteiner & Wittmann, 2023b)].

[16] According to estimates by the Global Carbon Project, LUC emissions 2019 are expected to have amounted to «LUC19» Gt (GCP, 2023).

[17] A different value can also be specified in the Excel tool used (Wolfsteiner & Wittmann, 2024c).

[18] Global CO2 budget to be distributed here = Global CO2 budget - ISA - LUC = 650 - 21 - (-100) = 729 Gt.

In the following, results are shown in the Regensburg Model at different convergence levels.[19] The web app http://RM.climate-calculator.info allows users to freely define the convergence level and shows the results for all countries in the world with different global CO2 budgets.

Convergence level 0.5 t per capita

RM Scenario Type:	1	5	3	4	6	Ø 3 - 5
national CO2 budgets 2020 - 2100 in Gt						
China	210	220	224	228	223	224
United States	82	88	91	94	91	91
EU27	54	55	56	57	56	56
India	70	62	59	56	60	59
Russia	32	34	35	36	35	35
Japan	20	21	21	22	21	21
Kenya	1.5	1.1	0.9	0.7	0.9	0.9
global results						
IWP 2020 - convergence year	19%	14%	12%	10%	14%	12%
IWP 2020 - 2100	**25%**	**15%**	**11%**	**7%**	**12%**	**11%**
change in emissions 2030 vs. 2019	-41%	-25%	-17%	-6%	-27%	-16%
convergence year	2066	2056	2052	2047	2055	2052
year emissions neutrality	2100	2076	2065	2054	2060	2065
overshoot in Gt	0	0	0	0	0	0

Tab. 5: National CO2 budgets and IWP – 0.5PC-0NNE-100LUC-650GB

The results show that the IWP strongly depends on whether an ambitious global emissions path is assumed at the beginning. RM 3 represents a certain compromise and basically corresponds to the average of RM 3 - 5. This could be a reason to use this average as a reference. This would make the weighting of the population independent of the scenario type selected for the global path. [20]

After the convergence year, the global path in the Regensburg Model is divided according to the population share in the base year 2019. Depending on how this affects the global path in the selected scenario type, the IWP therefore differ for the different time periods (2020 – convergence year or 2020 – 2100).[21]

With the RM Scenario Types, net negative emissions can also be mapped. In the Regensburg Model, globally negative emissions are distributed according to the share of emissions in the base year 2019. This at least partially takes into account the historical responsibility of industrialised countries for CO2 emissions in the past.[22]

---

[19] The results were determined using this Excel tool: (Wolfsteiner & Wittmann, 2024c):

[20] See Appendix for implications of the choice of scenario type for the global path. It should be noted that no initial rate of change based on a realistic estimate can be specified for RM-6 and RM-1 (see Appendix).

[21] The IWP 2020 – convergence year is derived from the respective national CO2 budget for this period and is also basically independent of the selected global CO2 budget.

[22] If a per capita distribution were also maintained in the case of negative global emissions, the IWP for the period 2020 – 2100 would be lower than in Tab. 6.

If, for example, the minimum annual emissions are set at -3.7 Gt (= -10% of global emissions in 2019), the results are shown in Tab. 6.[23]

RM Scenario Type:	1	5	3	4	6	Ø 3 - 5
national CO2 budgets 2020 - 2100 in Gt						
China	214	220	223	228	222	224
United States	84	88	91	94	90	91
EU27	54	55	56	57	56	56
India	67	62	60	56	61	59
Russia	33	34	35	36	35	35
Japan	20	21	21	22	21	21
Kenya	1.3	1.1	0.9	0.7	1.0	0.9
global results						
IWP 2020 - convergence year	17%	14%	12%	11%	14%	12%
IWP 2020 - 2100	**21%**	**15%**	**12%**	**7%**	**13%**	**11%**
change in emissions 2030 vs. 2019	-37%	-20%	-11%	-1%	-23%	-11%
convergence year	2069	2061	2057	2053	2061	2057
year emissions neutrality	2083	2071	2065	2057	2067	2064
overshoot in Gt	44	96	123	155	118	125

Tab. 6: National CO2 budgets and IWP – 0.5PC-10NNE-100LUC-650GB

The results in Tab. 5 and Tab. 6 show that the impact of taking into account a global overshoot has only a limited effect on the IWP.

Convergence level 1.0 t per capita

RM Scenario Type:	1	5	3	4	6	Ø 3 - 5
national CO2 budgets 2020 - 2100 in Gt						
China	196	208	213	220	209	214
United States	73	80	84	89	81	84
EU27	52	53	54	55	54	54
India	81	72	68	62	70	67
Russia	29	31	33	34	32	33
Japan	19	20	20	21	20	20
Kenya	2.1	1.6	1.4	1.1	1.5	1.4
global results						
IWP 2020 - convergence year	27%	25%	23%	21%	27%	23%
IWP 2020 - 2100	**39%**	**27%**	**22%**	**15%**	**25%**	**21%**
change in emissions 2030 vs. 2019	-37%	-20%	-11%	-1%	-23%	-11%
convergence year	2056	2053	2051	2049	2056	2051
year emissions neutrality	2083	2071	2065	2057	2067	2064
overshoot in Gt	44	96	123	155	118	125

Tab. 7: National CO2 budgets and IWP – 1.0PC-10NNE-100LUC-650GB

---

[23] 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, 2024b). As a LUC budget is reserved here at global level, the global net negative emissions assumed here must come from the non-LUC sector.

Convergence level 2.0 t per capita

RM Scenario Type:	1	5	3	4	6	Ø 3 - 5
national CO2 budgets 2020 - 2100 in Gt						
China	169	186	197	208	184	197
United States	55	66	73	80	64	73
EU27	47	50	52	53	50	52
India	102	89	80	72	90	80
Russia	22	26	29	31	26	29
Japan	16	17	19	20	17	19
Kenya	3.3	2.6	2.1	1.6	2.7	2.1
global results						
IWP 2020 - convergence year	39%	44%	46%	46%	49%	46%
IWP 2020 - 2100	**65%**	**49%**	**37%**	**27%**	**51%**	**38%**
change in emissions 2030 vs. 2019	-37%	-20%	-11%	-1%	-23%	-11%
convergence year	2039	2042	2044	2044	2046	2043
year emissions neutrality	2083	2071	2065	2057	2067	2064
overshoot in Gt	44	96	123	155	118	125

Tab. 8: National CO2 budgets and IWP – 2.0PC-10NNE-100LUC-650GB

Convergence level 3.0 t per capita

RM Scenario Type:	1	5	3	4	6	Ø 3 - 5
national CO2 budgets 2020 - 2100 in Gt						
China	151	167	180	194	158	181
United States	43	54	62	72	47	62
EU27	45	47	49	51	45	49
India	116	102	93	81	110	92
Russia	18	22	25	28	19	25
Japan	14	16	17	18	14	17
Kenya	4.2	3.4	2.8	2.2	3.8	2.8
global results						
IWP 2020 - convergence year	47%	60%	64%	66%	61%	64%
IWP 2020 - 2100	**83%**	**66%**	**54%**	**39%**	**76%**	**53%**
change in emissions 2030 vs. 2019	-37%	-20%	-11%	-1%	-23%	-11%
convergence year	2030	2035	2038	2040	2036	2038
year emissions neutrality	2083	2071	2065	2057	2067	2064
overshoot in Gt	44	96	123	155	118	125

Tab. 9: National CO2 budgets and IWP – 3.0PC-10NNE-100LUC-650GB

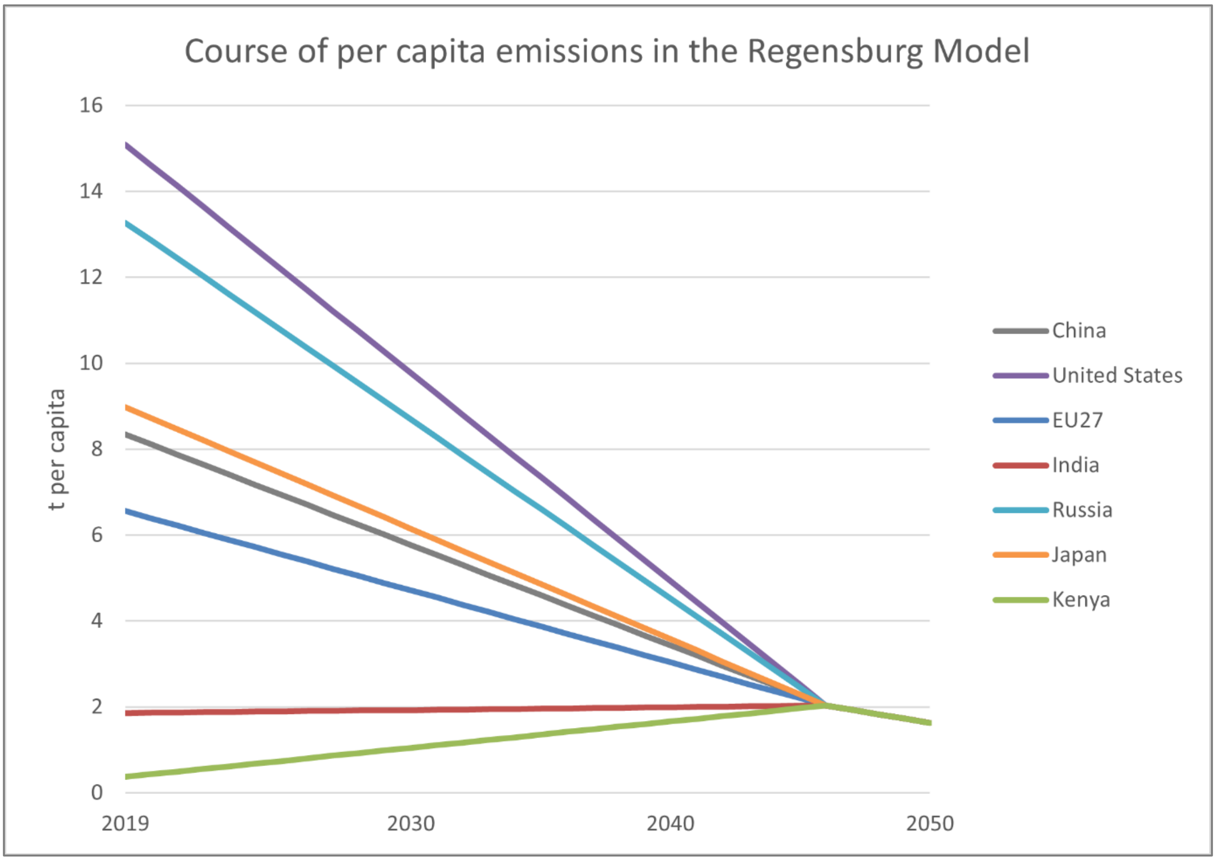

Fig. 1: Per capita emissions – 2.0PC-10NNE-100LUC-650GB-RM6

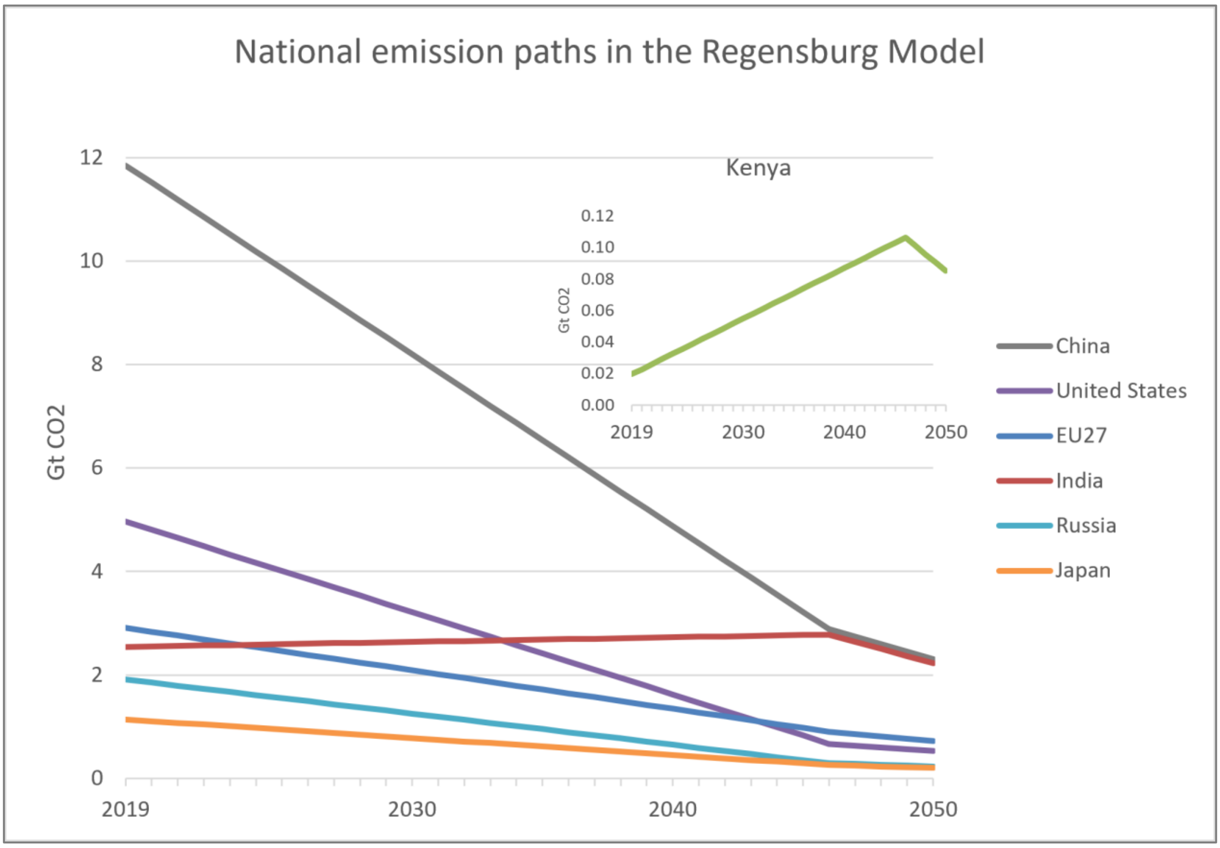

Fig. 2: National emission paths – 2.0PC-10NNE-100LUC-650GB-RM6

Conclusion

The national CO2 budgets based on the Regensburg Model represent a "moral floor" for industrialised countries, since the emission paths of countries that start below the chosen convergence level never exceed it. Each country that starts above the convergence level has to reduce its emissions from the beginning (also emerging countries). Industrialised countries whose targets themselves fall short of these CO2 budgets find themselves in need of explanation when justifying their NDCs if they in principle recognise convergence in per capita emissions as a goal (cf. Sargl, et al., 2024c).

The key question is what is a convergence level or a weighting of the population that leads to realisable territorial CO2 targets?[24] We have to face this difficult question. The Regensburg Model cannot provide a direct answer to this. But it shows which implicit weighting of the population is associated with which level of convergence (see Tab. 10). With the Extended Smooth Pathway Model (ESPM), we offer the possibility of identifying feasible CO2 targets with different population weightings and variations in other global framework data (cf. Sargl, et al., 2024b). In the web app http://national-budgets.climate-calculator.info we also offer a direct comparison with the NDCs submitted by the six largest emitters.[25]

Convergence level in t per capita	IWP 2020 – 2100
	Ø RM 3 - 5
0.5	11%
1.0	21%
2.0	38%
3.0	53%

Tab. 10: Overview IWP – 10NNE[26]

The parties to the Paris Agreement have so far committed to net-zero emission targets. Given the budgetary nature of CO2, the next step must be to set a national CO2 budget derived from a remaining global CO2 budget. This could set in motion a global discourse that would make a significant contribution to ensuring that the NDCs as a whole are compatible with Paris and that the Paris Agreement can therefore be adhered to.

---

[24] See also the corresponding excursus in (Sargl, et al., 2024b) on the basic possibilities for the allocation of a global CO2 budget.

[25] Overviews tools and papers on the ESPM:

- tabular: www.climate-calculator.info
- text: https://sway.cloud.microsoft/Arptw5rW5poP1LDy?ref=Link&loc=play
- detailed: http://downloads.save-the-climate.info

[26] For global per capita emissions in 2019, see Tab. 2. The results for other convergence levels are also shown with this web app: http://RM.climate-calculator.info.

References

BVerfG, 2021. *Beschluss des Ersten Senats vom 24. März 2021- 1 BvR 2656/18 -, Rn. 1-270.* [Online]
Available at: http://www.bverfg.de/e/rs20210324_1bvr265618.html

EDGAR, 2024. *European Commission, Joint Research Centre (JRC)/PBL Netherlands Environmental Assessment Agency. Emission Database for Global Atmospheric Research (EDGAR).* [Online]
Available at: https://edgar.jrc.ec.europa.eu/
[Accessed 10 09 2024].

GCP, 2023. [Online]
Available at: https://globalcarbonbudget.org
[Accessed 05 12 2023].

IPCC, 2021. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* [Online]
Available at: https://www.ipcc.ch/report/ar6/wg1/

Sargl, M., Wiegand, D., Wittmann, G. & Wolfsteiner, A., 2021. Berechnung Paris-kompatibler Emissionsziele für die sechs größten Emittenten mit dem ESPM. *Zeitschrift für Umweltpolitik & Umweltrecht*, Issue 3/2021, pp. 269 - 286.

Sargl, M., Wiegand, D., Wittmann, G. & Wolfsteiner, A., 2024a. *Berechnung Paris-kompatibler Emissionspfade mit dem ESPM am Beispiel Deutschlands und der EU.* [Online]
Available at: https://doi.org/10.5281/zenodo.5678717

Sargl, M., Wiegand, D., Wittmann, G. & Wolfsteiner, A., 2024b. *Calculation of Paris-compatible emission targets for the six largest emitters with the ESPM.* [Online]
Available at: https://doi.org/10.5281/zenodo.4764408

Sargl, M., Wiegand, D., Wittmann, G. & Wolfsteiner, A., 2024c. *Distribution of a Global CO2 Budget - A Comparison of Resource Sharing Models.* [Online]
Available at: https://doi.org/10.5281/zenodo.4603032

Sargl, M., Wittmann, G. & Wolfsteiner, A., 2024d. *Calculation of Paris-compatible emission targets and CO2 budgets for the six largest emitters with the Regensburg Model.* [Online]
Available at: https://zenodo.org/doi/10.5281/zenodo.6504452

Sargl, M., Wolfsteiner, A. & Wittmann, G., 2017. The Regensburg Model: reference values for the (I)NDCs based on converging per capita emissions. *Climate Policy*, 17(5), p. 664 – 677.

SRU, 2020. *Environmental Report 2020 - Chapter 2: Using the CO2 budget to meet the Paris climate targets.* [Online]
Available at: https://www.umweltrat.de

Wittmann, G. & Wolfsteiner, A., 2023. *Resource Sharing Models − A Mathematical Description.* [Online]
Available at: https://doi.org/10.5281/zenodo.4405448

Wolfsteiner, A., 2024a. *Ableitung eines impliziten CO2-Budgets für Deutschland aus dem Klimaschutzgesetz.* [Online]
Available at: https://doi.org/10.5281/zenodo.6535174

Wolfsteiner, A., 2024b. *What does the IPCC say about the remaining CO2 budgets?.* [Online]
Available at: http://ipcc-co2-budgets.climate-calculator.info

Wolfsteiner, A. & Wittmann, G., 2023a. *Mathematical Description of the Regensburg Model Scenario Types RM 1 – 6.* [Online]
Available at: https://doi.org/10.5281/zenodo.4540475

Wolfsteiner, A. & Wittmann, G., 2023b. *Treatment of the topics LUC and net negative emissions in the RM and ESPM tools.* [Online]
Available at: http://luc.climate-calculator.info

Wolfsteiner, A. & Wittmann, G., 2024a. *Tool for the Calculation of Paris-compatible Global Emission Paths with the RM Scenario Types.* [Online]
Available at: https://doi.org/10.5281/zenodo.4584562

Wolfsteiner, A. & Wittmann, G., 2024b. *Tool for the Calculation of Paris-compatible Global Emission Paths with the RM Scenario Types.* [Online]
Available at: https://doi.org/10.5281/zenodo.4584562

Wolfsteiner, A. & Wittmann, G., 2024c. *Tool for the Calculation of Paris-compatible National Emission Paths with the Regensburg Model.* [Online]
Available at: https://doi.org/10.5281/zenodo.5846043

Appendix: The Regensburg Model Scenario Types

The Regensburg Model Scenario Types RM 1 - 5 are based on the course of the annual reduction rates. In scenario types RM 2 - 5, the start change rate in the first year can be specified.[27]

Four basic types can be distinguished with regard to the increase in annual reduction rates with a monotonous course (see Fig. 3):

(1) Constant: constant annual reduction rates (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, scenario type RM-6 with linear emission paths is offered. Accordingly, the annual reduction rates for RM-6 have a concave course and the annual reduction amount is constant. The initial rate of change in the first year is endogenous, as in scenario type RM-1. The starting change rate cannot therefore be determined on a realistic basis using the change rates in previous years.

The RM Scenario Types can also be used to map net negative emissions. This means that the prescribed budget can be exceeded at times. This overshoot is then offset by net negative emissions until the end of 2100. The potential for overshoot is determined by the minimum annual emissions. If a negative value is specified, an overshoot is possible. The lower this value, the higher the overshoot can be.

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 also applies to a limited extent to 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

---

[27] A normalised starting rate of change for 2020 of +0.5% was used for the results in this tool. As the further course of the rates of change is determined on the basis of this starting rate of change, it does not make sense to take temporary effects such as coronavirus into account.

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 degree of credibility of climate policy and, in particular, of climate policy instruments, so that investments in a fossil-free future can be made in sufficient time and lock-in effects can be avoided. Emissions trading systems with hard emission caps could ensure this to a high degree.

As a reference for the population weighting (see chapter “Implicit Weighting Population (IWP)”), it might be appropriate to use the average of scenario types RM 3 – 5 in the context of the Regensburg Model.

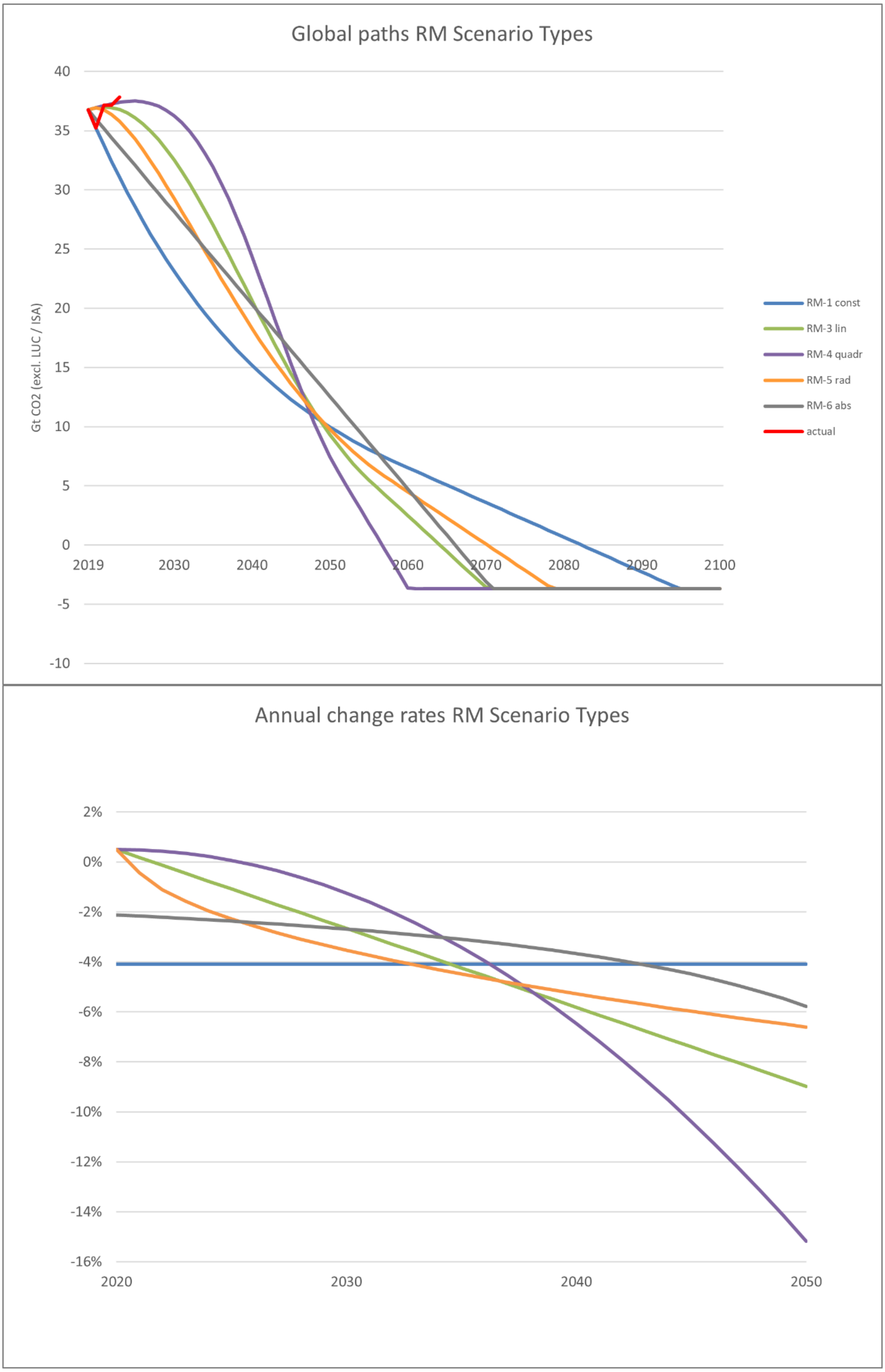

Fig. 3: Exemplary global paths – 10NNE-100LUC-650GB[28]

---

[28] In most cases, RM-2 leads to similar results as RM-4 and has therefore been omitted here for greater visual clarity.