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Instructions
for the Tool to
The Regensburg Model

Calculation of Paris-compatible national emission paths based on converging per capita emissions as reference to NDCs

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Download Excel tool from the zenodo platform (Wolfsteiner & Wittmann, 2022b):
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Web application for the Regensburg Model: http://rm.climate-calculator.info

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1 Brief introduction to the Regensburg Model

Our future cumulative CO_2 emissions are a decisive factor in whether we will be able to meet a given target for limiting global warming (cf. IPCC, 2021).

The crucial question is therefore who gets or takes how much of a remaining global CO_2 budget.

The Regensburg Model enables national emission paths to be derived from any global emission path (see sheet "graphs country"). In the convergence period, the **Regensburg Formula** is used, which leads to **converging emissions per capita** [cf. (Sargl, et al., 2017) and (Sargl, et al., 2022)]:

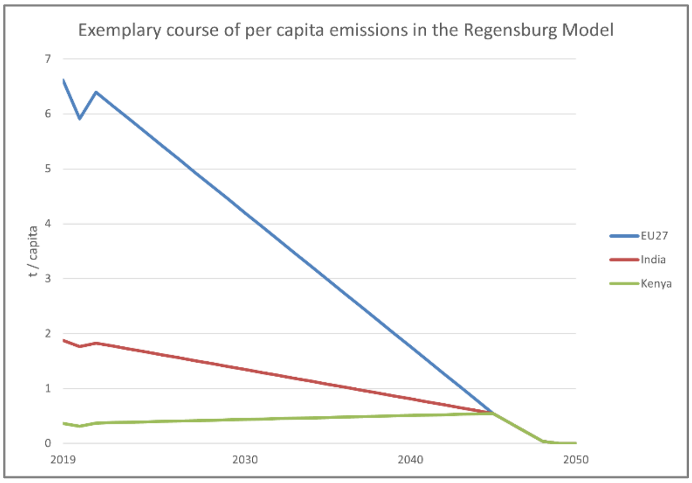

Figure 1: Exemplary course of per capita emissions in the Regensburg Model[1]

This tool offers the RM Scenario Types 1 – 6 for converting a **global CO_2 budget** 2020 – 2100 into plausible **global emission paths** (Wolfsteiner & Wittmann, 2022a). Figure 2 shows graphically the differences in the scenario types:

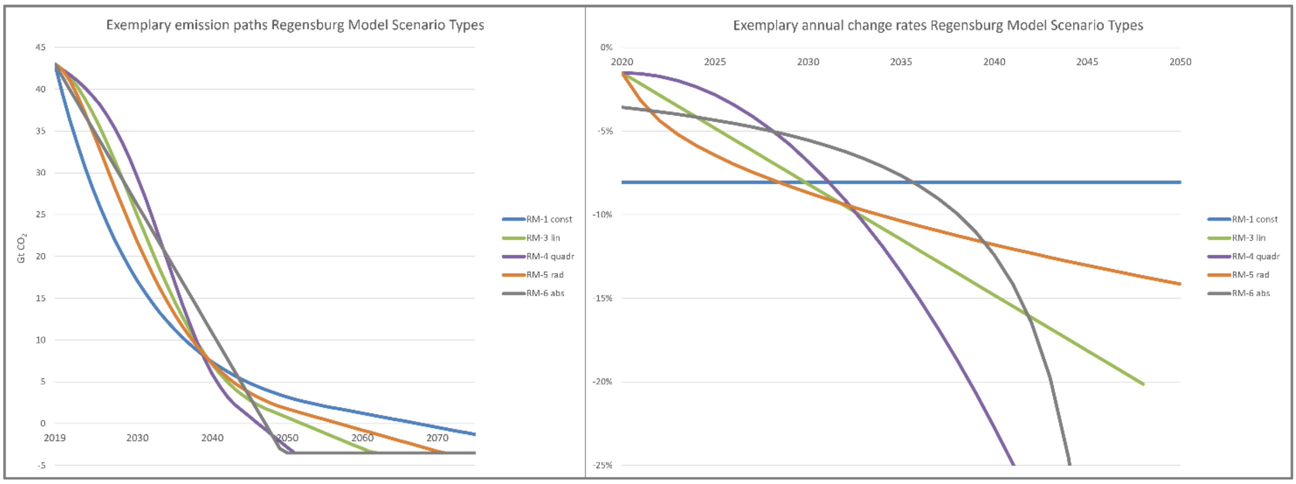

Figure 2: Exemplary emission paths and annual change rates of the RM Scenario Types

[1] In the sheet "convergence", any three countries and the scenario type can be selected to show the course of per capita emissions in the Regensburg Model and the convergence of per capita emissions. The kinks at the beginning are based on the actual emissions of the countries in 2020.

2 Brief introduction to the tool for the Regensburg Model

Go to the **sheet** "**graphs country**" in the tool and select a country from those offered in the drop-down list.

The tool calculates the national emission paths based on six scenario types for the global paths (RM 1 - 6). The RM Scenario Types differ primarily in the shape of the curve for annual global change rates (see Figure 2). The **free parameter** in the scenario type is determined with a **macro** in the **sheet "goal seek"**. If you change input data, you have to run this macro.

Important input values in the **sheet "base data"**:

- global CO_2 budget 2020 – 2100
- minimum emissions 2100 (potential global net negative emissions)
- convergence level:
  This means that the national emission paths are calculated using the Regensburg Formula in such a way that at the point in time at which this value is reached on the global path (convergence year) the per capita emissions of every country are at the same level.

In the **sheet "dashboard"** you get an overview of current input values and important results.

In the **sheet "navi"** you can show or hide groups of sheets or individual sheets to increase the clarity of the tool.

3 Global framework data - entries in the sheet "base data"

I. Entry of data to determine global emission paths from 2020 - 2100

I. a) Global CO_2 budget 2020 – 2100 as a basis for national reference values

Input global CO_2 budget 2020 - 2100 based for example on the IPCC AR6 WG I (see the downloadable paper in the sheet summarizing the main statements of the IPCC on this issue).

I. b) Global CO_2 emissions 2012 – 2020 (info)

Sources:[2]

- CO_2 emissions due to the use of fossil fuels and through cement production: (EDGAR, 2022)
- LUC emissions: (Global Carbon Project, 2021)

I. c) Global budget 2020 – 2100 without LUC and ISA

Since, among other things, it is difficult to find national figures for CO_2 emissions caused by land use changes (**LUC**), these emissions are not included here and must therefore be deducted from the global budget.

Enter the LUC budget 2020 – 2100 in Gt. You can find our separate paper on this topic here (Wolfsteiner & Wittmann, 2021).

Emissions from international shipping and aviation (**ISA**) also have to be deducted, since attributing them to countries is difficult. The current share of global ISA emissions is given for information.

LUC and ISA are also not included in the national data used (EDGAR, 2022).

I. d) Global budget 2020 – 2100 to distribute in this tool

A certain value is calculated from the data entered. You may however also enter your own budget. You can select the value to be used in the tool from the drop-down menu. In this case, please make sure that the budget does not include LUC and ISA.

I. e) Global emissions in 2019 (base year) and in 2100

For the emissions in the base year 2019 (E_{2019}) I. b) is used.

For the emissions for 2100, you can set a minimum value (E_{min}) which may not be undercut. In doing so, a negative value is also possible, standing for **global negative emissions** (net negative emissions). The specification is made by entering a percentage that will be applied to global emissions in 2019. See our separate paper on this topic for downloading in the sheet (Wolfsteiner & Wittmann, 2021).

II. Initial values for national emission paths

Convergence level

Using the Regensburg Formula, national emission paths in which the per capita emissions converge are deduced from a global path. At this point you can set the **convergence level** at which the per capita emissions should converge. Depending on the global path the smallest value is then sought

[2] Note that the total emissions reported are thus derived from two sources. GCP gives a slightly different amount for total emissions. This has no relevance for the calculations in this tool.

which is greater than or the same as the convergence level set. This value then constitutes the convergence year of the global path. The convergence level in the case of the concrete global path will generally be somewhat higher than the value set here (see sheet “country”).

Population

Since the Regensburg Formula is designed to include converging per capita emissions, the choice of population figures in the convergence year on which the calculations are based is crucial.

We offer two options:

(1) Freeze the population figures at those of the base year, 2019.

(2) Take today’s population forecasts into consideration.

If option (1) is chosen, the population figures according to the sheet "EDGAR-P" are used. If option (2) is chosen, the figures in the sheet "UN-P" are used, which also include an estimate for the future.

III. Increasing global emissions: See page 9.

4 Determination of global emission paths

4.1 Entries in the sheet “goal seek”

- RM 2 – 5: rates of change for 2020 (***RR_{20}***)
  The actual RR_{20} cannot be used because of the temporary corona effect. Instead, a value should be used that would probably have been set without corona. The rates of change of the last few years are given as an indication.
- Different thresholds (*TV*) für RM 1 und RM 2 - 5
  In the scenarios RM 1 - 5, a constant reduction amount is applied from this threshold values for the transition to **net negative emissions**.

4.2 Where and how the global paths are determined

The global emission paths are calculated in the **sheet “RM”**. The results are transferred to the sheet “country”. In the **sheet “graphs global”** you can see the graphical results.

The global emission paths are determined using the Regensburg Model Scenario Types 1 – 6 (see Chapter 4.3).

In the **sheet “goal seek”** the **free parameter** of the respective scenario is determined so that the global budget 2020 - 2100 is adhered to. The macro 'goal seek' in this sheet uses the target value search integrated in Excel (see Chapter 4.4).

Actual emissions after the base year 2019

As soon as they are available, we will adapt the tool in each case and transfer the actual global emissions to the "RM" sheet. Thus, the free parameter is only determined for the remaining budget period.

In the **sheet “FI”** it is possible to enter a global path of one’s own choice.

4.3 RM Scenario Types 1 – 6

See Figure 2 for a graphical representation of the scenario types. Here is a brief description.

For a comprehensive description, we refer to our paper ‘Mathematical Description of the Regensburg Model Scenario Types RM 1 – 6’ published on zenodo (Wolfsteiner & Wittmann, 2022a).

4.4 Macro in the sheet “goal seek”

The **macro 'goal seek'** tries to determine the free parameter in the scenario (row 12 or 13) so that the budget (row 16) is adhered to (► row 15 = row 16).

If this does not succeed at first go, the macro tries to find a solution with a different rate of change for 2020 in the scenario types RM 2 - 5. The initial value you specify is changed by a maximum of 2.5 percentage points in both directions in 0.01 steps. The start value you specified will therefore be changed. If a solution cannot be found either, the macro will inform you and advise you to change the start value for 2020 more significantly.

In the RM-1 scenario, the macro increases the threshold value (*TV*) if necessary to find a solution.

The macro also tries in scenario RM-1 that the minimum value (E_{min}) specified in the sheet 'base data' is reached (► row 18 = row 19). If this does not succeed straight away, the macro increases the threshold value (*TV*) in the RM-1. If *E_min* can still not be reached, the original *TV* will be reset.

5 Determination of national emission paths

5.1 The Regensburg Formula

For a comprehensive mathematical description see (Wittmann, 2021).

The national emission paths are calculated in the **sheet "country"**.

By using the Regensburg Formula, national emission paths are derived from a global path. The national emission paths yield **converging per capita emissions** in the convergence period. In the "convergence" sheet, convergence is shown graphically using three selectable countries (see also Figure 1).

The Regensburg Formula:

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

where:

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

Note: $C_{BY} = 0$; $C_{CY} = 1$

CY = convergence year; *BY* = base year = 2019 in the tool; *P* = population

Was does the Regensburg Formula do?

The allocation based on the emissions in the base year will be gradually replaced by an allocation based on equal emissions per capita. The globally necessary ambition is thereby transposed to each country. In this way we can be sure that the global path is adhered to, and every country reaches its target quantity in the convergence year.

Convergence year

The convergence year in the respective global path results from the convergence level which you can determine in the sheet "base data". Thus, also the emissions in the convergence year (E_{CY} *and* E_{CY}^i) are determined.

Summary of the properties of the Regensburg Formula:

- converging per capita emissions; same per capita emissions in each country in the convergence year
- a global monotonic path leads to national monotonic paths
  - countries that start with per capita emissions below the convergence level will never exceed this convergence level (no "hot air" for developing countries)
  - countries that start above the convergence level with per capita emissions must reduce their emissions from the outset (including emerging countries)
- reference values on this basis therefore represent a kind of “moral lower limit” for industrialised countries if the convergence level is chosen relatively low

5.2 Deviations from the Regensburg Formula in the Regensburg Model

5.2.1 Actual emissions

As soon as available, the tool will be adapted so that the actual emissions of a country from and including 2020 are used in the "country" sheet (EDGAR, 2022).

5.2.2 Consideration of increasing global emissions post 2019

In RM-scenarios 3 - 5, a positive RR_{20} can be set. In this case global emissions start off by increasing. Similarly, the inclusion of actual emissions after 2019 may lead to an increase in global emissions after 2019 compared to the base year 2019.

In the case of increasing global emissions compared to 2019, it is not appropriate to determine E_t^i using the Regensburg Formula, as cited in 5.1, since countries whose (per capita) emissions in the base year are below the (per capita) emissions in the convergence year (generally developing countries) would be allocated decreasing emissions whilst global emissions are on the increase.[3] Therefore, for those years with increasing emissions with regard to the base year, the Regensburg Formula was not applied. Instead, the global increase was distributed according to population with the weighting factor PC_t and according to the emissions in the year t-1 with the weighting factor (1 - PC_t) (see Formulas Chapter 5.3). The weighting factor for the year 2020 (PC_{20}) can be entered in the sheet “base data” under III. For the following years a constant weighting factor or a rate of annual escalation (ER_{PC}) of PC_t can be set.

5.2.3 Breakdown of global negative emissions

It can be considered unacceptable that every country would have to realise or finance the same negative emissions per capita, regardless of historical emissions, if global emissions are negative.

That is why we chose the share of a country's emissions in global emissions in the base year as the key to allocating global negative emissions. This is therefore a small compensation for the fact that the Regensburg Formula is very favourable for industrialised countries if the convergence level is chosen relatively low.

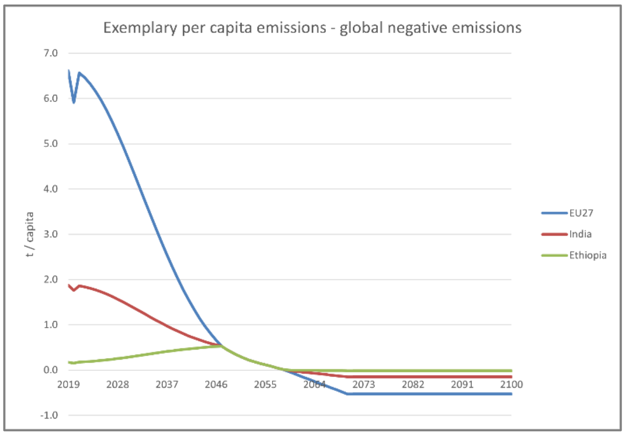

Figure 3: Exemplary per capita emissions including global negative emissions

[3] Rearranging the Regensburg Formula in chapter 5.1 yields $E_t^i = E_{BY}^i + C_t * \left(E_{CY}^i - E_{BY}^i\right)$. In the case of globally increasing emissions, C_t is negative. $E_{CY}^i - E_{BY}^i$ is positive for countries whose emissions in the convergence year are higher than the emissions in the base year. Thus we obtain $E_t^i < E_{BY}^i$.

5.3 Formulae to determine national paths in the Regensburg Model

The following formulae are used to determine the emissions of country *i* in the year *t* (E_t^i) in the tool 2020 - 2100:

A. Actual emissions if available:

$$E_t^i = actual\ E_t^i$$

B. Convergence period:

$C_t > 0$ (globally decreasing emissions with regard to the BY):

The Regensburg Formula:

$$E_t^i = (1 - C_t) * E_{2019}^i + C_t * E_{CY}^i$$

$$C_t = \frac{E_{2019} - E_t}{E_{2019} - E_{CY}}$$

$$E_{CY}^i = \frac{E_{CY}}{P_{CY}} * P_{CY}^i$$

$C_t < 0$ (globally increasing emissions with regard to the BY):

$$E_t^i = E_{t-1}^i + ((1 - PC_t) * \frac{E_{t-1}^i}{E_{t-1}} + PC_t * \frac{P_t^i}{P_t}) * (E_t - E_{t-1})$$

exception 2021 due to temporary corona effect in 2020: $E_{2021}^i = E_{2019}^i + ((1 - PC_{2021}) * \frac{E_{2019}^i}{E_{2019}} + PC_t * \frac{P_{2021}^i}{P_{2021}}) * (E_{2021} - E_{2019})$

$$0 \leq PC_t \leq 1;\ PC_t = PC_{t-1} * (1 + ER_{PC})$$

C. After the convergence year (CY):

$E_t > 0$ (global positive emissions):

$$E_t^i = \frac{P_t^i}{P_t} * E_t$$

$E_t < 0$ (global negative emissions):

$$E_t^i = \frac{E_{BY}^i}{E_{BY}} * E_t$$

6 Reference values for every country in the world

In the **sheet "graphs country"** any country in the world may be chosen from the drop-down list. The tool calculates corresponding emission paths for the country chosen, for all the scenarios.

In the sheet "graphs country" the ratio of a country's emissions in certain target years compared to reference years is shown for each scenario type as **reference values**.

Additional information per scenario type:

- national budgets and shares in the global budget
- sum national net negative emissions (overshoot)
- convergence year
- year of emission neutrality
- implicit weighting of the population (IWP) 2021 - 2100
- scope of the remaining budgets

In the **sheet** "**output countries**" you can choose a scenario type. Reference values for the target years 2050 and 2030 are calculated for all the countries in the world when the macro is started. The national budgets 2020 - 2100 for the different scenario types are also shown, among others.

7 Implicit Weighting of the Population

National budgets can be derived from a global budget with the help of a weighting formula:

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

where

E_{BY} *or* E^i_{BY}	global emissions or emissions of country *i* in the base year
P_{BY} *or* P^i_{BY}	global population or population of country *i* in the base year
B	global CO_2 budget
B^i	national CO_2 budget of the country *i*
$\hat{C}$	weighting of population

Applying the Regensburg Formula results in an implicit weighting of the population ($\hat{C}$) in the convergence period that is the same for each country and depends on the global path chosen (cf. Wittmann, 2021).[4] This also applies to the entire period of the Regensburg Model without years with actual emissions (current: 2021 – 2100). This means that a meaningful key figure can be given for the scenario types. Furthermore, if this implicit weighting is known, the national budgets can be calculated directly.

Since the implicit weighting is the same for all countries, it can also be calculated from the data of one country with the following formula:

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

Calculation of the implicit weighting in the tool

In the sheet "**IWP**", this implicit weighting of the population ($\hat{C}$) can be calculated in the convergence period (current: 2022 – *CY*).

In the sheet "**IWP-T_RM**", the implicit weighting of the population can be determined for the period 2022 – 2100.

The implicit weighting of the population is the same for all countries in the sheets "IWP" and "IWP-T_RM".

In the sheet "**IWP-T**", the implicit weighting of the population can be determined for the period 2020 - 2100. However, since the actual emissions after the base year are included in the paths, the implicit weighting is no longer exactly the same for all countries. Nevertheless, the results give a good indication of this implicit weighting, as shown by the generally small difference in results between the example Germany and that for the whole world.

Procedure calculation implicit weighting population

In order to calculate the implicit weighting of the population for each scenario, first the budgets (B^i) for each country must be determined using the macro "update data". Then the macro "Solver" can be used to calculate the weighting of the population that minimises the squared deviation between the national budgets and distribution according to the weighted distribution key.

[4] This is shown in the tool by determining the implicit weighting across all countries and for Germany as an example.

In the sheet "IWP-T_RM", the implicit weighting is also calculated directly using the above formula for the example country 'Germany'.

A prerequisite for the calculation of the implicit weighting of the population is that ‘frozen population figures’ is selected in the sheet "base data". The macro "update data" automatically makes this setting and restores the previously set value after termination.

Implicit weighting of population and convergence level

The implicit weighting of the population (besides the choice of the global path) is significantly influenced by the given convergence level.

The implicit weighting of the population increases with the chosen convergence level. If the per capita emissions of the base year are specified as the convergence level, then the convergence year and the base year are the same. This results in an implicit weighting of the population of 100% (see sheets "IWP-T" or “IWP-T_RM”).

Specify population weighting explicitly

With our Extended Smooth Pathway Model (ESPM), the weighting of the population can be explicitly specified when allocating a global budget. In the ESPM, national emission paths are then determined using the RM Scenario Types (cf. Sargl, et al., 2022a).

8 Macro security

The macros are signed with a certificate from Sectigo. This also rules out the code having been changed subsequently.

Please use Microsoft's instructions to allow macros if they have been blocked.

In most cases, you can unblock macros by changing the properties of the file as follows:

- Open Windows File Explorer and go to the folder where you saved the file.
- Right-click on the file and select Properties from the context menu.
- At the bottom of the General tab, select the Unlock check box and then OK.

If you do not want to use the built-in macros, you can save the file as an xlsx file. This will remove all macros.

We have published the code of the key macro 'goal seek' here:

https://doi.org/10.5281/zenodo.7494168

This gives you the option of integrating the macro into your Excel file yourself.

9 Criteria for the distribution of a global CO_2 budget[5]

The basic idea of the Regensburg Formula is as follows: Starting from the emissions of each country in the base year, emission paths are described with **converging per capita emissions** and equal per capita emissions in the convergence year. This results in an implicit weighting of the population in the allocation of a global budget (see Chapter 7).

There is widespread demand for **immediate climate justice** (i.e., immediate full allocation of emissions according to population size). In the Regensburg Model, this can be implemented by choosing a convergence level that corresponds to today's global per capita emissions. However, immediate climate justice could lead to economic disruption that ultimately harms all countries.

Instead of an allocation formula based on current population and emissions (cf. Sargl, et al., 2022b), other criteria are conceivable. The United Nations Climate Change Framework Convention of 1992, for example, asks for consideration of the following: "*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*". Here, the criteria of **historic responsibility** and **technological** resp. **economic capability** are addressed. These criteria are not explicitly considered in the Regensburg Formula. However, the question remains as to what extent these criteria should not preferably be considered in conjunction with transfer payments rather than with territorial emission paths.

[5] See also corresponding excursus in (Sargl, et al., 2022a).

10 Résumé of the Regensburg Model

The Regensburg Model allows plausible global emission paths to be determined which adhere to a specific global budget. Independent of the method used to determine the global emission path, **national emission paths** can be determined using the **Regensburg Formula** in the convergence period. The national paths are compatible with a given **global budget 2020 - 2100** and lead to **converging emissions per capita**. The convergence level can be set.

The **scenarios** can be used to show what leeway we still have for global emissions from 2020 to 2100. The conclusion demonstrated (one which is not surprising in essence but is perhaps in its dimensions) is that the later we act, the smaller the leeway.

The **reference values** can serve as guidelines when judging the national contributions (NDCs) to be submitted by each country in the process of review and revision agreed upon in **Paris Ambition Mechanism**. Industrialised countries in particular are in need of explanations if their national contributions are still below the results of the Regensburg Model, because they receive comparatively lighter treatment compared to other resource sharing models if a relatively low convergence level is specified. The results of the Regensburg Model can then be seen as a kind of "moral floor" for industrialised countries.

There are basically two ways to allocate a remaining global CO_2 budget to countries and to determine concrete national emission paths (cf. Sargl, et al., 2022b):

1. Allocate a global path, which adheres to a predefined remaining global budget, to countries. Our Regensburg Model is one possible implementation option [cf. (Sargl, et al., 2017) and (Sargl, et al., 2022)].
2. Dividing a remaining global budget among countries and deriving national paths that adhere to the remaining national budget. Our Extended Smooth Pathway Model is one possible implementation (cf. Sargl, et al., 2022a).

Using the implicit weighting of the population in the Regensburg Model as explicit in the ESPM, leads to very similar results there for industrialised countries as in the Regensburg Model.

Even if a top-down approach failed in Copenhagen 2009, this does not mean that science, civil society and politics cannot use a top-down method when calculating reference values for NDCs. In the end, the NDCs must be Paris-compatible in sum. A discourse on global framework data can be helpful here. The Regensburg Model and the Extended Smooth Pathway Model have the advantage that the number of parameters to be decided politically on a scientific basis is manageable and the results are therefore transparent and comprehensible.

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