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 ex ecute 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

data status	
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“

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	
420	**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					420 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%	-55 Gt	12.9%
international shipping and aviation (ISA) from 2018 on			how much should be reserved?	3.0%	-13 Gt	2.9%
sub sum					353 Gt	
(projected) global CO2 emissions 2018 - 2019					-74 Gt	
global CO2 budget 2020 - 2100 (without FOLU and ISA)					**279 Gt**	A

II.) National CO2 budget 2020 - 2100

weighting population key in the weighted key	50%	selected country:	EU27	sheet: 'reference values'

share selected country in global population 2019	5.769%	weigh-	50%	population in 2019	444,987 thousand	info
share selected country in global emissions 2019	8.158%	ting:	50%	projected emissions in 2019	3,023.61 Mill. t	
weighted key	**6.963%**	**B**		scope of the budget	6.43 years	

national CO2 budget 2020 - 2100; **weighted key applied on the global budget 2020 - 2100**	**19,435**	Mill. t	**= A * B**

national CO2 budget 2020 - 2100; **free input**		Mill. t

national CO2 budget 2020 - 2100 (basis for this tool)	here calculated value		**19,435**	**Mill. t**

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 CO_2 emissions (a negative value stands for net negative emissions); E_{min} :	**-181.4**	**Mill. t**

background information to net negative emissions:

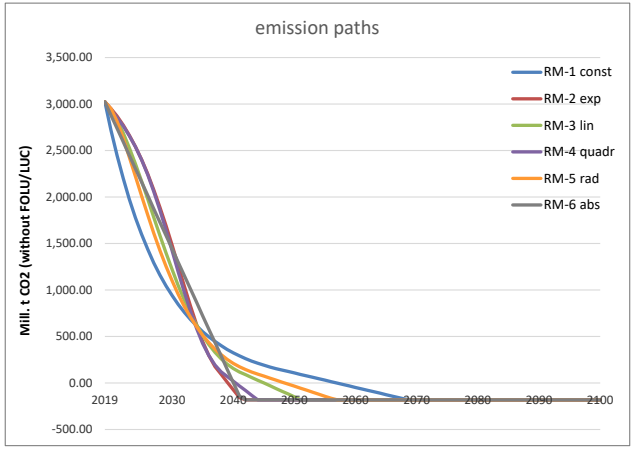
	2019
global CO2 without FOLU and ISA in Gt	37.1
E_min % actual input above	-6.00%
≈ E_min global analog in Gt	-2.22
total global emissions in Gt	43.8
share of total global emissions	**-5.1%**

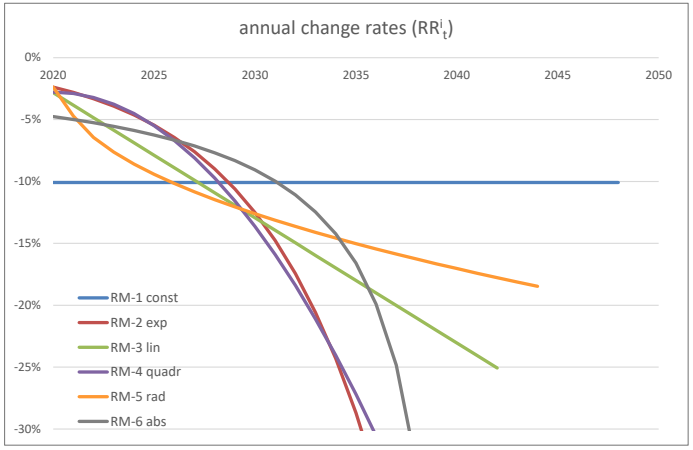
global CO2 without FOLU and ISA in 2019 in Gt	37.1		
IPCC SR15 illustrative model paths in the year 2100 in Gt	P1	P2	average
	-3.52	-4.47	**-4.00**
E_min proposals	**-9.51%**	**-12.07%**	**-10.79%**

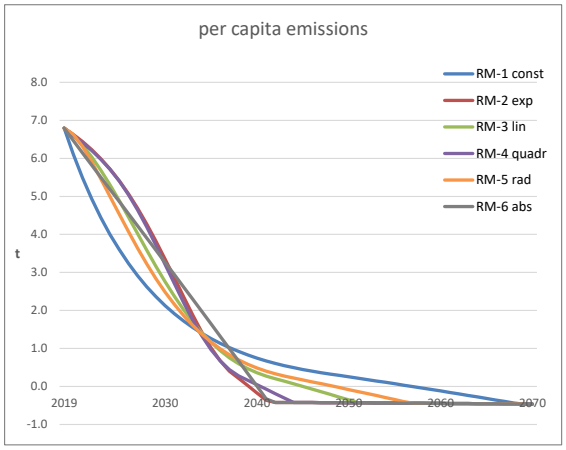
EU27	→ select a country	projection emissions 2019		
			individual change rate sheet 'data countries'	'goal seek' is ok
		base year projection: 2018	-02 % p.a.	sheet 'goal seek'

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

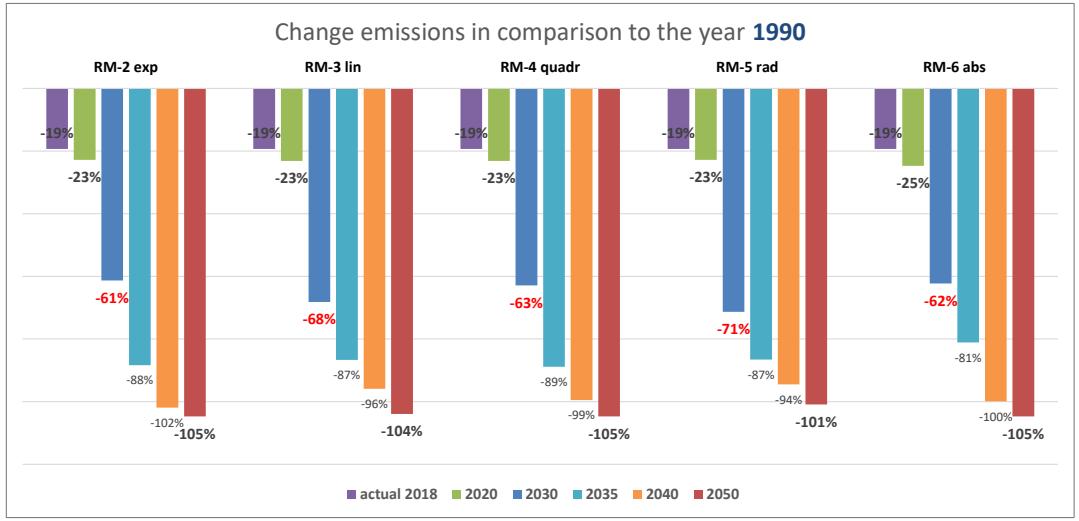
global per capita emissions 2019: 4.8052 t

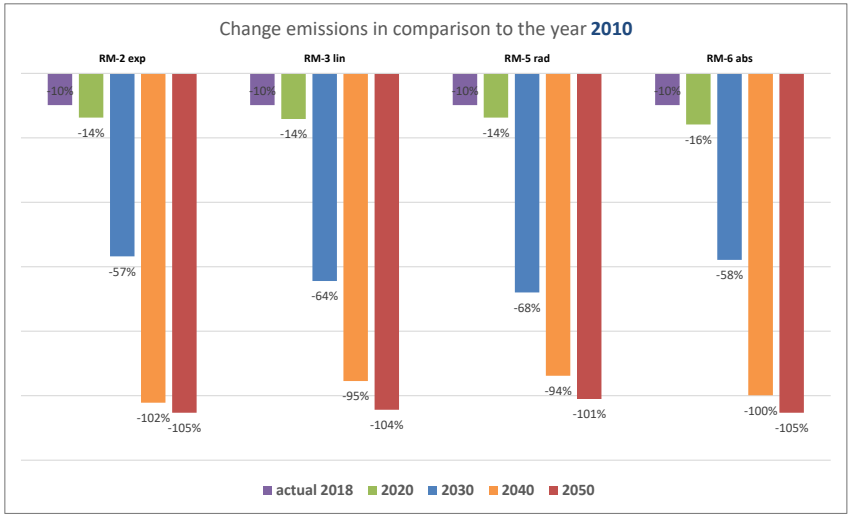




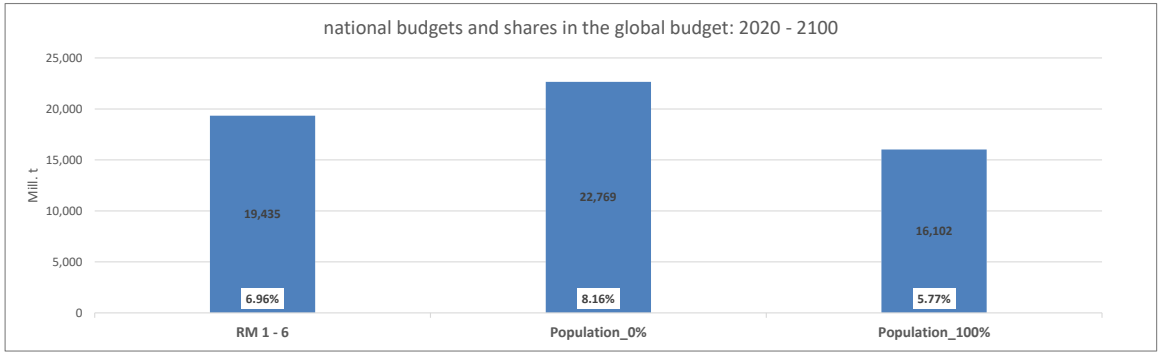


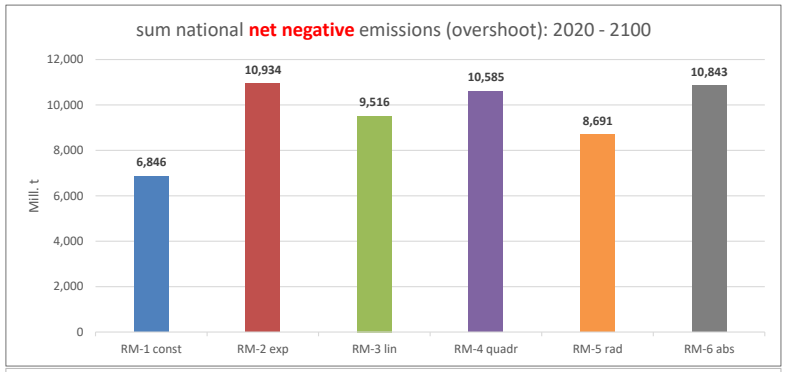
Reference values for the country: EU27

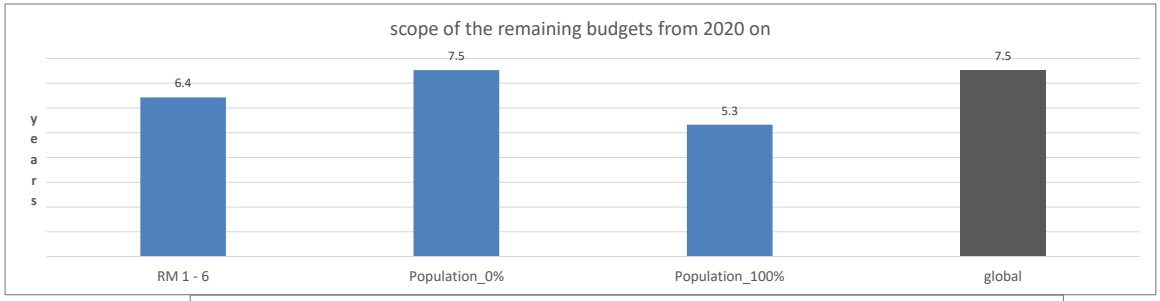




selected country:	EU27







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.

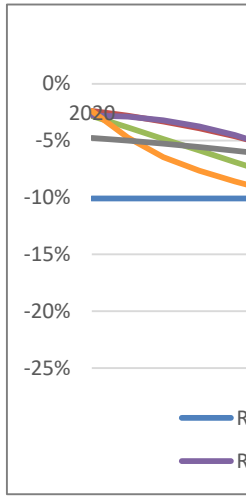
In this tool, the global overshoot can not be specified. For this one would have to know the results of all countries. However, what you can say is that with the scenario type RM-5-rad, the global paths described by the IPCC (see C.1 Summary for Policy Makers, Special Report 2018) can best be mapped.

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:		RM-1 const	RM-2 exp	RM-3 lin	RM-4 quadr	RM-5 rad	RM-6	info	
characteristics of the scenario		RR_t const	RR_t exp	RR_t lin	RR_t quadr	RR_t rad	RA const	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 (RR_{20})		**-10.08%**	**-2.38%**	**-2.83%**	**-2.78%**	**-2.38%**	**-4.76%**	-2.00%	-1.9%
initial value		*-8%*	*10%*	*-1%*	*0*	*0*	-121		
		RR_t constant	a	a	a	a	RA		
free parameters are determined by Goal Seek in such a way as that the budget is adhered to.		-10.08%	18.06%	-1.01091%	-0.00108469	-0.03319225	**-143.80**		
scenario ∑ 2020 - 2100; sheet 'RM'	Mill. t	19,435	19,435	19,435	19,435	19,435	19,435		
budget ∑ 2020 - 2100; sheet 'base data'	Mill. t	19,435	19,435	19,435	19,435	19,435	19,435		
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 E_{min} is achieved		2069	2042	2052	2044	2057	2042		
change rate 2030 / 1990		-75%	-61%	-68%	-63%	**-71%**	-62%		



				from emissions 2019
At which level of emissions (threshold value; ***TV***) shall the annual percentage reduction be change into a constant annual reduction?	**RM 2 - 5:**	105.83	Mill. t	3.50%
	RM-1:	148.16	Mill. t	4.90%

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

RM-1 const

constant annual reduction rate

cumulative budget 2020 - 2100 in Mill. t	19,435
scenario sum emissions 2020 - 2100 in Mill. t	19,435
E_min in Mill. t	-181.4
scenario emissions in year 2100 in Mill. t	-181.4
free paramter	-10.08%

RM-2 exp

exponential increase of annual reduction rates is assumed

cumulative budget 2020 - 2100 in Mill. t	19,435
scenario sum emissions 2020 - 2100 in Mill. t	19,435
E_min in Mill. t	-181.4
scenario emissions in year 2100 in Mill. t	-181.4
RR_20; input value sheet "goal seek"	**-2.38%**
free paramter	**18.06%**

RM-3 lin

linear increase of annual reduction rates is assumed

cumulative budget 2020 - 2100 in Mill. t	19,435
scenario sum emissions 2020 - 2100 in Mill. t	19,435
E_min in Mill. t	-181.4
scenario emissions in year 2100 in Mill. t	-181.4
RR_20; input value sheet "goal seek"	**-2.83%**
free paramter	**-1.01%**

year	t	RM-1 const: CO2 emissions in Mill. t (see formula below E_t)	RM-1 const: absolute change vs. prev. year in Mill. t ($E_t - E_{t-1}$)	RM-1 const: relative change vs. prev. year (RR_t const)	RM-1 const: relative change vs. prev. year (actual RR_t)	RM-2 exp: CO2 emissions in Mill. t (see formula below E_t)	RM-2 exp: absolute change vs. prev. year in Mill. t ($E_t - E_{t-1}$)	RM-2 exp: relative change vs. prev. year (see formula below)	RM-2 exp: relative change vs. prev. year (actual RR_t)	RM-3 lin: CO2 emissions in Mill. t (see formula below E_t)	RM-3 lin: absolute change vs. prev. year in Mill. t ($E_t - E_{t-1}$)	RM-3 lin: relative change vs. prev. year (see formula below)	RM-3 lin: relative change vs. prev. year (actual RR_t)
	2019	3,023.61				3,023.61				3,023.61			
	2020	2,718.80	-304.81	-10.08%	-10.08%	2,951.71	-71.90	**-2.38%**	-2.38%	2,938.10	-85.51	**-2.83%**	-2.83%
	2021	2,444.71	-274.09	-10.08%	-10.08%	2,868.84	-82.87	-2.81%	-2.81%	2,825.31	-112.79	-3.84%	-3.84%
	2022	2,198.26	-246.45	-10.08%	-10.08%	2,773.75	-95.09	-3.31%	-3.31%	2,688.29	-137.02	-4.85%	-4.85%
	2023	1,976.65	-221.61	-10.08%	-10.08%	2,665.21	-108.54	-3.91%	-3.91%	2,530.74	-157.55	-5.86%	-5.86%
	2024	1,777.38	-199.27	-10.08%	-10.08%	2,542.09	-123.13	-4.62%	-4.62%	2,356.83	-173.90	-6.87%	-6.87%
	2025	1,598.20	-179.18	-10.08%	-10.08%	2,403.44	-138.65	-5.45%	-5.45%	2,171.05	-185.78	-7.88%	-7.88%
	2026	1,437.08	-161.12	-10.08%	-10.08%	2,248.68	-154.76	-6.44%	-6.44%	1,977.97	-193.08	-8.89%	-8.89%
	2027	1,292.21	-144.87	-10.08%	-10.08%	2,077.73	-170.95	-7.60%	-7.60%	1,782.07	-195.91	-9.90%	-9.90%
	2028	1,161.94	-130.27	-10.08%	-10.08%	1,891.26	-186.48	-8.97%	-8.97%	1,587.55	-194.52	-10.92%	-10.92%
	2029	1,044.80	-117.14	-10.08%	-10.08%	1,690.86	-200.39	-10.60%	-10.60%	1,398.22	-189.33	-11.93%	-11.93%
	2030	939.47	-105.33	-10.08%	-10.08%	1,479.34	-211.52	-12.51%	-12.51%	1,217.33	-180.89	-12.94%	-12.94%
	2031	844.77	-94.71	-10.08%	-10.08%	1,260.86	-218.48	-14.77%	-14.77%	1,047.53	-169.79	-13.95%	-13.95%
	2032	759.60	-85.16	-10.08%	-10.08%	1,041.02	-219.84	-17.44%	-17.44%	890.83	-156.70	-14.96%	-14.96%
	2033	683.03	-76.58	-10.08%	-10.08%	826.73	-214.29	-20.58%	-20.58%	748.57	-142.26	-15.97%	-15.97%
	2034	614.17	-68.86	-10.08%	-10.08%	625.81	-200.92	-24.30%	-24.30%	621.46	-127.11	-16.98%	-16.98%
	2035	552.25	-61.92	-10.08%	-10.08%	446.26	-179.56	-28.69%	-28.69%	509.65	-111.81	-17.99%	-17.99%
	2036	496.58	-55.67	-10.08%	-10.08%	295.10	-151.16	-33.87%	-33.87%	412.80	-96.85	-19.00%	-19.00%
	2037	446.52	-50.06	-10.08%	-10.08%	177.09	-118.01	-39.99%	-39.99%	330.19	-82.62	-20.01%	-20.01%
	2038	401.51	-45.01	-10.08%	-10.08%	93.48	-83.61	-47.21%	-47.21%	260.77	-69.42	-21.02%	-21.02%
	2039	361.03	-40.48	-10.08%	-10.08%	9.87	-83.61	-55.74%	-89.44%	203.31	-57.46	-22.04%	-22.04%
	2040	324.63	-36.40	-10.08%	-10.08%	-73.74	-83.61	-65.81%		156.45	-46.85	-23.05%	-23.05%
	2041	291.91	-32.73	-10.08%	-10.08%	-157.34	-83.61	-77.69%		118.81	-37.64	-24.06%	-24.06%
	2042	262.48	-29.43	-10.08%	-10.08%	-181.40	-24.06	-91.72%		89.03	-29.78	-25.07%	-25.07%
	2043	236.02	-26.46	-10.08%	-10.08%	-181.40	0.00	-108.29%		59.25	-29.78	-26.08%	-33.45%
	2044	212.23	-23.79	-10.08%	-10.08%	-181.40	0.00	-127.84%		29.46	-29.78	-27.09%	-50.27%
	2045	190.83	-21.39	-10.08%	-10.08%	-181.40	0.00	-150.93%		-0.32	-29.78	-28.10%	
	2046	171.59	-19.24	-10.08%	-10.08%	-181.40	0.00	-178.19%		-30.11	-29.78	-29.11%	
	2047	154.29	-17.30	-10.08%	-10.08%	-181.40	0.00	-210.37%		-59.89	-29.78	-30.12%	
	2048	138.74	-15.55	-10.08%	-10.08%	-181.40	0.00	-248.36%		-89.68	-29.78	-31.13%	
	2049	123.19	-15.55	-10.08%	-11.21%	-181.40	0.00	-293.22%		-119.46	-29.78	-32.14%	
	2050	107.63	-15.55	-10.08%	-12.63%	-181.40	0.00	-346.17%		-149.24	-29.78	-33.16%	
	2051	92.08	-15.55	-10.08%	-14.45%	-181.40	0.00	-408.69%		-179.03	-29.78	-34.17%	
	2052	76.52	-15.55	-10.08%	-16.89%	-181.40	0.00	-482.50%		-181.40	-2.37	-35.18%	
	2053	60.97	-15.55	-10.08%	-20.33%	-181.40	0.00	-500.00%		-181.40	0.00	-36.19%	
	2054	45.41	-15.55	-10.08%	-25.51%	-181.40	0.00	-500.00%		-181.40	0.00	-37.20%	
	2055	29.86	-15.55	-10.08%	-34.25%	-181.40	0.00	-500.00%		-181.40	0.00	-38.21%	
	2056	14.30	-15.55	-10.08%	-52.10%	-181.40	0.00	-500.00%		-181.40	0.00	-39.22%	
	2057	-1.25	-15.55	-10.08%		-181.40	0.00	-500.00%		-181.40	0.00	-40.23%	
	2058	-16.81	-15.55	-10.08%		-181.40	0.00	-500.00%		-181.40	0.00	-41.24%	
	2059	-32.36	-15.55	-10.08%		-181.40	0.00	-500.00%		-181.40	0.00	-42.25%	
	2060	-47.92	-15.55	-10.08%		-181.40	0.00	-500.00%		-181.40	0.00	-43.26%	
	2061	-63.47	-15.55	-10.08%		-181.40	0.00	-500.00%		-181.40	0.00	-44.28%	

calculation RM 1 - 6		RM-1 const constant annual reduction rate			RM-2 exp exponential increase of annual reduction rates is assumed			RM-3 lin linear increase of annual reduction rates is assumed		
	2062	-79.02	-15.55	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-45.29%
	2063	-94.58	-15.55	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-46.30%
	2064	-110.13	-15.55	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-47.31%
	2065	-125.69	-15.55	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-48.32%
	2066	-141.24	-15.55	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-49.33%
	2067	-156.80	-15.55	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-50.34%
	2068	-172.35	-15.55	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-51.35%
	2069	-181.40	-9.05	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-52.36%
	2070	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-53.37%
	2071	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-54.38%
	2072	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-55.40%
	2073	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-56.41%
	2074	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-57.42%
	2075	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-58.43%
	2076	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-59.44%
	2077	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-60.45%
	2078	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-61.46%
	2079	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-62.47%
	2080	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-63.48%
	2081	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-64.49%
	2082	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-65.50%
	2083	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-66.52%
	2084	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-67.53%
	2085	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-68.54%
	2086	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-69.55%
	2087	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-70.56%
	2088	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-71.57%
	2089	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-72.58%
	2090	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-73.59%
	2091	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-74.60%
	2092	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-75.61%
	2093	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-76.62%
	2094	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-77.64%
	2095	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-78.65%
	2096	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-79.66%
	2097	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-80.67%
	2098	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-81.68%
	2099	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-82.69%
	2100	-181.40	0.00	-10.08%	-181.40	0.00	-500.00%	-181.40	0.00	-83.70%
	sum	**19,435**			**19,435**			**19,435**		
		-6,846	negative emissions in Mill. t		-10,934	negative emissions in Mill. t		-9,516	negative emissions in Mill. t	

RM-4 quadr

quadratic formula for annual reduction rates

cumulative budget 2020 - 2100 in Mill. t	19,435
scenario sum emissions 2020 - 2100 in Mill. t	19,435
E_min in Mill. t	-181.4
scenario emissions in year 2100 in Mill. t	-181.4
RR_20; input value sheet "goal seek"	**-2.78%**
free paramter	**-0.0011**

year	CO2 emissions in Mill. t	absolute change vs. prev. year in Mill. t	relative change vs. prev. year	
t	*see formula below* E_t	$E_t - E_{t-1}$	*see formula below*	*actual* RR_t
2019	3,023.61			
2020	2,939.61	-84.00	-2.78%	-2.78%
2021	2,854.76	-84.85	-2.89%	-2.89%
2022	2,763.07	-91.69	-3.21%	-3.21%
2023	2,659.34	-103.73	-3.75%	-3.75%
2024	2,539.31	-120.03	-4.51%	-4.51%
2025	2,399.91	-139.40	-5.49%	-5.49%
2026	2,239.53	-160.38	-6.68%	-6.68%
2027	2,058.28	-181.24	-8.09%	-8.09%
2028	1,858.22	-200.06	-9.72%	-9.72%
2029	1,643.33	-214.88	-11.56%	-11.56%
2030	1,419.43	-223.90	-13.62%	-13.62%
2031	1,193.70	-225.73	-15.90%	-15.90%
2032	974.09	-219.61	-18.40%	-18.40%
2033	768.47	-205.62	-21.11%	-21.11%
2034	583.75	-184.72	-24.04%	-24.04%
2035	425.06	-158.68	-27.18%	-27.18%
2036	295.22	-129.84	-30.55%	-30.55%
2037	194.48	-100.75	-34.13%	-34.13%
2038	120.73	-73.75	-37.92%	-37.92%
2039	70.10	-50.63	-41.94%	-41.94%
2040	19.47	-50.63	-46.17%	-72.22%
2041	-31.15	-50.63	-50.61%	
2042	-81.78	-50.63	-55.28%	
2043	-132.41	-50.63	-60.16%	
2044	-181.40	-48.99	-65.26%	
2045	-181.40	0.00	-70.57%	
2046	-181.40	0.00	-76.10%	
2047	-181.40	0.00	-81.85%	
2048	-181.40	0.00	-87.82%	
2049	-181.40	0.00	-94.00%	
2050	-181.40	0.00	-100.40%	
2051	-181.40	0.00	-107.02%	
2052	-181.40	0.00	-113.85%	
2053	-181.40	0.00	-120.90%	
2054	-181.40	0.00	-128.17%	
2055	-181.40	0.00	-135.65%	
2056	-181.40	0.00	-143.35%	
2057	-181.40	0.00	-151.27%	
2058	-181.40	0.00	-159.41%	
2059	-181.40	0.00	-167.76%	
2060	-181.40	0.00	-176.33%	
2061	-181.40	0.00	-185.11%	

RM-5 rad

radical formula for annual reduction rates

correcting factor	0.5
cumulative budget 2020 - 2100 in Mill. t	19,435
scenario sum emissions 2020 - 2100 in Mill. t	19,435
E_min in Mill. t	-181.4
scenario emissions in year 2100 in Mill. t	-181.4
RR_20; input value sheet "goal seek"	**-2.38%**
free paramter	**-0.0332**

	CO2 emissions in Mill. t	absolute change vs. prev. year in Mill. t	relative change vs. prev. year	
	see formula below E_t	$E_t - E_{t-1}$	*see formula below*	*actual* RR_t
2019	3,023.61			
2020	2,951.71	-71.90	-2.38%	-2.38%
2021	2,812.24	-139.47	-4.73%	-4.73%
2022	2,631.04	-181.20	-6.44%	-6.44%
2023	2,430.39	-200.65	-7.63%	-7.63%
2024	2,221.68	-208.71	-8.59%	-8.59%
2025	2,012.42	-209.26	-9.42%	-9.42%
2026	1,807.91	-204.51	-10.16%	-10.16%
2027	1,611.92	-195.98	-10.84%	-10.84%
2028	1,427.07	-184.86	-11.47%	-11.47%
2029	1,255.03	-172.03	-12.06%	-12.06%
2030	1,096.79	-158.24	-12.61%	-12.61%
2031	952.74	-144.05	-13.13%	-13.13%
2032	822.85	-129.90	-13.63%	-13.63%
2033	706.72	-116.13	-14.11%	-14.11%
2034	603.72	-102.99	-14.57%	-14.57%
2035	513.06	-90.66	-15.02%	-15.02%
2036	433.81	-79.25	-15.45%	-15.45%
2037	365.01	-68.81	-15.86%	-15.86%
2038	305.65	-59.36	-16.26%	-16.26%
2039	254.74	-50.90	-16.65%	-16.65%
2040	211.35	-43.40	-17.04%	-17.04%
2041	174.56	-36.79	-17.41%	-17.41%
2042	143.54	-31.02	-17.77%	-17.77%
2043	117.53	-26.01	-18.12%	-18.12%
2044	95.82	-21.71	-18.47%	-18.47%
2045	74.12	-21.71	-18.81%	-22.65%
2046	52.41	-21.71	-19.14%	-29.29%
2047	30.71	-21.71	-19.46%	-41.41%
2048	9.00	-21.71	-19.78%	-70.69%
2049	-12.71	-21.71	-20.10%	
2050	-34.41	-21.71	-20.41%	
2051	-56.12	-21.71	-20.71%	
2052	-77.82	-21.71	-21.01%	
2053	-99.53	-21.71	-21.30%	
2054	-121.23	-21.71	-21.59%	
2055	-142.94	-21.71	-21.87%	
2056	-164.65	-21.71	-22.15%	
2057	-181.40	-16.75	-22.43%	
2058	-181.40	0.00	-22.70%	
2059	-181.40	0.00	-22.97%	
2060	-181.40	0.00	-23.24%	
2061	-181.40	0.00	-23.50%	

RM-6 abs

constant absolute annual change

cumulative budget 2020 - 2100 in Mill. t	19,435
scenario sum emissions 2020 - 2100 in Mill. t	19,435
E_min in Mill. t	-181.4
scenario emissions in year 2100 in Mill. t	-181.4
RR_20; info	**-4.76%**
free paramter	**-143.80**

	CO_2 emissions in Mill. t	absolute change vs. prev. year in Mill. t		relative change vs. prev. year
	see formula below E_t	$E_t - E_{t-1}$	*actual* $E_t - E_{t-1}$	RR_t
2019	3,023.61			
2020	2,879.81	-143.80	-143.80	-4.76%
2021	2,736.00	-143.80	-143.80	-4.99%
2022	2,592.20	-143.80	-143.80	-5.26%
2023	2,448.40	-143.80	-143.80	-5.55%
2024	2,304.60	-143.80	-143.80	-5.87%
2025	2,160.79	-143.80	-143.80	-6.24%
2026	2,016.99	-143.80	-143.80	-6.66%
2027	1,873.19	-143.80	-143.80	-7.13%
2028	1,729.39	-143.80	-143.80	-7.68%
2029	1,585.58	-143.80	-143.80	-8.32%
2030	1,441.78	-143.80	-143.80	-9.07%
2031	1,297.98	-143.80	-143.80	-9.97%
2032	1,154.18	-143.80	-143.80	-11.08%
2033	1,010.37	-143.80	-143.80	-12.46%
2034	866.57	-143.80	-143.80	-14.23%
2035	722.77	-143.80	-143.80	-16.59%
2036	578.97	-143.80	-143.80	-19.90%
2037	435.16	-143.80	-143.80	-24.84%
2038	291.36	-143.80	-143.80	-33.05%
2039	147.56	-143.80	-143.80	-49.36%
2040	3.76	-143.80	-143.80	-97.45%
2041	-140.05	-143.80	-143.80	
2042	-181.40	-143.80	-41.35	
2043	-181.40	-143.80		
2044	-181.40	-143.80		
2045	-181.40	-143.80		
2046	-181.40	-143.80		
2047	-181.40	-143.80		
2048	-181.40	-143.80		
2049	-181.40	-143.80		
2050	-181.40	-143.80		
2051	-181.40	-143.80		
2052	-181.40	-143.80		
2053	-181.40	-143.80		
2054	-181.40	-143.80		
2055	-181.40	-143.80		
2056	-181.40	-143.80		
2057	-181.40	-143.80		
2058	-181.40	-143.80		
2059	-181.40	-143.80		
2060	-181.40	-143.80		
2061	-181.40	-143.80		

	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	-194.12%	-181.40	0.00	-23.76%	-181.40	-143.80
2063	-181.40	0.00	-203.34%	-181.40	0.00	-24.02%	-181.40	-143.80
2064	-181.40	0.00	-212.77%	-181.40	0.00	-24.27%	-181.40	-143.80
2065	-181.40	0.00	-222.43%	-181.40	0.00	-24.52%	-181.40	-143.80
2066	-181.40	0.00	-232.30%	-181.40	0.00	-24.77%	-181.40	-143.80
2067	-181.40	0.00	-242.39%	-181.40	0.00	-25.01%	-181.40	-143.80
2068	-181.40	0.00	-252.69%	-181.40	0.00	-25.25%	-181.40	-143.80
2069	-181.40	0.00	-263.21%	-181.40	0.00	-25.49%	-181.40	-143.80
2070	-181.40	0.00	-273.95%	-181.40	0.00	-25.73%	-181.40	-143.80
2071	-181.40	0.00	-284.90%	-181.40	0.00	-25.97%	-181.40	-143.80
2072	-181.40	0.00	-296.08%	-181.40	0.00	-26.20%	-181.40	-143.80
2073	-181.40	0.00	-307.47%	-181.40	0.00	-26.43%	-181.40	-143.80
2074	-181.40	0.00	-319.07%	-181.40	0.00	-26.66%	-181.40	-143.80
2075	-181.40	0.00	-330.90%	-181.40	0.00	-26.88%	-181.40	-143.80
2076	-181.40	0.00	-342.94%	-181.40	0.00	-27.11%	-181.40	-143.80
2077	-181.40	0.00	-355.19%	-181.40	0.00	-27.33%	-181.40	-143.80
2078	-181.40	0.00	-367.67%	-181.40	0.00	-27.55%	-181.40	-143.80
2079	-181.40	0.00	-380.36%	-181.40	0.00	-27.77%	-181.40	-143.80
2080	-181.40	0.00	-393.26%	-181.40	0.00	-27.98%	-181.40	-143.80
2081	-181.40	0.00	-406.39%	-181.40	0.00	-28.20%	-181.40	-143.80
2082	-181.40	0.00	-419.73%	-181.40	0.00	-28.41%	-181.40	-143.80
2083	-181.40	0.00	-433.29%	-181.40	0.00	-28.62%	-181.40	-143.80
2084	-181.40	0.00	-447.07%	-181.40	0.00	-28.83%	-181.40	-143.80
2085	-181.40	0.00	-461.06%	-181.40	0.00	-29.04%	-181.40	-143.80
2086	-181.40	0.00	-475.27%	-181.40	0.00	-29.24%	-181.40	-143.80
2087	-181.40	0.00	-489.69%	-181.40	0.00	-29.45%	-181.40	-143.80
2088	-181.40	0.00	-504.34%	-181.40	0.00	-29.65%	-181.40	-143.80
2089	-181.40	0.00	-519.20%	-181.40	0.00	-29.85%	-181.40	-143.80
2090	-181.40	0.00	-534.27%	-181.40	0.00	-30.05%	-181.40	-143.80
2091	-181.40	0.00	-549.57%	-181.40	0.00	-30.25%	-181.40	-143.80
2092	-181.40	0.00	-565.08%	-181.40	0.00	-30.44%	-181.40	-143.80
2093	-181.40	0.00	-580.81%	-181.40	0.00	-30.64%	-181.40	-143.80
2094	-181.40	0.00	-596.75%	-181.40	0.00	-30.83%	-181.40	-143.80
2095	-181.40	0.00	-612.91%	-181.40	0.00	-31.03%	-181.40	-143.80
2096	-181.40	0.00	-629.29%	-181.40	0.00	-31.22%	-181.40	-143.80
2097	-181.40	0.00	-645.89%	-181.40	0.00	-31.41%	-181.40	-143.80
2098	-181.40	0.00	-662.70%	-181.40	0.00	-31.60%	-181.40	-143.80
2099	-181.40	0.00	-679.73%	-181.40	0.00	-31.79%	-181.40	-143.80
2100	-181.40	0.00	-696.98%	-181.40	0.00	-31.97%	-181.40	-143.80
sum	**19,435**			**19,435**			**19,435**	
	-10,585	negative emissions in Mill. t		-8,691	negative emissions in Mill. t		-10,843	negative emissions in Mill. t

M-2 exp	RM-3 lin	RM-4 quadr
nnual 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)

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

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	$a \ge 0$	► concave
RM-4 quadr[4]	$RR_t = a * (t - (BY + 1))^2 + RR_{BY+1}$	$y = ax^2 + b$	$a \le 0$	
RM-5 rad[5]	$RR_t = a * \sqrt{t - (BY + 1) - 0.5} + RR_{BY+1}$	$y = a\sqrt{x} + b$	$a \le 0$	► convex
RM-3 lin	$RR_t = a * \left(t - (BY + 1)\right) + RR_{BY+1} = RR_{t-1} + a$	$y = ax + b$	$a \le 0$	► linear
RM-1 const	$RR_t = a$	$y = a$	$a \le 0$	► 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: $E_t = \max\left(E_{min};\ E_{t-1} + RA\right)$

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