ESA / T. Reiter

The Regensburg Model[1]

Background Paper

Reference values for states on the basis of converging per capita emissions

The Paris Agreement left the door slightly "holding the increase in the global average temperature to well below 2°C above pre-industrial levels". Now momentum must be obtained pointed from Paris. The largest emitters must quickly present higher ambitions and implement concrete policies which make these ambitions credible to investors. That is probably the last chance to make the necessary ecological structural change in an economically sensible way.

The process of review and revision agreed upon in the Paris Agreement started in 2018.

The Regensburg Model serves as orientation as to what can be considered a fair proportion for any state of the requisite global efforts.

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The latest version of the tool can be downloaded at www.save-the-climate.info.

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[1] Cf. Sargl, M., Wolfsteiner, A. & Wittmann, G.: The Regensburg Model: reference values for the (I)NDCs based on converging per capita emissions. Climate Policy, Published online: 14 Jun 2016, DOI:10.1080/14693062.2016.1176006

Contents

1 Why this preoccupation with emission pathways?

A crucial factor in determining whether we shall be able to achieve any prescribed objective for maximum global warming are the cumulative CO_2 emissions[2] which we will be producing in future and not so much the reduction achieved by any particular valuation date. This is why the IPCC[3] published[4] a **CO_2 budget** of **2,900 Gt** since industrialisation in Part 1 of its report dealing with the scientific basis for global warming; it concludes that the **2°C limit** can be met with a probability of **> 66 %**[5] on condition that the other greenhouse effects develop as per the RCP2.6 scenario[6]. Creating a budget for non-CO_2 greenhouse gases is less relevant since their reduction leads to the containment of climate change more quickly. This is not to say that their role should be played down, but the most urgent call to action is that of CO_2.

That is why it would have been good if a **global emissions budget** had been agreed upon in Paris, one which adheres to the 2°C limit with a sufficient degree of probability. It was apparently not (yet) possible to produce such a concrete figure at the time of the conference. However, all those participating are aware of the fact that we only have a limited CO_2 budget left. So the question remains: who receives how much of the remaining CO_2 budget?

This tool offers several scenario types for converting the remaining **CO_2 budget** into plausible **global emissions pathways** (see sheet “graphs global”). The scenarios and the determination of the free parameters in the sheets “goal seek” resp. “implicit budget” show the political leeway available for compliance with the 2°C limit resp. with a prescribed budget.

Above all, the Regensburg Model makes it possible to deduce consistent **national emissions pathways** (see “graphs country”) from any optional global emissions pathway[7]. When applying the Regensburg Formula, this results in converging per capita emissions.

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[2]Anthropogenic CO_2 emissions are composed of emissions from the combustion of fossil fuels, emissions from industrial processes (e. g. the manufacture of cement) and the reduction of CO_2 stored in biomass as a result of human intervention (FOLU: Forestry and Other Land Use). The proportion of anthropogenic greenhouse gases measured in CO_2 equivalents (CO_2eq) in 2010 was as follows: CO_2 from fossil fuels and industrial processes 65%, FOLU CO_2 emissions 11%, methane and nitrous oxide 22%, fluorinated gases (F-gases) 2 % (source: IPCC WGIII AR5 Figure SPM.1).

[3] Intergovernmental Panel on Climate Change

[4] IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC; p. 27.

[5] In our opinion it should be more politically discussed, whether this probability is sufficient.

[6] The RCP2.6 scenario is the only scenario of the new scenario family of the IPCC Fifth Assessment Report to comply with the 2°C target. It contains very ambitious reductions in annual emissions, even for non-CO_2 greenhouse gases. For example, we have to come to grips with emissions of methane from cattle farming by reducing our consumption of meat and milk, and by putting the cattle to pasture instead of keeping them in cattle sheds. One important source of nitrous oxide is overfertilisation of the soil.

[7] However, in the Regensburg Model we only consider global emissions pathways which show a plausible trajectory. By plausible we mean here that the emissions agreed upon as a principle do not increase. They may by way of exception only increase in the years immediately following 2019. Any increase in emissions after they once have fallen would, as we understand it, not constitute a plausible global emission pathway.

2 Brief introduction to the tool

With this Excel tool, you can obtain a quick overview of the concrete challenges to be faced by any particular nation when striving to adhere to the 2°C limit in conjunction with converging per capital emissions, and how great its leeway is. You can compare the results with the offers made by countries, for example prior to the climate conference in Paris in 2015 (they are called INDCs) or with those new offers (NDCs) which have been under discussion in the course of the process of review and revision since Paris.

Go to the sheet "**graphs country**" in the tool and select a country from those offered in the drop-down list. In particular, the **reference values for 2050 and 2030** appear in this sheet.

The tool calculates national emissions pathways for four types of scenario. The types of scenario differ primarily in the shape of the curve for annual global reduction rates.

The tool offers many ways to adjust the main parameters, which we shall cover in more detail in the following chapters. At this juncture we should like to reveal the default settings on which the national emissions pathways are calculated if you do not make any adjustments:

(1) Input values

a. Version "goal seek": here, the convergence level can be set. This means that the national emissions pathways 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 pathway (convergence year) the per capita emissions of every country are at the same level. The setting is 0.25 t per capita. The initial values for the global reduction rates are set for 2020: scenario 2: -0.5%; scenario 3: -2.3%; scenario 4: -2.3%.

b. Version "implicit budget": here, the convergence year is set at 2050. One of the adjustable values is the reduction of global emissions in 2050 compared with 1990 by 85%.

c. Minimum emissions 2100: -2 Gt. This means it is based on global negative emissions achieved by active removal of CO_2 from the atmosphere (primarily by reforestation and BECCS).

d. Basis for population figures: UN forecasts.

(2) Only CO_2 emissions from fossil sources and the production of cement between the years 2012 – 2100 are considered.

(3) Main global parameters (input values; can also be adjusted)

a. total budget from the time of industrialisation: 2,900 Gt CO_2

b. emitted up to and including 2011: 1,890 Gt CO_2

c. CO_2 emissions caused by land use, land use change and forestry (FOLU) 2012 − 2100: 169 Gt CO_2

d. CO_2 emissions from fossil sources and cement production 2012 − 2019: 290 Gt CO_2

(4) In the sheet "**cockpit**", you get an overview of current input values and important results.

3 Global constraints and other original data

Entries in sheet "base data":

I. Entry of data to determine <u>global emissions pathways</u> from 2020 - 2100

I. a) Total budget and remaining budget as of 2012

The IPCC has specified a range for the **total budget** as determined by the other greenhouse factors. Where the other greenhouse factors behave in accordance with scenario RCP2.6, the IPCC specifies a value of **2,900 Gt CO_2**. According to the IPCC, **1,890 Gt CO_2** have been emitted **up to and including 2011** since industrialisation. This figure must be deducted from the **total budget.** This leaves a remainder in the magnitude of 1,000 Gt CO_2 starting 2012.

FOLU is the abbreviation used for CO_2 emissions caused by land use, changes in land use, and forestry. However, it is still difficult to put a figure on these emissions. This is the reason why no valid data base by individual country exists yet, as far as we know. In this tool, therefore, FOLU emissions are not considered and therefore also need to be deducted. We have based our estimations on the proportion of FOLU emissions cited in the RCP2.6 scenario. The value may, however, be overwritten at any time.

I. b) Emissions 2012 − 2019

Since this tool is designed to calculate emissions pathways for the period 2020 – 2100, the emissions for the years 2012 – 2019 also need to be deducted. For 2010, the IPCC has produced actual values reflecting uncertainty margins. For the years 2011 – 2019, a forecast for the average annual rise in emissions can be entered into the tool. It is also possible to make a direct entry of the values for 2012 – 2019.

I. c) Budget 2020 - 2100

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.

I. d) Emissions in 2019, the base year, and in 2100

For the emissions in 2019 (E_{2019}), the projection calculated in I. b) is used.

For the emissions for 2100, you can set a minimum value ($E_{2100min}$) which may not be undercut. In doing so, a negative value is also possible, standing for global negative emissions. By actively removing CO_2 from the atmosphere, negative emissions are in principle possible. One possibility is an increase in biomass as a result of reforestation. Another possibility is to sequester the CO_2 occurring in the combustion of biomass and to inject it into geological repositories (BECCS). For your orientation we have cited the global negative emissions proposed in two IPCC scenarios.

However, we consider it problematical to assume over-optimistic negative emissions at this point in time. The uncertainties are great as to the technical availability of such a solution, the question of whether sufficient sustainably producible biomass will be available, and whether other alternatives (such as improvements in efficiency) might not be more economical. Besides this, global negative emissions can only reverse ocean acidification to a limited extent. The later we act, however, the greater our dependence on the active removal of CO_2 from the atmosphere – with all the risks and expense entailed.

II. Initial values for national emissions pathways

<u>Convergence level</u>

Using the Regensburg Formula, national emissions pathways in which the per capita emissions converge are deduced from a global pathway. At this point you can set the **convergence level** at which the per capita emissions should converge. Depending on the global pathway - determined with the sheet “goal seek” - 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 pathway. The convergence level in the case of the concrete global pathway will generally be somewhat higher than the value set here.

However, we also offer another way of determining global pathways, using the sheet “implicit budget” (see also chapter 5.3; p. 11). If you select “implicit budget” in the sheet “graphs country”, the convergence level entered here will not be used.

Population

Since the Regensburg Model 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 three options:

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

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

(3) Take the minimum figure from the forecast and consideration of population developments already determined and which cannot be substantially influenced by demographic engineering policies, whichever is the lower. In this way the number of parent generations already born partly determines population development, even if the fertility rate of this generation changes. The population could, for example, be capped at the population figure calculated at a fertility rate which would lead to stable demographic development long-term (replacement fertility rate resp. instant replacement).

III. Proportionate distribution according to population formula in the event of increasing global emissions

See chapter 5.2, page 10.

4 Determination of a global emissions pathway

The tool in principle offers two methods of determining the global pathway:

4.1 Sheet "goal seek"

The convergence level can be dictated in the sheet "base data".

A global emissions pathway can be determined using scenarios 1 – 4 (see sheet "scenarios_RM"). Under the sheet "goal seek" the free parameter of the respective scenario is determined centrally in such a way that the budget set is adhered to. That is what the macro "goal seek" is designed to do. Under the sheet "S5" it is possible to enter a global pathway of one's own choice. We have embedded scenario RCP2.6 of the IPCC there.[8]

The global emissions in year *t* (E_t) in the period 2020 - 2100 in principle result in scenarios 1 – 4 from the application of an annual reduction rate (RR_t). However, in the "goal seek" sheet you can enter a threshold value (*TV*) for the global emissions. If the global emissions are below TV a constant amount will be deducted from the global emissions of the previous year. In doing so the value that resulted from the last application of a reduction rate is used as the constant amount. We would recommend a threshold value of 1 Gt.

4.2 Sheet "implicit budget"

The global pathways determined in the sheet "implicit budget" all have the same cumulative emissions for the years 2020 - 2050. This makes the determination of pathways more complicated (see detailed instruction in Chapter 5.3 Implicit budgets in the Regensburg Model; p. 11).

4.3 Scenario types 1 - 4: Different approaches used in annual reduction rate

In Scenario 1 a **constant annual reduction rate** is assumed. The constant RR_t to which the budget adheres is determined using the goal seek feature.

E_t = max. (E_{2100}; E_{t-1} * (1 + RR_t)); where: RR_t = constant.

In Scenario 2 an **exponential increase**[9] of the annual reduction rates is assumed. The **initial value** (RR_{20}) may be set. This initial value is escalated annually. The escalation rate (ER_{RR}) to which the budget adheres is determined using the goal seek feature.

E_t = max (E_{2100}; E_{t-1} * (1 + RR_t)); where: $RR_t = RR_{t-1} * (1 + ER_{RR})$

In Scenario 3 the **linear increase** of the annual reduction rates is assumed. For the year 2020, an **initial value** (RR_{20}) may be set. The constant negative adjustment (*A*) to which the budget adheres is determined using the goal seek feature.

E_t = max (E_{2100}; E_{t-1} * (1 + RR_t)); where: $RR_t = RR_{t-1} + A$.

[8] However, scenario RCP2.6 does not adhere to the budget of 2,900 Gt by 2100. This is partly due to the fact that the emissions data prior to 2020 are no longer up-to-date and partly because, in the case of this scenario, it was assumed that any overshoot of the 2,900 Gt budget could still be compensated for after 2100. In our scenarios, in contrast, any overshoot will be compensated for by 2100. The tool could be adjusted correspondingly if a different specification were desired on the basis of scientific findings e. g. tipping points in the climate system or the way sinks work. The original data of the RCP2.6 scenario can be found in their own sheet "RCP2.6".

[9] The recursive form $RR_t = RR_{t-1} * (1 + ER_{RR})$ is analogous to the following explicit form: $RR_t = RR_{20} * e^{-(t-2020)*a}$ where $a = -\ln(1 + ER_{RR})$.

In Scenario 4 a **quadratic increase** of the annual reduction rates is assumed. An **initial value** (RR_{20}) may be set. The parameter to which the budget adheres is determined using the goal seek feature.

E_t = max (E_{2100}; E_{t-1} * (1 + RR_t)); where: $RR_t = a(t - 2020)^2 - RR_{20}$

4.4 Global paths between credibility and cost efficiency

Ideally, the global pathway chosen is such that the cost of conversion to less CO_2-intensive production methods is kept to the minimum (cost efficiency). The most important distinguishing feature of the global pathways in this tool is the shape of the annual reduction rates, whereby three basic versions can be distinguished:

	Trajectory (RR_t)	**Scenario**	**Reasonable from a cost aspect if**
1.	constant rate	1	constant technological developments and conversion of the infrastructure are expected.
2.	linear increase	3	a linear increase in technological developments and conversion of the infrastructure are expected.
3.	disproportionate increase	2, 4	it can be assumed that very high reduction rates are possible in future due to an early political announcement.

As a prerequisite for conversion to production methods which can operate at zero CO_2 emissions or even at negative emissions, new products and technologies must be developed, investments in the corresponding infrastructure made and new lifestyles adopted. All this requires forward planning. It is important to recognise the fact that the earlier political initiative is taken, the more economical will be the conversion. Disproportionate trajectories reflect the assumption that, if a political decision is taken early enough, very high reduction rates in technological fields with relatively low conversion costs are possible in the more distant future, since, for example, many investments can be made within normal investment cycles and existing investments devalued at a lower rate. This however depends on political decisions being presented in a wholly convincing manner.

The disproportionate increase in reduction rates therefore holds great potential to minimise conversion costs; relatively high reduction rates in initial years would in contrast tend to increase investors' belief that their politicians mean it seriously.

Furthermore it is important to recognise the fact that the lower the reduction rates at the beginning (which could be economically reasonable), the greater must they be later on (a classic trade-off).

5 Determination of national emissions pathways with the Regensburg Model

5.1 Determination of annual emissions of individual nations using the Regensburg Formula

Using the Regensburg Formula, consistent **national emissions pathways** may be deduced, **independent of the method used to determine the global emissions pathway.** The national emission pathways yield **converging per capita emissions** in the convergence period.

For mathematical proof, see separate paper: Mathematics Details on the Regensburg Formula; download at www.save-the-climate.info.

The Regensburg Formula:[10]

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

where:

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

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

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

<u>Was does the Regensburg Formula do?</u>

The allocation formula for actual emissions is gradually substituted by the allocation formula per head of the population. Global performance against objectives is applied to every country. In this way we can be sure that the global pathway is adhered to and every country reaches its target quantity in the convergence year. The convergence magnitude of any one nation *i* in the convergence year (E_{CY}^i) in the Regensburg Model is the result of the multiplication of global per capita emissions in the convergence year with the population of the country in the convergence year (P^i_{CY}).

<u>The convergence year</u>

Method sheet “goal seek”: The convergence year results in the respective global path through the convergence level which you can determine in the "base data". This also E_{CY} is determined.

If you work with the version “implicit budget”, the convergence year is already set at 2050.

[10] In the Regensburg Formula there are three representation options. In earlier publications we placed focus on the following option: $E_t^i = E_{t-1}^i + CR_{t-1} * (E_{t-1}^i - TA^i)$ where $CR_{t-1} = (E_t - E_{t-1})/(E_{t-1} - TA)$. See also our paper: Mathematical Details of the Regensburg Formula; download: www.save-the-climate.info. In the case of increasing global emissions, see: 5.2 Consideration of (further) increasing global emissions post 2019.

5.2 Consideration of (further) increasing global emissions post 2019

In scenarios 3 and 4, a positive RR_{20} can be set. In this case global emissions start off by increasing (further). In the case of increasing global emissions it is not appropriate to determine E^i_t using the Regensburg Formula, as cited in 5.1, since for countries using E^i_{t-1} - $E^i_{CY} < 0$ (generally developing countries) this would result in the reduction of their emissions whilst global emissions are on the increase.[11] In such cases the question arises as to **how rights to additional emissions starting 2020 should be allocated per country.** In our tool, the allocation formulae "per capita" and "in percent" are used. The weighting of the allocation per capita (PC_t) can be entered in sheet "base data" under III. Here a rate of annual escalation (ER_{PC}) of PC_t can be set. This results in the following formulae to determine E^i_t in the tool:

Convergence period (2020 - *CY*):

$$\boldsymbol{E_{t-1} > E_t}$$
$$(globally\ decreasing\ emissions)$$

The Regensburg Formula:

$$E^i_t = (1 - C_t) * E^i_{2019} + C_t * E^i_{CY}$$

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

$$E^i_{CY} = \frac{E_{CY}}{P_{CY}} * P^i_{CY}$$

$$\boldsymbol{E_t > E_{t-1}}$$
$$(\boldsymbol{globally\ increasing\ emissions})$$

$$E^i_t = E^i_{t-1} + (1 - PC_t) * RR_t * E^i_{t-1} + PC_t * \frac{P^i_t}{P_t} * (E_t - E_{t-1})$$

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

After the convergence year:

$$\boldsymbol{E^i_t} = \frac{P^i_t}{P_t} * E_t$$

Some rethinking needs to be done, however, about the allocation of the global pathway after the convergence year. We particularly consider per capita allocation of global negative emissions to be unacceptable.

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[11] In the case of globally increasing emissions, C_t would be negative. This leads to decreasing emissions in countries which show rates below their target quantity in the year *t*, since $|C_t| * E^i_{2019} < |C_t| * E^i_{CY}$.

5.3 Implicit budgets in the Regensburg Model[12]

One characteristic of the Regensburg Formula is that the cumulative emissions in the convergence period attributed to a state (BG^i; implicit budget) do not depend on the concrete trajectory of the global emissions pathway as long as these pathways abide by the same global cumulative emissions in the convergence period (*BG*) and the same global convergence amount (E_{CY}).[13]

$$BG^i = \sum_{t=BY+1}^{CY} E_t^i = E_{CY}^i * (CY - BY) + (BG - E_{CY} * (CY - BY)) * \; a^i$$ [14]

Where:

$$a^i = \frac{E_{BY}^i - E_{CY}^i}{E_{BY} - E_{CY}}$$

BG: global cumulative budget in the convergence period
BG^i: cumulative emissions of a state *i* in the convergence period
a^i: proportional factor of a state *i* to the global reduction quantity: $\sum_i a^i = 1$

By adding up the emissions of a state according to equation CWF or C&C (which are described in Chapter 6.2 Alternative resource sharing models, page 15) over the period of convergence, it becomes apparent that this property does not apply for these approaches.

Excurse:

If the Regensburg Model is used as the basis for the distribution of the remaining budget to states as emission rights in the form of national emissions pathways followed by emissions trading between different countries within the context of a global climate agreement, then the negotiations on the determination of the global pathway could concentrate on questions such as which concrete trajectory minimises conversion costs (cost efficiency) or indicates the greatest credibility to investors. Direct allocations of the global cumulative budget to individual countries should not be made according to the implicit budget formula of the Regensburg Model because in this case it would no longer be possible to make annual assessments in the context of emission trading between states as to whether these states actually are on the right path or have purchased emission rights. It should be noted at this point that the top-down allocation of the remaining budget is not on the political agenda, especially since the global community has at the moment chosen to adopt a policy of national determined contributions (NDCs) in the framework of a review process.

By using the version "implicit budget", global pathways can be determined which fulfil the requirements for implicit budgets. However, to do so the global emissions pathways must be determined for two stages: (1) 2020 - 2050 (convergence period) and 2051 - 2100. As a first step, the global emissions in the convergence year must be set in the sheet "implicit budget". This is done by entering a reduction rate for global emissions in 2050 in comparison to 1990 (RR_{9050}). In order for the global pathways for 2020 – 2050 to show the same budget, the global pathways post 2050 must be identical. To this end a reduction rate for 2051 (RR_{51}) is set the sheet "implicit

[12] Cf. Sargl et al.: The Regensburg Model: reference values for the (I)NDCs based on converging per capita emissions. Climate Policy, Published online: 14 Jun 2016, DOI:10.1080/14693062.2016.1176006

[13] See also our paper: Mathematical Details of the Regensburg Formula; download: www.save-the-climate.info.

[14] According to budget formula, at first every state is accorded emissions on the basis of identical per capita emissions in the convergence year. Then the remaining budget in the convergence period is allocated to each state using the proportional factor a^i. a^i is negative for countries starting with emissions below their convergence amount and positive for countries which start with emissions above it.

budget“. The resulting absolute value is then deducted from the previous year’s value up to 2100. In doing so, RR_{51} should be aligned with the average of the resulting RR_{50} in scenarios IB-2 - IB-4. This could make several iterations necessary.

The global pathways 2020 - 2050 may then be determined via various macros that are described in more detail in the tool.

The determination of global pathways using the version “implicit budget” has the advantage that national budgets are independent of the global pathway chosen in the convergence period. Its disadvantages are: less leeway for the global pathway, and no consistency in the reduction rates for 2050 and 2051.

If you wish to use the global pathways which were determined in the sheet “implicit budget”, you can choose them in the sheet “graphs country” for scenarios 2 – 4.

5.4 Determination of national emissions pathways for nearly every country in the world

In the sheet “graphs country”, any country in the world may be chosen from the drop-down list. On this basis the tool calculates corresponding emissions pathways for the country chosen, for all the scenarios. In the same sheet, you can then quickly find a compilation of the results.

Entries in sheet “country”

In order to be able to calculate national emissions pathways using the Regensburg Model, the emissions of any one country in 2019, the base year, are required.

Population figures are taken from a UN data base (see corresponding sheets). For the emissions, we have resorted to data from EDGAR (EU). Extrapolation to 2019 is based in principle on the current figure and an estimate of the annual rate of change on the basis of historic data.

Where no rates of change can be calculated on the basis of historic data, a standard rate is applied that can be altered in the sheet “data countries” (cell R9). This extrapolation for 2019 does not lead to realistic results for every country. For this reason you can either enter your own rate of change or a concrete figure for emissions in 2019, the base year, in the sheet “country”. Please delete these entries when you choose a new country.

Entries in sheet “data countries”

You may embed an individual extrapolation rate in column V for any one country permanently in the sheet “data countries”. For the following countries we have already embedded an individualised extrapolation rate:

- Germany: the basis is a reduction target of 40% in 2020 compared with 1990.
- EU: the basis is a reduction rate of 20% in 2020 compared with 1990.
- China and India: historic values resulted in rates of change between 7% - 8 %. These rates no longer seem realistic to us for the extrapolation of a figure for 2019. Rates of 1.5% for China and 2% for India agree with our forecast for global emissions in 2019.
- For Japan we have reduced the rate derived from historic data from 4.9% to 1.5% for the extrapolation.

We were not able to check whether the extrapolation rate resulting from historic data is plausible in the future for every country. For this reason an upper limit can be set in cell U253 in the sheet “data countries”.

In order for the reference values for individual countries to be calculated correctly, the total of all the extrapolations for 2019 for all the countries must largely correspond to the global emissions in 2019 as set in the sheet “base data”. For this reason any deviation is shown as a percentage in cell W258 (where necessary use the goal seek feature) or other resp. new individual extrapolation rates set. An adjustment of the extrapolation of the global value for 2019 could be considered.

In the sheet “convergence”, you can choose three optional countries resp. “global” and a scenario. When you start the macro, the converging trajectory of the per capita emissions is shown.

5.5 Reference values for the Paris process of review and revision

All countries were called on to submit their targets for their climate policy post 2020 (“intended nationally determined contributions”, INDCs for short) to the UN Climate Secretariat in preparation for the climate change conference in Paris in December, 2015. On the basis of the INDCs submitted, the UN Climate Secretariat concluded that these targets were not sufficient to adhere to the 2°C limit.

For this reason a process of review and revision was decided upon in Paris (ratchet up mechanism), to be performed in a five-year cycle starting in 2018. However, wealthy industrial nations are called upon to re-examine their ambitions as of today. The NDCs must be revised by 2020 at the latest. In Paris a decision was also taken that in principle no country may backslide to ambitions below those once set.

In the context of this process of review and revision, the following pressing question now arises: **What can be deemed a fair proportional contribution for any specific country towards the global efforts which it is necessary to make?** The Regensburg Model cannot produce any definitive answers to this question but it can provide guidance. Industrial nations are hard pressed for excuses if their ambitions fall below those shown as reference values in the Regensburg Model.

In the sheet “graphs country”, it is primarily the ratio of emissions of one country in 2030 resp. 2050 (reference points) in comparison with the reference years 1990 resp. 2010 in the relative scenario which is shown as a **reference value.** If you wish to compare various reference values, be they calculated with the Regensburg Model using other base data, or on other criteria, it is important to give particulars of the global pathway taken as a basis. The cumulative emissions up to the reference point and the cumulative global negative emissions assumed are particularly helpful.

In the sheet “**output countries**” you can choose a scenario and then the reference values for 2050 and 2030, among other things, are calculated for all the countries in the world when the macro is started.

5.6 Emission trading

The Regensburg Formula also allows easy implementation of emission trading between countries. The national emission pathways would be the basis for the allocation of emission rights.

The amount of certificates held by country i in year t, and the modification of the target amount through emission trading, would result from the following formulae:

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

$$TA_{2019}^i = E_{CY}^i = \frac{E_{CY}}{P_{CY}} * P_{CY}^i$$

$$TA_t^i = TA_{t-1}^i + T_t^i$$

T_t^i = trade volume bought or sold by country *i* for year *t*

TA_t^i = target amount of country *i* in year *t*

Main advantages of emission trading between countries based on national emission pathways:

- Flexibility: no country would have to agree on unalterable emission limitation.
- Cost efficiency: a global price for CO_2 would be generated, which would ensure that reductions would first be made where it is possible in the most cost-efficient way.
- Review-process: Annual check-ups can examine whether a country has enough certificates.

6 Alternative approaches[15]

6.1 Criteria for the determination of national emissions pathways

The basic idea of the **Regensburg Model** is as follows: starting with the emissions of any one country in the base year (at tool: 2019), an emissions pathway is described which converts to **gradual fundamentally equal per capita emissions** ("one human – one emission right") in the convergence year.

In contrast to this, there are often calls for **immediate climate justice** i. e. the immediate complete allocation of emissions according to population figures. Immediate climate justice can be obtained

- by first determining a global pathway and then allocating in each year the global emissions according to populations figures or
- by first allocating a global remaining budget on countries and then transforming the allocated national budgets into national pathways.

In the case of allocating a global remaining budget smooth pathways can be obtained. Nevertheless, we do not consider immediate climate justice economically expedient. It would probably trigger a world economic crisis, which would do no-one any good.

Instead of an allocation formula based on population, 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 Model. However, the question remains as to what extent these criteria should not preferably be considered in conjunction with transfer payments rather than with emission pathways.

On the other hand, emission pathways calculated according to the Regensburg Model do present a great challenge, particularly to emerging economies, since they would have to reduce their emissions relatively quickly even though their more carbon-dependent infrastructures have only been in place for a short time.

In our opinion this means that wealthy industrial states in particular need to demonstrate higher ambitions with regard to their emissions than those which result from calculations under the Regensburg Model.

6.2 Alternative resource sharing models

(See also our tool "Comparison Resource Sharing Models.xls" and our paper about "Mathematical Details on Resource Sharing Models" which can be downloaded from www.save-the-climate.info via the menu item "Downloads".)

[15] An elaboration of the Australian Climate Change Authority provides an initial overview.

If you wish to transfer the allocation of global emissions per country gradually from the allocation formula "ratio 2019 in percent" to the allocation formula "per capita", the following approach (which we call the ***Common Weighting Formula*** [CWF]) would seem appropriate:

$$E_t^i = \left((1 - C_t) * \frac{E_{2019}^i}{E_{2019}} + C_t * \frac{P_t^i}{P_t}\right) * E_t.$$

A similar approach can be taken using the model called ***Contraction & Convergence*** (www.gci.org.uk):

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

In this case you need to choose a (non-decreasing) function (C_t) for the per capita weighting in year t. C_t assumes a value zero for the base year (2019) and the value 1 for the convergence year. In choosing this function you can determine how soon the allocation formula for the percentage of the population is to take effect.[16]

Where these models are used, the emissions in countries which start off below the target magnitude ($E^i_{2019} < E_{CY}^i$) generally exceed the convergence magnitude at times even during the convergence period (pathways are not monotonic during the convergence period). By contrast, in the Regensburg Model the pathways of these countries form a monotonically increasing shape during the convergence period. There is therefore an overall tendency for these countries to be allocated greater emissions rights using the C&C model and the CWF formula than under the Regensburg Model.

Calculating certain global emissions pathways using the C&C model and the CWF formula can result in an inappropriate pattern whereby the emissions first of all increase, then decline and finally increase again.

The above mentioned models of converging per capita emission reach a positive convergence amount at a certain point of time. Besides, there a two more resource sharing models, we should like to describe briefly.

The first model was presented by ***Raupach et al.***[17], who showed how to transform an allocated remaining budget (RB) into pathways with a smooth transition from the current pathway and with near-zero emissions in the future. They used for the emission at the time x the function

$$f(x) = f_0(1 + (r + m)x)e^{-mx}, \quad (1)$$

where

f_0 are the present emissions ($f(0) = f_0$),

[16] LIMITS used the SCM approach $C_t = \frac{t-BY}{CY-BY}$ to calculate emissions by region. For C_t C&C also discusses: $C_t = e^{-a(1-\frac{t-BY}{CY-BY})}$ besides this approach.

[17] Raupach, M. R., Davis, S. J., Peters, G. P., Andrew, R. M., Canadell, J. G., Ciais, P., Friedlingstein, P., Jotzo, F., van Vuuren, D. P. and Le Quere, C (2014). Sharing a quota on cumulative carbon emissions. Nature Climate Change 4 873–9. DOI: 10.1038/NCLIMATE2384

Free supplementary information containing mathematical details on the properties of the formula in equation (1) can be retrieved from http://www.nature.com/nclimate/journal/v4/n10/extref/nclimate2384-s1.pdf.

r is the present rate of change of emissions ($\frac{f'(0)}{f(0)} = r$) and

m is the mitigation rate (or the decay parameter).

The mitigation rate *m* is determined such that the allocated remaining budget (*RB*) is met:

$$\int_0^\infty f(x)\,dx = RB.$$

Thus, if $r > -1/T$, the mitigation rate *m* is given by

$$m = \frac{1+\sqrt{1+rT}}{T},$$

where $T = \frac{RB}{f_0}$. Otherwise, there is no solution for the mitigation rate *m*.

Since we are more interested in the emissions in the year *t* (E_t) than in the emissions at a point of time *x*, we integrate equation (1) and obtain:

$$E_t = \int_{t-1}^{t} f(x)\,dx =$$

$$= -f_0 \frac{e^{-mt}}{m^2}[(rm + m^2)t + 2mr] + f_0 \frac{e^{-m(t-1)}}{m^2}[(rm + m^2)(t-1) + 2mr].$$

This model guarantees zero emissions at infinity for each country. It seems that the point of time when a country's emissions reach "almost" zero differs considerably from country to country.

The second model was described by ***Chakravarty et al.***[18], who determined with a least square fit an emission probability density function *f* for each country *i* with the population P_i. Then they determined a cap C such that the emission in all countries yield the agreed upon global emissions in the year *t* (E_t):

$$\sum_i P_i \left(\int_{-\infty}^{C} z\,f(z)\,dz + C \int_{C}^{\infty} f(z)\,dz \right) = E_t$$

This model allows each person a maximum of emissions at the amount of C. Thus all countries are confronted with decreasing emissions when global emissions are decreasing.

[18] Chakravartya, S., Chikkaturb, A., de Coninckc, H., Pacala, S., Socolowa, R. and Tavonia, T. (2009). Sharing global CO_2 emission reductions among one billion high emitters. PNAS Vol. 106 no. 29, 11884 – 11888. www.pnas.org/cgi/doi/10.1073/pnas.0905232106

7 Résumé of the Regensburg Model

The Regensburg Model allows plausible global emissions pathways to be determined which adhere to a specific budget. Independent of the method used to determine the global emissions pathway, **national emissions pathways** can be determined using the Regensburg Formula which **achieve a limit for maximum global warming as set and gradually lead to the convergence of per capita emissions.**

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 important guidelines when judging the national contributions to be submitted by 2020 at the latest by each country as a result of the process of review and revision agreed upon in Paris. Industrial nations in particular will be hard pressed for excuses if their ambitions fall short of these reference values, because they receive comparatively lighter treatment under the Regensburg Model compared to other resource of sharing models.