

Instructions to the Excel tool for the Regensburg Model

*Calculation of Paris-compatible national emission paths and
budgets based on converging per capita emissions*

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Download Excel tool from the zenodo platform (Wolfsteiner & Wittmann, 2024):

<https://doi.org/10.5281/zenodo.5846043>

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 CO₂ 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 CO₂ budget.

On the general question of the distribution of a global budget, see the corresponding excursus in: (Sargl, et al., 2024b).

The **Regensburg Model** makes it possible to determine national CO₂ budgets that comply with a predefined global CO₂ budget, with **per capita emissions converging** [cf. (Sargl, et al., 2017) and (Sargl, et al., 2024c)]. For this purpose, a global emission path is distributed among the countries using the **Regensburg Formula**.

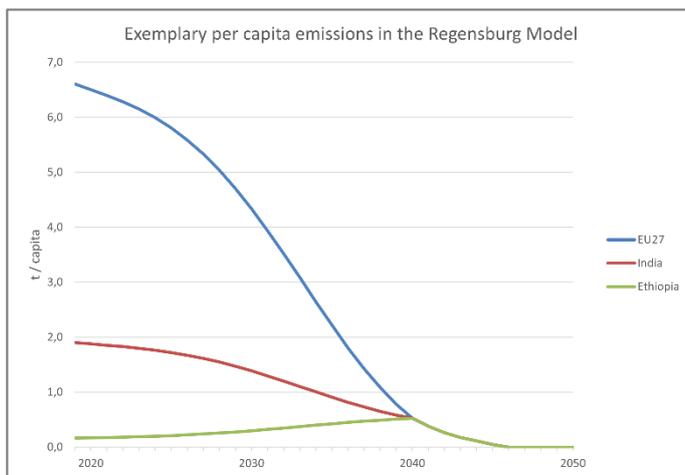


Figure 1: Exemplary course of per capita emissions in the Regensburg Model¹

This tool offers the RM Scenario Types 1 – 6 for converting a **global CO₂ budget 2020 – 2100** into plausible **global emission paths** (Wolfsteiner & Wittmann, 2023a). Figure 2 shows graphically the differences in the scenario types:

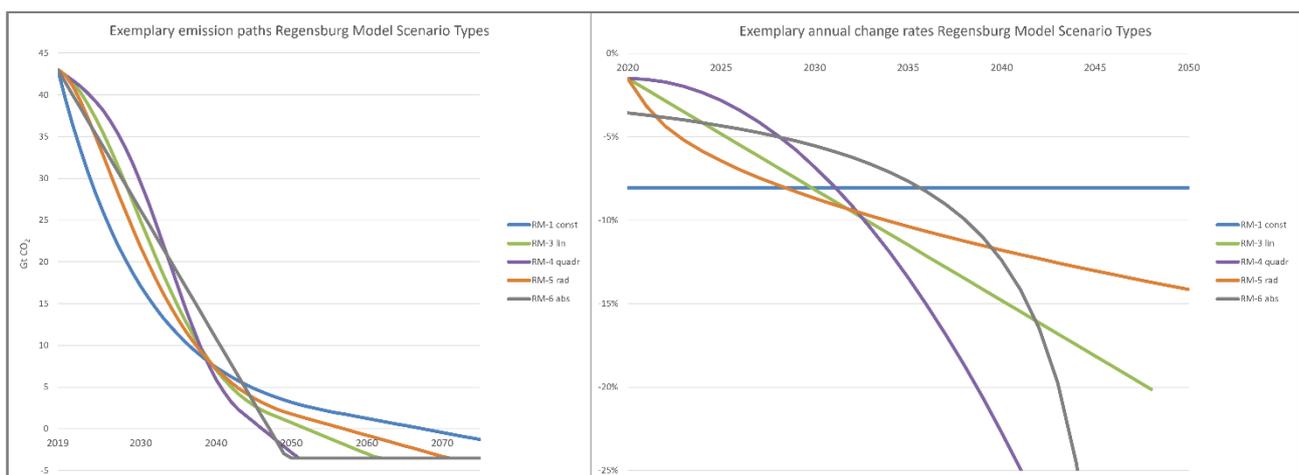


Figure 2: Exemplary emission paths and annual change rates of the RM Scenario Types

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.

2 Brief introduction to the Excel 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 CO₂ 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 CO₂ budget 2020 – 2100 as a basis for national reference values

Input global CO₂ 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. c) Global budget 2020 – 2100 without LUC and ISA

Since, among other things, it is difficult to find national figures for CO₂ 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, 2023b).

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, 2023).

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. d) Emissions 2100 (potential for net negative emissions)

For the emissions for 2100, you 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](#) also our separate paper on this topic for downloading in the sheet (Wolfsteiner & Wittmann, 2023b).

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 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 “dashboard”).

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 (data status 2019), which also include an estimate for the future.

III. Increasing global emissions: See page 10.

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 4.4).

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 4.5).

4.3 Actual emissions after the base year 2019

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 7) 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)].

4.4 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, 2023a).

4.5 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 & Wolfsteiner, 2023).

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:

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

where:

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

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 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.

In the case of increasing global emissions, 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.² Therefore, for those years with increasing global emissions, 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.

5.2.2 After the convergence year

5.2.2.1 Breakdown of global positive emissions

Per capita distribution

5.2.2.2 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.

5.2.3 Actual emissions after the base year 2019

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 7) 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)].

² Rearranging the Regensburg Formula in chapter 5.1 yields $E_t^i = E_{BY}^i + C_t * (E_{CY}^i - E_{BY}^i)$. 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 Formulas 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. 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*):

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

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

B. 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
- implicit weighting of the population (**IWP**)
- sum national net negative emissions (overshoot)
- convergence year
- year of emissions neutrality
- 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 Population (IWP)

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

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

where

E_{BY} or E_{BY}^i	global emissions or emissions of country i in the base year
P_{BY} or P_{BY}^i	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
C	weighting of population

Applying the Regensburg Model results in an implicit weighting of the population (C) that is the same for each country and depends only on the chosen global path and the chosen convergence level (cf. Wittmann & Wolfsteiner, 2023). 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:

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

The IWP is calculated in the "country" sheet.

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., 2024b).

8 Macro security

The macros are signed with a certificate from Sectigo. This also ensures that the code has not 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.

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