

National paths based on a given national budget (Extended Smooth Pathway Model)

Brief instructions on how to use the tool

With this tool you can determine plausible **national emission paths** and reference values based on a **national CO2 budget 2020 - 2100 you specified**.

In the **sheet 'base data'** you can set the basic conditions such as the budgets which are to be met, and the minimum value of annual emissions (potential for net negative emissions). To determine the national budget a simple weighting model (emissions and population in the base year 2019) is offered.

In the **sheet 'reference values'**, you can select a country from the drop-down list, to get an impression of which challenges the chosen country is confronted with, and can then compare these with the offers this country has submitted so far or plans to submit (NDCs). In particular, the **reference values** for 2050 and 2030 are shown in this sheet.

In the **sheet 'output countries'** you can create a list of all countries in the world, which gives the **national budgets** 2020 - 2100 for a given weighting of the population and **reference values** for the **largest emitters**. The macro can be started without first performing the target value search in the sheet 'goal seek'.

For deriving **national paths** the tool offers the scenario types **RM 1 - 6**. There differ in particular in terms of different assumptions on the trajectory of annual reduction rates resp. reduction amount. In the **sheet 'goal seek'** you have to input **start change rates for 2020** (RM 2 - 5).

When modifying input data (which the cells shaded in yellow are designated for) or select a other country, you must always execute the **macro** in the **sheet 'goal seek'** to adjust the free parameter in the scenarios such as to meet the national budget 2020 - 2100 which is set out in sheet 'base data'.

Entries can be made in the following sheets: base data, reference values (select a country), goal seek (start change rates 2020 and TVs) and data countries (individual change rates 2019).

Cells shaded in yellow in the following sheets are input fields, where you can enter data.

Suggestions and feedback are welcome:

save-the-climate@online.ms

You can download the current version of the tool from the following website:

www.save-the-climate.info

version:	2018 - 2020	37.0
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<u>data status</u>	
global emissions	Sep. 19
emissions countries	Sep. 19
population	2019

There you can download a comprehensive mathematical description of the Regensburg Model Scenario Types or use this direct link
Mathematicel Description RM 1 - 6
and a comprehensive instruction to the tool.

base data

input fields	values from the sheet „EDGAR“
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I. Input of base data for the determination of a global budget 2020 - 2100

I. a) Global CO2 budget 2018 - 2100

global CO2 budget from 2018 to 2100 in Gt	
570	see Table 2.2

Ultimately, it is a political decision which CO2 budget we aim to meet by the end of this century, taking into account the current scientific findings.

I. b) Global CO2 Emissions 2018 - 2019

annual change rates		1.7%	0.9%	-0.2%	1.1%	1.2%	1.9%	1.2%		
	year:	2012	2013	2014	2015	2016	2017	2018	2019	sum 2018 - 2019
CO2 emissions without FOLU and ISA (int. shipping/aviation) in Gt		34.3	34.9	35.2	35.1	35.5	35.9	36.6	37.1	74
CO2 emissions incl. FOLU and ISA in Gt									43.8	info

I. c) Global CO2 budget 2020 - 2100 without FOLU and ISA (deduction due to poor data, especially at country level)

global CO2 budget 2018 - 2100						570 Gt	info: actual share
net positive FOLU (npLUC; land-use change) from 2018 on	actual about in Gt	5.5	how much should be reserved?	13.0%		-74 Gt	12.9%
international shipping and aviation (ISA) from 2018 on			how much should be reserved?	3.0%		-17 Gt	2.9%
sub sum						479 Gt	
(projected) global CO2 emissions 2018 - 2019						-74 Gt	
global CO2 budget 2020 - 2100 (without FOLU and ISA)						405 Gt	A

II.) National CO2 budget 2020 - 2100

weighting population key in the weighted key	50%	selected country:	EU27	sheet: 'reference values'
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share selected country in global population 2019	5.769%	weigh- ting:	50%	population in 2019	444,987 thousand	info
share selected country in global emissions 2019	8.158%		50%	projected emissions in 2019	3,023.61 Mill. t	
weighted key	6.963%	B		scope of the budget	9.33 years	

national CO2 budget <u>2020 - 2100</u> ; weighted key applied on the global budget 2020 - 2100	28,209	Mill. t	= A * B
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national CO2 budget <u>2020 - 2100</u> ; free input		Mill. t
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national CO2 budget 2020 - 2100 (basis for this tool)	here calculated value	28,209	Mill. t
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III) National minimum emissions until 2100

emissions in 2019 of the selected country	3,023.6 Mill. t
What percentage of emissions in 2019 should represent the minimum of emissions by 2100? A negative value stands for net negative emissions.	-6.0%

minimum annual CO₂ emissions (a negative value stands for net negative emissions); E_{min} :	-181.4	Mill. t
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background information to net negative emissions:

	2019
global CO2 without FOLU and ISA in Gt	37.1
E_min % actual input above	-6.00%
≈ E_min global analog in Gt	-2.22
total global emissions in Gt	43.8
share of total global emissions	-5.1%

global CO2 without FOLU and ISA in 2019 in Gt	37.1		
IPCC SR15 illustrative model paths in the year 2100 in Gt	P1	P2	average
	-3.52	-4.47	-4.00
E_min proposals	-9.51%	-12.07%	-10.79%

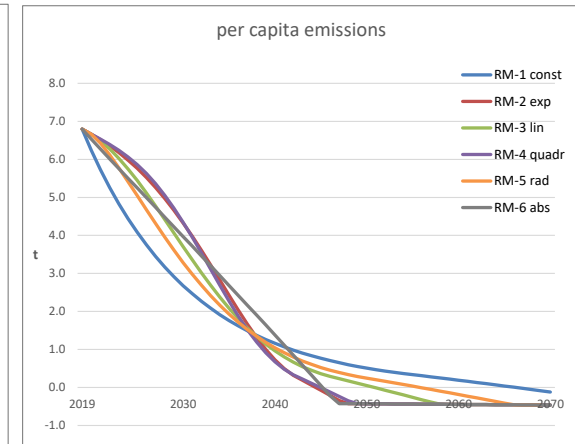
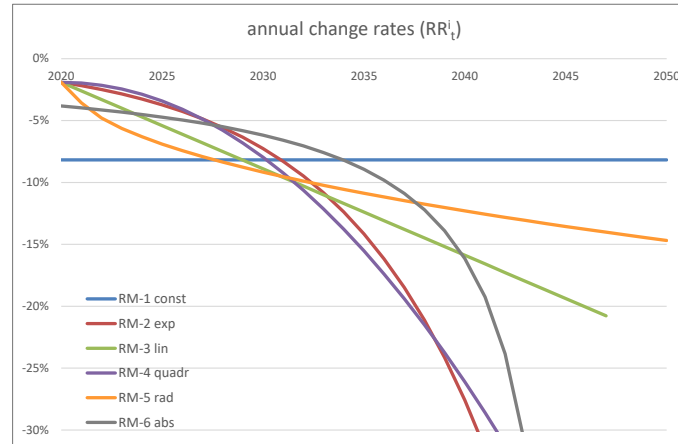
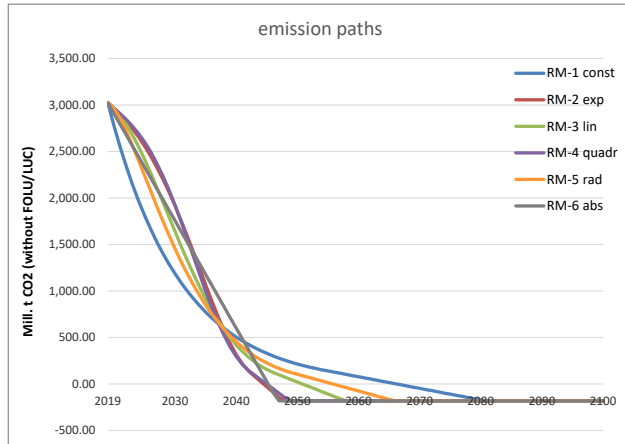
EU27

→ select a country

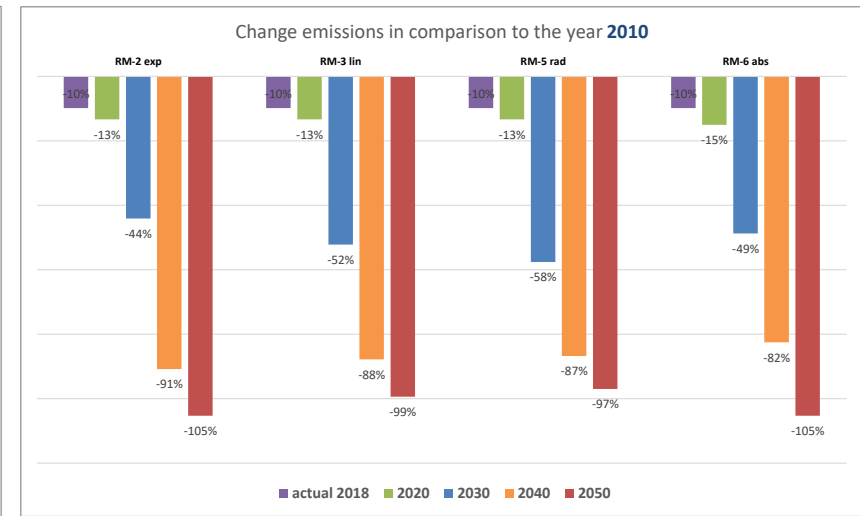
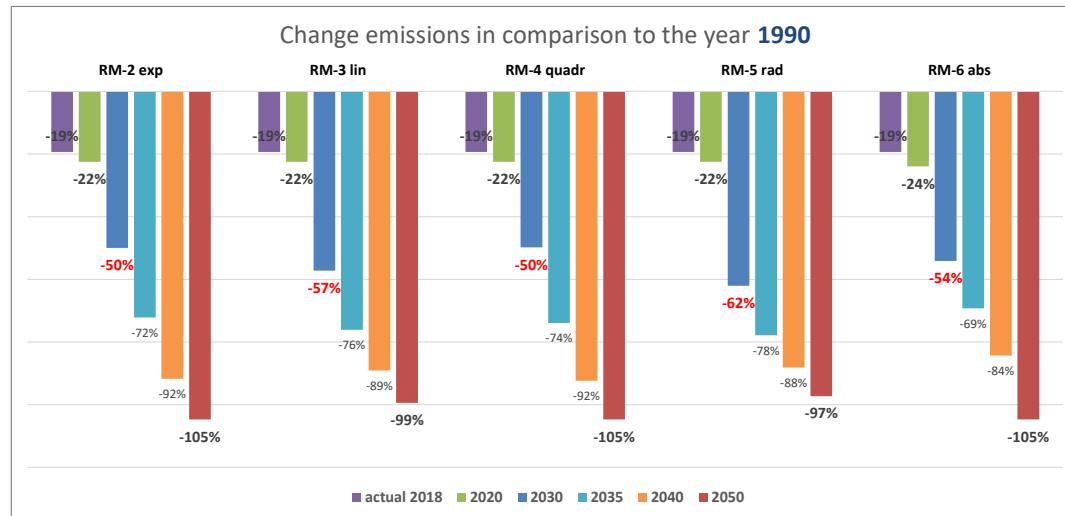
projection emissions 2019	
individual change rate sheet 'data countries'	'goal seek' is ok
base year projection: 2018	-02 % p.a. sheet 'goal seek'

50%	share population key RM 1 - 6 and SPM_FP
570	Gt global budget

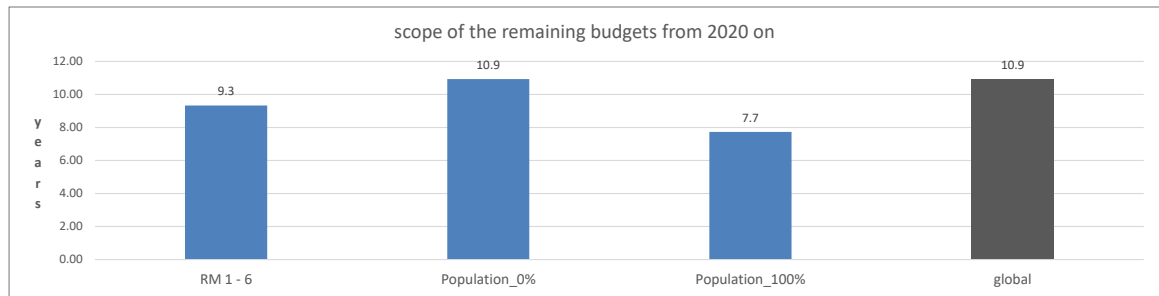
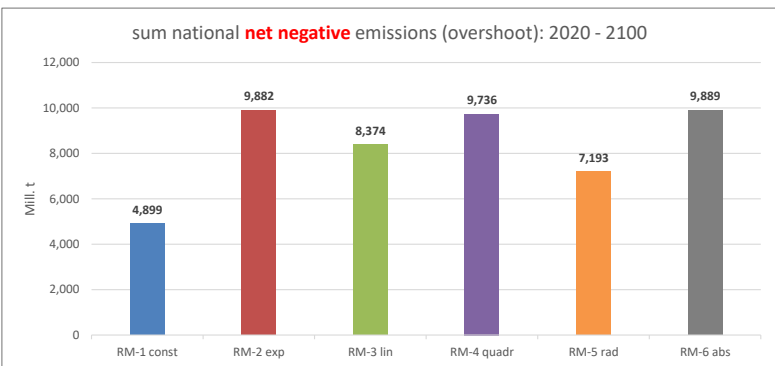
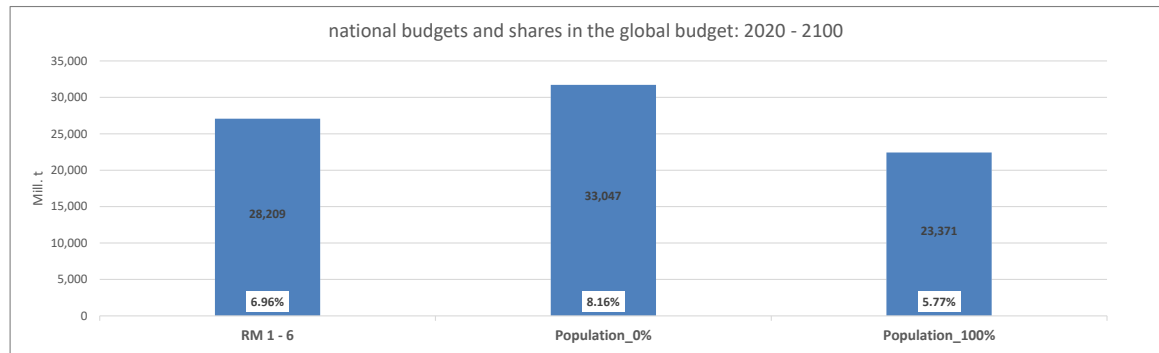
global per capita emissions 2019: 4.8052 t



Reference values for the country: EU27



selected country: **EU27**



Scope of the remaining national resp. global budget with unchanged emissions as in the base year 2019.

Important notes on negative emissions

Since we as humanity have not acted sufficiently, compliance with the 1.5°C limit is only possible with globally negative emissions. However, these global negative emissions mean that the remaining budget is temporarily exceeded. The higher the volume of this "overshoot" and the longer it lasts, the higher the likelihood that tipping points in the climate system will be exceeded. For tipping points with positive feedback effects, global warming may not be limited to, for example, 1.5°C, although mathematically the global negative emissions are sufficient to meet the remaining budget.

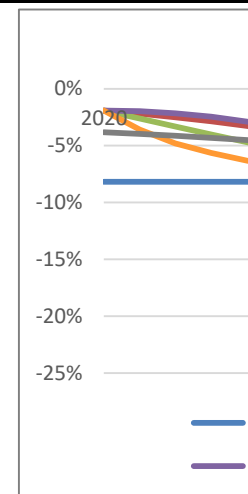
The later we reduce our CO2 emissions, the more we have to rely on global negative emissions and the higher the risks. In addition, the potential and costs of negative emissions are still relatively unclear today.

In this tool, the global overshoot can not be specified. For this one would have to know the results of all countries. However, what you can say is that with the scenario type RM-5-rad, the global paths described by the IPCC (see C.1 Summary for Policy Makers, Special Report 2018) can best be mapped.

This tool has the advantage that countries can choose their own emission path depending on a remaining national budget. In the end, however, it has to be reviewed in an overall view that the resulting global path is compatible

Determination of the free parameter in the RM scenarios 2020 - 2100

input value		determination via "goal seek"	target value of "goal seek"	target is not met			target is met			
RM scenarios:		<u>RM-1 const</u>	<u>RM-2 exp</u>	<u>RM-3 lin</u>	<u>RM-4 quadr</u>	<u>RM-5 rad</u>	<u>RM-6</u>	info		
characteristics of the scenario		<i>RR_t const</i>	<i>RR_t exp</i>	<i>RR_t lin</i>	<i>RR_t quadr</i>	<i>RR_t rad</i>	<i>RA const</i>	basis projection 2019	last actual change rate	
A corona effect should not be considered here.			only a negative RR ₂₀ possible	a positive RR ₂₀ is also possible (= increasing emissions after 2019)			info			
change rate 2020 (RR₂₀)		-8.17%	-1.91%	-1.91%	-1.91%	-1.91%	-3.82%	-2.00%	-1.9%	
<i>initial value</i>		-8%	10%	-1%	0	0	-121			
		<i>RR_t constant</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>RA</i>			
free parameters are determined by Goal Seek in such a way as that the budget is adhered to.		-8.17%	14.29%	-0.69863%	-0.00060497	-0.02352197	-115.43			
scenario Σ 2020 - 2100; sheet 'RM'	Mill. t	28,209	28,209	28,209	28,209	28,209	28,209			
budget Σ 2020 - 2100; sheet 'base data'	Mill. t	28,209	28,209	28,209	28,209	28,209	28,209			
emissions 2100 scenario; sheet 'RM'	Mill. t	-181.4	-181.4	-181.4	-181.4	-181.4	-181.4			
minimum emissions 2100 ; sheet 'base data'	Mill. t	-181.4	-181.4	-181.4	-181.4	-181.4	-181.4			
Year <i>E_{min}</i> is achieved		2081	2048	2058	2049	2066	2047			
change rate 2030 / 1990		-69%	-50%	-57%	-50%	-62%	-54%			
		from emissions 2019								
At which level of emissions (threshold value; <i>TV</i>) shall the annual percentage reduction be change into a constant annual reduction?		RM 2 - 5:	105.83	Mill. t	3.50%					
		RM-1:	142.11	Mill. t	4.70%					



calculation
RM 1 - 6
formula
base data
input sheet
'goal seek'
goal seek
sheet "goal seek"

RM-1 const	
constant annual reduction rate	
cumulative budget 2020 - 2100 in Mill. t	28,209
scenario sum emissions 2020 - 2100 in Mill. t	28,209
E_min in Mill. t	-181.4
scenario emissions in year 2100 in Mill. t	-181.4
free paramter	-8.17%

RM-2 exp	
exponential increase of annual reduction rates is assumed	
cumulative budget 2020 - 2100 in Mill. t	28,209
scenario sum emissions 2020 - 2100 in Mill. t	28,209
E_min in Mill. t	-181.4
scenario emissions in year 2100 in Mill. t	-181.4
RR_20; input value sheet "goal seek"	-1.91%
free paramter	14.29%

RM-3 lin	
linear increase of annual reduction rates is assumed	
cumulative budget 2020 - 2100 in Mill. t	28,209
scenario sum emissions 2020 - 2100 in Mill. t	28,209
E_min in Mill. t	-181.4
scenario emissions in year 2100 in Mill. t	-181.4
RR_20; input value sheet "goal seek"	-1.91%
free paramter	-0.70%

year	CO2 emissions in Mill. t		absolute change vs. prev. year in Mill. t	relative change vs. prev. year	
	E_t	$E_t - E_{t-1}$	RR_t const	actual RR_t	
2019	3,023.61				
2020	2,776.45	-247.16	-8.17%	-8.17%	
2021	2,549.49	-226.96	-8.17%	-8.17%	
2022	2,341.09	-208.40	-8.17%	-8.17%	
2023	2,149.72	-191.37	-8.17%	-8.17%	
2024	1,973.99	-175.73	-8.17%	-8.17%	
2025	1,812.63	-161.36	-8.17%	-8.17%	
2026	1,664.46	-148.17	-8.17%	-8.17%	
2027	1,528.40	-136.06	-8.17%	-8.17%	
2028	1,403.47	-124.94	-8.17%	-8.17%	
2029	1,288.74	-114.72	-8.17%	-8.17%	
2030	1,183.40	-105.35	-8.17%	-8.17%	
2031	1,086.66	-96.73	-8.17%	-8.17%	
2032	997.83	-88.83	-8.17%	-8.17%	
2033	916.27	-81.57	-8.17%	-8.17%	
2034	841.37	-74.90	-8.17%	-8.17%	
2035	772.59	-68.78	-8.17%	-8.17%	
2036	709.44	-63.15	-8.17%	-8.17%	
2037	651.45	-57.99	-8.17%	-8.17%	
2038	598.20	-53.25	-8.17%	-8.17%	
2039	549.30	-48.90	-8.17%	-8.17%	
2040	504.40	-44.90	-8.17%	-8.17%	
2041	463.16	-41.23	-8.17%	-8.17%	
2042	425.30	-37.86	-8.17%	-8.17%	
2043	390.54	-34.77	-8.17%	-8.17%	
2044	358.61	-31.92	-8.17%	-8.17%	
2045	329.30	-29.31	-8.17%	-8.17%	
2046	302.38	-26.92	-8.17%	-8.17%	
2047	277.66	-24.72	-8.17%	-8.17%	
2048	254.97	-22.70	-8.17%	-8.17%	
2049	234.12	-20.84	-8.17%	-8.17%	
2050	214.99	-19.14	-8.17%	-8.17%	
2051	197.41	-17.57	-8.17%	-8.17%	
2052	181.28	-16.14	-8.17%	-8.17%	
2053	166.46	-14.82	-8.17%	-8.17%	
2054	152.85	-13.61	-8.17%	-8.17%	
2055	140.36	-12.49	-8.17%	-8.17%	
2056	127.86	-12.49	-8.90%	-8.90%	
2057	115.37	-12.49	-9.77%	-9.77%	
2058	102.87	-12.49	-10.83%	-10.83%	
2059	90.38	-12.49	-12.15%	-12.15%	
2060	77.88	-12.49	-13.82%	-13.82%	
2061	65.39	-12.49	-16.04%	-16.04%	

year	CO2 emissions in Mill. t		absolute change vs. prev. year in Mill. t	relative change vs. prev. year	
	E_t	$E_t - E_{t-1}$	see formula below	actual RR_t	
2019	3,023.61				
2020	2,965.89	-57.72	-1.91%	-1.91%	
2021	2,901.19	-64.70	-2.18%	-2.18%	
2022	2,828.86	-72.33	-2.49%	-2.49%	
2023	2,748.25	-80.61	-2.85%	-2.85%	
2024	2,658.76	-89.50	-3.26%	-3.26%	
2025	2,559.80	-98.95	-3.72%	-3.72%	
2026	2,450.92	-108.88	-4.25%	-4.25%	
2027	2,331.78	-119.14	-4.86%	-4.86%	
2028	2,202.23	-129.55	-5.56%	-5.56%	
2029	2,062.40	-139.83	-6.35%	-6.35%	
2030	1,912.74	-149.66	-7.26%	-7.26%	
2031	1,754.11	-158.63	-8.29%	-8.29%	
2032	1,587.85	-166.26	-9.48%	-9.48%	
2033	1,415.85	-172.00	-10.83%	-10.83%	
2034	1,240.56	-175.28	-12.38%	-12.38%	
2035	1,065.04	-175.53	-14.15%	-14.15%	
2036	892.82	-172.22	-16.17%	-16.17%	
2037	727.82	-165.00	-18.48%	-18.48%	
2038	574.10	-153.72	-21.12%	-21.12%	
2039	435.52	-138.58	-24.14%	-24.14%	
2040	315.37	-120.15	-27.59%	-27.59%	
2041	215.94	-99.43	-31.53%	-31.53%	
2042	138.13	-77.81	-36.03%	-36.03%	
2043	81.25	-56.88	-41.18%	-41.18%	
2044	24.36	-56.88	-47.06%	-70.01%	
2045	-32.52	-56.88	-53.79%		
2046	-89.40	-56.88	-61.47%		
2047	-146.29	-56.88	-70.26%		
2048	-181.40	-35.11	-80.29%		
2049	-181.40	0.00	-91.77%		
2050	-181.40	0.00	-104.88%		
2051	-181.40	0.00	-119.86%		
2052	-181.40	0.00	-136.98%		
2053	-181.40	0.00	-156.56%		
2054	-181.40	0.00	-178.92%		
2055	-181.40	0.00	-204.49%		
2056	-181.40	0.00	-233.70%		
2057	-181.40	0.00	-267.09%		
2058	-181.40	0.00	-305.25%		
2059	-181.40	0.00	-348.86%		
2060	-181.40	0.00	-398.70%		
2061	-181.40	0.00	-455.66%		

year	CO2 emissions in Mill. t		absolute change vs. prev. year in Mill. t	relative change vs. prev. year	
	E_t	$E_t - E_{t-1}$	see formula below	actual RR_t	
2019	3,023.61				
2020	2,965.89	-57.72	-1.91%	-1.91%	
2021	2,888.56	-77.33	-2.61%	-2.61%	
2022	2,793.06	-95.50	-3.31%	-3.31%	
2023	2,681.21	-111.85	-4.00%	-4.00%	
2024	2,555.10	-126.11	-4.70%	-4.70%	
2025	2,417.08	-138.03	-5.40%	-5.40%	
2026	2,269.62	-147.46	-6.10%	-6.10%	
2027	2,115.31	-154.32	-6.80%	-6.80%	
2028	1,956.70	-158.60	-7.50%	-7.50%	
2029	1,796.32	-160.38	-8.20%	-8.20%	
2030	1,636.54	-159.78	-8.90%	-8.90%	
2031	1,479.53	-157.00	-9.59%	-9.59%	
2032	1,327.26	-152.28	-10.29%	-10.29%	
2033	1,181.38	-145.88	-10.99%	-10.99%	
2034	1,043.28	-138.10	-11.69%	-11.69%	
2035	914.04	-129.24	-12.39%	-12.39%	
2036	794.42	-119.62	-13.09%	-13.09%	
2037	684.90	-109.51	-13.79%	-13.79%	
2038	585.70	-99.20	-14.48%	-14.48%	
2039	496.78	-88.93	-15.18%	-15.18%	
2040	417.88	-78.89	-15.88%	-15.88%	
2041	348.60	-69.28	-16.58%	-16.58%	
2042	288.36	-60.23	-17.28%	-17.28%	
2043	236.52	-51.84	-17.98%	-17.98%	
2044	192.35	-44.17	-18.68%	-18.68%	
2045	155.08	-37.27	-19.37%	-19.37%	
2046	123.95	-31.13	-20.07%	-20.07%	
2047	98.21	-25.75	-20.77%	-20.77%	
2048	72.46	-25.75	-21.47%	-26.22%	
2049	46.71	-25.75	-22.17%	-35.53%	
2050	20.96	-25.75	-22.87%	-55.12%	
2051	-4.78	-25.75	-23.57%		
2052	-30.53	-25.75	-24.26%		
2053	-56.28	-25.75	-24.96%		
2054	-82.03	-25.75	-25.66%		
2055	-107.77	-25.75	-26.36%		
2056	-133.52	-25.75	-27.06%		
2057	-159.27	-25.75	-27.76%		
2058	-181.40	-22.13	-28.46%		
2059	-181.40	0.00	-29.16%		
2060	-181.40	0.00	-29.85%		
2061	-181.40	0.00	-30.55%		

calculation		RM-1 const				RM-2 exp			RM-3 lin		
RM 1 - 6		constant annual reduction rate				exponential increase of annual reduction rates is assumed			linear increase of annual reduction rates is assumed		
2062	52.89	-12.49	-8.17%	-19.11%	-181.40	0.00	-500.00%	-181.40	0.00	-31.25%	
2063	40.40	-12.49	-8.17%	-23.62%	-181.40	0.00	-500.00%	-181.40	0.00	-31.95%	
2064	27.91	-12.49	-8.17%	-30.93%	-181.40	0.00	-500.00%	-181.40	0.00	-32.65%	
2065	15.41	-12.49	-8.17%	-44.77%	-181.40	0.00	-500.00%	-181.40	0.00	-33.35%	
2066	2.92	-12.49	-8.17%	-81.08%	-181.40	0.00	-500.00%	-181.40	0.00	-34.05%	
2067	-9.58	-12.49	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-34.74%	
2068	-22.07	-12.49	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-35.44%	
2069	-34.57	-12.49	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-36.14%	
2070	-47.06	-12.49	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-36.84%	
2071	-59.56	-12.49	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-37.54%	
2072	-72.05	-12.49	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-38.24%	
2073	-84.55	-12.49	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-38.94%	
2074	-97.04	-12.49	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-39.63%	
2075	-109.53	-12.49	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-40.33%	
2076	-122.03	-12.49	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-41.03%	
2077	-134.52	-12.49	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-41.73%	
2078	-147.02	-12.49	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-42.43%	
2079	-159.51	-12.49	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-43.13%	
2080	-172.01	-12.49	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-43.83%	
2081	-181.40	-9.39	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-44.53%	
2082	-181.40	0.00	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-45.22%	
2083	-181.40	0.00	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-45.92%	
2084	-181.40	0.00	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-46.62%	
2085	-181.40	0.00	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-47.32%	
2086	-181.40	0.00	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-48.02%	
2087	-181.40	0.00	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-48.72%	
2088	-181.40	0.00	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-49.42%	
2089	-181.40	0.00	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-50.11%	
2090	-181.40	0.00	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-50.81%	
2091	-181.40	0.00	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-51.51%	
2092	-181.40	0.00	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-52.21%	
2093	-181.40	0.00	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-52.91%	
2094	-181.40	0.00	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-53.61%	
2095	-181.40	0.00	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-54.31%	
2096	-181.40	0.00	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-55.00%	
2097	-181.40	0.00	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-55.70%	
2098	-181.40	0.00	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-56.40%	
2099	-181.40	0.00	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-57.10%	
2100	-181.40	0.00	-8.17%		-181.40	0.00	-500.00%	-181.40	0.00	-57.80%	
sum	28,209				28,209			28,209			
		-4,899	negative emissions in Mill. t								
					-9,882	negative emissions in Mill. t					
								-8,374	negative emissions in Mill. t		

RM-4 quadr	
quadratic formula for annual reduction rates	
cumulative budget 2020 - 2100 in Mill. t	28,209
scenario sum emissions 2020 - 2100 in Mill. t	28,209
E_min in Mill. t	-181.4
scenario emissions in year 2100 in Mill. t	-181.4
RR_20; input value sheet "goal seek"	-1.91%
free paramter	-0.0006

RM-5 rad	
radical formula for annual reduction rates	
correcting factor	0.5
cumulative budget 2020 - 2100 in Mill. t	28,209
scenario sum emissions 2020 - 2100 in Mill. t	28,209
E_min in Mill. t	-181.4
scenario emissions in year 2100 in Mill. t	-181.4
RR_20; input value sheet "goal seek"	-1.91%
free paramter	-0.0235

RM-6 abs	
constant absolute annual change	
cumulative budget 2020 - 2100 in Mill. t	28,209
scenario sum emissions 2020 - 2100 in Mill. t	28,209
E_min in Mill. t	-181.4
scenario emissions in year 2100 in Mill. t	-181.4
RR_20; info	-3.82%
free paramter	-115.43

year	CO2 emissions in Mill. t	absolute change vs. prev. year in Mill. t	relative change vs. prev. year	
t	<i>see formula below</i> E_t	<i>see formula below</i> $E_t - E_{t-1}$	<i>see formula below</i> $E_t - E_{t-1}$	actual RR_t
2019	3,023.61			
2020	2,965.89	-57.72	-1.91%	-1.91%
2021	2,907.49	-58.41	-1.97%	-1.97%
2022	2,844.95	-62.53	-2.15%	-2.15%
2023	2,775.16	-69.79	-2.45%	-2.45%
2024	2,695.32	-79.83	-2.88%	-2.88%
2025	2,603.11	-92.21	-3.42%	-3.42%
2026	2,496.73	-106.38	-4.09%	-4.09%
2027	2,375.06	-121.67	-4.87%	-4.87%
2028	2,237.76	-137.29	-5.78%	-5.78%
2029	2,085.39	-152.37	-6.81%	-6.81%
2030	1,919.42	-165.97	-7.96%	-7.96%
2031	1,742.28	-177.14	-9.23%	-9.23%
2032	1,557.24	-185.04	-10.62%	-10.62%
2033	1,368.30	-188.94	-12.13%	-12.13%
2034	1,179.94	-188.37	-13.77%	-13.77%
2035	996.80	-183.14	-15.52%	-15.52%
2036	823.40	-173.41	-17.40%	-17.40%
2037	663.72	-159.68	-19.39%	-19.39%
2038	520.95	-142.77	-21.51%	-21.51%
2039	397.24	-123.72	-23.75%	-23.75%
2040	293.53	-103.71	-26.11%	-26.11%
2041	209.61	-83.91	-28.59%	-28.59%
2042	144.23	-65.38	-31.19%	-31.19%
2043	95.32	-48.91	-33.91%	-33.91%
2044	46.41	-48.91	-36.76%	-51.31%
2045	-2.50	-48.91	-39.72%	
2046	-51.42	-48.91	-42.81%	
2047	-100.33	-48.91	-46.01%	
2048	-149.24	-48.91	-49.34%	
2049	-181.40	-32.16	-52.79%	
2050	-181.40	0.00	-56.36%	
2051	-181.40	0.00	-60.05%	
2052	-181.40	0.00	-63.86%	
2053	-181.40	0.00	-67.79%	
2054	-181.40	0.00	-71.84%	
2055	-181.40	0.00	-76.02%	
2056	-181.40	0.00	-80.31%	
2057	-181.40	0.00	-84.73%	
2058	-181.40	0.00	-89.27%	
2059	-181.40	0.00	-93.93%	
2060	-181.40	0.00	-98.70%	
2061	-181.40	0.00	-103.61%	

year	CO2 emissions in Mill. t	absolute change vs. prev. year in Mill. t	relative change vs. prev. year	
t	<i>see formula below</i> E_t	<i>see formula below</i> $E_t - E_{t-1}$	<i>see formula below</i> $E_t - E_{t-1}$	actual RR_t
2019	3,023.61			
2020	2,965.89	-57.72	-1.91%	-1.91%
2021	2,859.95	-105.94	-3.57%	-3.57%
2022	2,722.97	-136.98	-4.79%	-4.79%
2023	2,569.72	-153.25	-5.63%	-5.63%
2024	2,407.59	-162.13	-6.31%	-6.31%
2025	2,241.50	-166.09	-6.90%	-6.90%
2026	2,075.06	-166.44	-7.43%	-7.43%
2027	1,911.01	-164.05	-7.91%	-7.91%
2028	1,751.43	-159.58	-8.35%	-8.35%
2029	1,597.89	-153.54	-8.77%	-8.77%
2030	1,451.54	-146.35	-9.16%	-9.16%
2031	1,313.20	-138.34	-9.53%	-9.53%
2032	1,183.38	-129.82	-9.89%	-9.89%
2033	1,062.38	-121.00	-10.23%	-10.23%
2034	950.29	-112.10	-10.55%	-10.55%
2035	847.03	-103.26	-10.87%	-10.87%
2036	752.42	-94.61	-11.17%	-11.17%
2037	666.17	-86.25	-11.46%	-11.46%
2038	587.90	-78.27	-11.75%	-11.75%
2039	517.20	-70.70	-12.03%	-12.03%
2040	453.61	-63.59	-12.30%	-12.30%
2041	396.64	-56.97	-12.56%	-12.56%
2042	345.81	-50.83	-12.82%	-12.82%
2043	300.62	-45.18	-13.07%	-13.07%
2044	260.61	-40.02	-13.31%	-13.31%
2045	225.29	-35.32	-13.55%	-13.55%
2046	194.23	-31.06	-13.79%	-13.79%
2047	167.00	-27.23	-14.02%	-14.02%
2048	143.22	-23.79	-14.24%	-14.24%
2049	122.50	-20.72	-14.47%	-14.47%
2050	104.51	-17.99	-14.68%	-14.68%
2051	86.52	-17.99	-14.90%	-17.21%
2052	68.53	-17.99	-15.11%	-20.79%
2053	50.55	-17.99	-15.32%	-26.25%
2054	32.56	-17.99	-15.52%	-35.59%
2055	14.57	-17.99	-15.72%	-55.25%
2056	-3.42	-17.99	-15.92%	
2057	-21.41	-17.99	-16.12%	
2058	-39.40	-17.99	-16.31%	
2059	-57.38	-17.99	-16.50%	
2060	-75.37	-17.99	-16.69%	
2061	-93.36	-17.99	-16.88%	

year	CO2 emissions in Mill. t	absolute change vs. prev. year in Mill. t	relative change vs. prev. year	
t	<i>see formula below</i> E_t	<i>see formula below</i> $E_t - E_{t-1}$	actual RR_t	
2019	3,023.61			
2020	2,908.18	-115.43	-115.43	-3.82%
2021	2,792.75	-115.43	-115.43	-3.97%
2022	2,677.32	-115.43	-115.43	-4.13%
2023	2,561.89	-115.43	-115.43	-4.31%
2024	2,446.46	-115.43	-115.43	-4.51%
2025	2,331.03	-115.43	-115.43	-4.72%
2026	2,215.60	-115.43	-115.43	-4.95%
2027	2,100.17	-115.43	-115.43	-5.21%
2028	1,984.74	-115.43	-115.43	-5.50%
2029	1,869.31	-115.43	-115.43	-5.82%
2030	1,753.88	-115.43	-115.43	-6.18%
2031	1,638.45	-115.43	-115.43	-6.58%
2032	1,523.02	-115.43	-115.43	-7.05%
2033	1,407.59	-115.43	-115.43	-7.58%
2034	1,292.16	-115.43	-115.43	-8.20%
2035	1,176.73	-115.43	-115.43	-8.93%
2036	1,061.30	-115.43	-115.43	-9.81%
2037	945.87	-115.43	-115.43	-10.88%
2038	830.44	-115.43	-115.43	-12.20%
2039	715.01	-115.43	-115.43	-13.90%
2040	599.58	-115.43	-115.43	-16.14%
2041	484.15	-115.43	-115.43	-19.25%
2042	368.71	-115.43	-115.43	-23.84%
2043	253.28	-115.43	-115.43	-31.31%
2044	137.85	-115.43	-115.43	-45.57%
2045	22.42	-115.43	-115.43	-83.73%
2046	-93.01	-115.43	-115.43	
2047	-181.40	-115.43	-88.39	
2048	-181.40	-115.43		
2049	-181.40	-115.43		
2050	-181.40	-115.43		
2051	-181.40	-115.43		
2052	-181.40	-115.43		
2053	-181.40	-115.43		
2054	-181.40	-115.43		
2055	-181.40	-115.43		
2056	-181.40	-115.43		
2057	-181.40	-115.43		
2058	-181.40	-115.43		
2059	-181.40	-115.43		
2060	-181.40	-115.43		
2061	-181.40	-115.43		

RM-4 quadr				RM-5 rad				RM-6 abs			
quadratic formula for annual reduction rates				radical formula for annual reduction rates				constant absolute annual change			
2062	-181.40	0.00	-108.63%								
2063	-181.40	0.00	-113.77%								
2064	-181.40	0.00	-119.03%								
2065	-181.40	0.00	-124.42%								
2066	-181.40	0.00	-129.92%								
2067	-181.40	0.00	-135.55%								
2068	-181.40	0.00	-141.29%								
2069	-181.40	0.00	-147.16%								
2070	-181.40	0.00	-153.15%								
2071	-181.40	0.00	-159.26%								
2072	-181.40	0.00	-165.49%								
2073	-181.40	0.00	-171.85%								
2074	-181.40	0.00	-178.32%								
2075	-181.40	0.00	-184.91%								
2076	-181.40	0.00	-191.63%								
2077	-181.40	0.00	-198.47%								
2078	-181.40	0.00	-205.42%								
2079	-181.40	0.00	-212.50%								
2080	-181.40	0.00	-219.70%								
2081	-181.40	0.00	-227.02%								
2082	-181.40	0.00	-234.46%								
2083	-181.40	0.00	-242.02%								
2084	-181.40	0.00	-249.71%								
2085	-181.40	0.00	-257.51%								
2086	-181.40	0.00	-265.44%								
2087	-181.40	0.00	-273.48%								
2088	-181.40	0.00	-281.65%								
2089	-181.40	0.00	-289.94%								
2090	-181.40	0.00	-298.35%								
2091	-181.40	0.00	-306.88%								
2092	-181.40	0.00	-315.53%								
2093	-181.40	0.00	-324.30%								
2094	-181.40	0.00	-333.19%								
2095	-181.40	0.00	-342.21%								
2096	-181.40	0.00	-351.34%								
2097	-181.40	0.00	-360.60%								
2098	-181.40	0.00	-369.98%								
2099	-181.40	0.00	-379.47%								
2100	-181.40	0.00	-389.09%								
sum	28,209			28,209				28,209			
	-9,736	negative emissions in Mill. t			-7,193	negative emissions in Mill. t			-9,889	negative emissions in Mill. t	

M-2 exp	RM-3 lin	RM-4 quadr
annual reduction rates is assumed	linear increase of annual reduction rates is assumed	quadratic formula for annual reduction rates

3 Formulae Regensburg Model Scenario Types

3.1 Determination of paths via annual rates of change (scenario types RM 1 – 5)

$$E_t = \begin{cases} \max(E_{min}; E_{t-1} * (1 + RR_t)) & \text{for } E_{t-1} > TV \\ \max(E_{min}; E_{t-1} + (E_{t-1} - E_{t-2})) & \text{for } E_{t-1} \leq TV \end{cases}$$

where:

E_t emissions in the year t ; here: 2020 – 2100

The **reduction rates** in the individual scenario types are based on the following formulae:

name scenario type	formula	basic function type	con-straint	property course of the reduction rates
RM-2 exp ³	$RR_t = RR_{t-1} * (1 + a)$	e^x	$a \geq 0$	► concave
RM-4 quadr ⁴	$RR_t = a * (t - (BY + 1))^2 + RR_{BY+1}$	$y = ax^2 + b$	$a \leq 0$	
RM-5 rad ⁵	$RR_t = a * \sqrt{t - (BY + 1) - 0.5} + RR_{BY+1}$	$y = a\sqrt{x} + b$	$a \leq 0$	► convex
RM-3 lin	$RR_t = a * (t - (BY + 1)) + RR_{BY+1} = RR_{t-1} + a$	$y = ax + b$	$a \leq 0$	► linear
RM-1 const	$RR_t = a$	$y = a$	$a \leq 0$	► constant

In the scenario types RM 2, 5 and 3 for $t = BY + 1$ the predefined RR_{BY+1} (see chapter 2) must be used. Thus the equations above hold for $t > BY + 1$ (here: $t > 2020$).

The free parameter a is determined for each scenario type with the target value search integrated in Excel so that the budget (B) is met. The target value search is integrated in a macro in the Excel tools, which also ensures that the constraints are met.

3.2 Determination of paths via annual change amount (scenario type RM-6)

RM-6 abs: $E_t = \max(E_{min}; E_{t-1} + RA)$

The free parameter RA (constant reduction amount) is determined with the target value search integrated in Excel so that the budget (B) is met.