

Necessary Change in CO2 Emissions per GDP to Reach 1.5°C-2.0°C Climate Change Limit in 2100

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Version 1.1.1, 30 October 2022

DOI:10.5281/zenodo.7264421

all versions DOI:10.5281/zenodo.7264420

Abstract

The necessary cumulative CO2 emissions reduction to reach the 1.5°C Global Warming limit in 2100 is 2,353,587 MtCO₂. This may be done by decreasing the world's CO2 emissions per GDP (Cp\$) annually by 18%.

The necessary cumulative CO2 emissions reduction to reach the 1.7°C Global Warming limit in 2100 is 2,086,161 MtCO₂. This may be done by decreasing the world's CO2 emissions per GDP (Cp\$) annually by 9.34%.

The necessary cumulative CO2 emissions reduction to reach the 2.0°C Global Warming limit in 2100 is 1,684,038 MtCO₂. This may be done by decreasing the world's CO2 emissions per GDP (Cp\$) annually by 5.91%.

Keywords: Climate Change, Global Warming, CO2 emissions, CO2 per GDP, GDP per capita, Global Warming forecast

Glossary

ΔCO_2	CO2 emissions of the country above the world emissions per capita in the period 1991-2020, tCO2
$\Delta\text{CO}_2/\text{y}$	change in CO2 emissions per year
$\Sigma\Delta\text{CO}_2/\text{y}$	cumulative change in CO2 emissions per year in 2100 in the mitigation program
$\Sigma\Sigma\Delta\text{CO}_2/\text{y}$	sum of cumulative (2026-2100) change in CO2 emissions per year in the mitigation program
Ave	average
BAU	Business As Usual
BL	baseline
CCO2	global cumulative CO2 emissions according to publication [1] [2], CO2 emissions produced from fossil fuels and cement production only – land use change is not included, tCO2
CO2	emissions of Carbon Dioxide, CO2
CO2→GW	correlation between cumulative CO2 emissions and Global Warming = 0.000745°C/GtCO2 [4]
Cp\$	CO2 emissions per GDP, tCO2/y,\$ (ton CO2 per year, per \$2017)
Global Warming	global surface temperature change over land+ocean above 1850-1900 baseline (°C)
GDP	Gross Domestic Product, constant international \$(2017)
GtCO2	Giga-ton of CO2, 10 ⁹ ton, 10 ⁹ ton, 1,000,000,000 ton of CO2
ktCO2	kilo-ton CO2 = 10 ³ ton, 10 ³ ton, 1,000 ton CO2
MtCO2	Mega-ton CO2 = 10 ⁶ ton, 10 ⁶ ton, 1,000,000 ton CO2
OWID	Our World in Data – Internet site [1] [2]
Ref	reference
tCO2	ton CO2

tCO2/y,cap ton CO2 per year, per capita

WB World Bank

Formula for Average Annual Change

Formula 1 - Average annual change of parameter X in the period 1990-2020
[%/year]

$$rX = (X2/X1)^{(1/(y2-y1))} - 1$$

rX average annual change of parameter X in the period from y1 to y2,
%/year
X1 value of parameter X at the beginning of the period
X2 value of parameter X at the end of the period
y1 beginning of the period = 1990
y2 end of the period = 2020

Correlation between Cumulative CO2 Emissions and Global Warming

The correlation between cumulative CO2 emissions and Global Warming was analyzed in the publication "*Global Warming and Cumulative CO2*" [4].

Formula 2 - Correlation between Cumulative CO2 Emissions and Global Warming
[4] [°C/GtCO2]

$$CO2 \rightarrow GW = 0.000745^\circ C / GtCO2$$

Sources of Data

The datasets are from the following sources:

- OWID [1] [2] CO2 emissions produced from fossil fuels and cement production only – land use change is not included
- World Bank (WB) [3] GDP, PPP (constant 2017 international \$)

Dataset

Table 1 - [Dataset \[1\] \[2\] \[3\]](#)

	CO2 emissions	GDP
Source of data	OWID	World Bank
Reference	[1] [2]	[3]
From year	1990	1990
To year	2020	2020
CO2 from fossil fuels	Yes	
CO2 from cement production	Yes	
CO2 from other sources	No	
Other GHG	No	
Land use change	No	
Units	Mt O2/y	Constant International \$ 2017
Resolution	1 ktCO2/y	1 Constant International \$ 2017

The CO2 emissions dataset is from publication [1] [2], CO2 emissions produced from fossil fuels and cement production only – land use change is not included.

Table 2 - [CO2 emissions dataset without international transport \[1\] \[2\]](#)
[\[MtCO2/y\]](#)

		1990	2020
countries		192	192
dataset countries' CO2 emissions	MtCO2/y	22,023	33,654
world CO2 emissions	MtCO2/y	22,192	33,803
dataset/world	MtCO2/y	99.24%	99.56%

Table 3 - [GDP dataset \[3\] \[M\\$GDP/y\]](#)

		1990	2020
countries		192	192
dataset countries' GDP	M\$GDP/y	50,994,261	125,514,935
world GDP	M\$GDP/y	51,241,011	126,318,951
dataset/world	M\$GDP/y	99.52%	99.36%

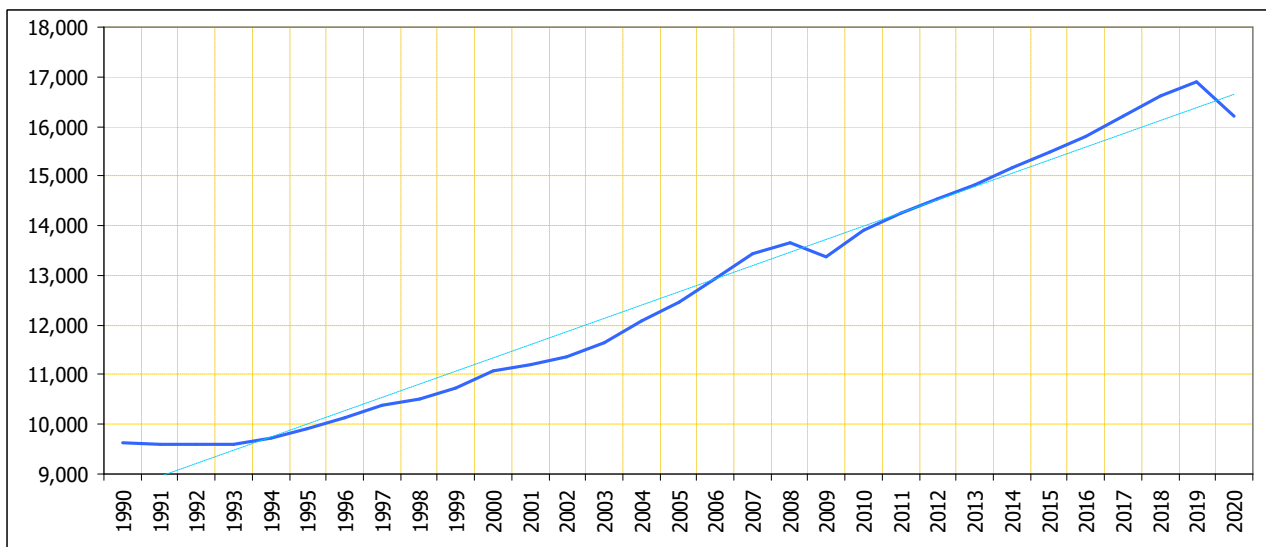
GDP per Capita and CO2 Emissions per GDP 1990-2020

GDP per capita and CO2 emissions per GDP in the period 1990-2020 were analyzed in the publication "CO2 Emissions per GDP" [6]

Table 4 - World Averages [1] [2] [3]

		1990	2020	2020/1990	change 1990-2020 %/year
Population		5,327,529,078	7,794,798,725	146%	1.277%
CO2 emissions	MtCO2/y	22,192	33,803	152%	1.413%
CO2 per Capita	tCO2/y,cap	4.17	4.34	104%	0.134%
GDP	M\$/y	51,241,011	126,318,951	247%	3.053%
GDP per Capita	\$/y,cap	9,618	16,206	168%	1.754%
CO2 per GDP	tCO2/\$GDP	0.000433	0.000268	62%	-1.592%

Chart 1 - GDP per capita 1990-2020 [1] [2] [8] [\$GDP per year, per capita]

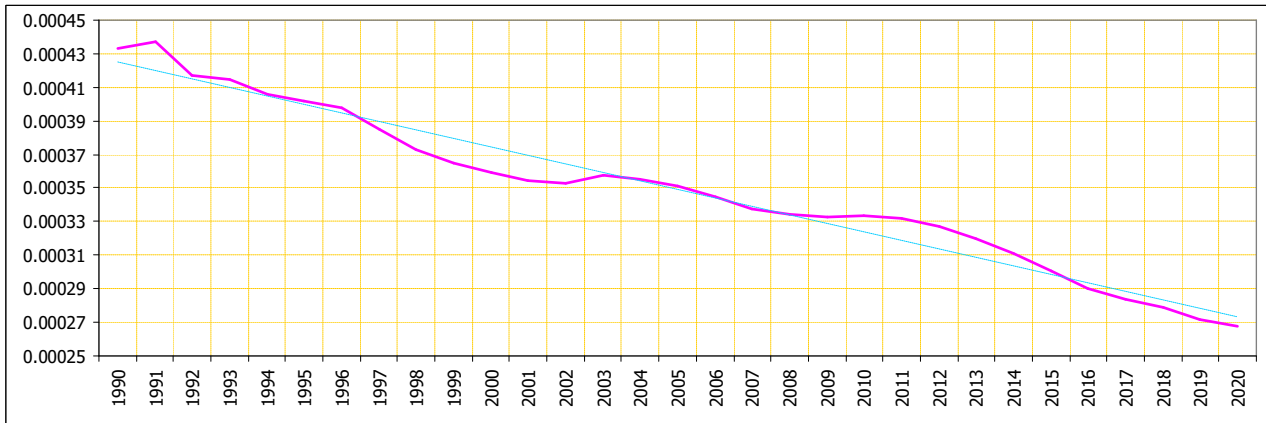


The world's CO2 emissions are without international transport.

The average annual changes were calculated using Formula 1.

The average change in CO2 per GDP in the period 1990-2020 is -1.592% per year (decreasing).

Chart 2 - World CO2 emissions per GDP [1] [2] [3] [tCO2 per year, per \$GDP]



Cumulative Global CO2 Emissions

The CO2 emissions dataset [1] [2] was converted to the 1875 baseline in publication [5].

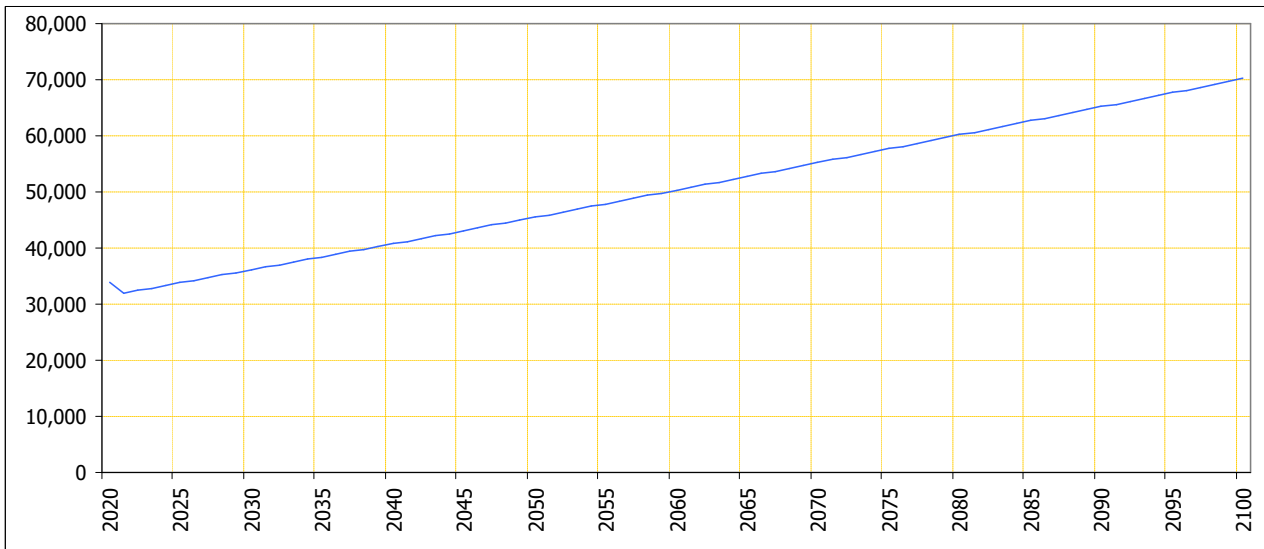
Table 5 - Global cumulative CO2 emissions and international transport [5] [tCO2 above 1875 baseline]

		1990	2020
Global cumulative CO2 emissions including international transport	tCO2	792,689,057,443	1,681,608,597,211
International transport cumulative CO2 emissions	tCO2	16,042,804,984	43,700,803,946
Global cumulative CO2 emissions without international transport	tCO2	776,646,252,459	1,637,907,793,265

CO2 Emissions Forecast

The CO2 emissions forecast for 2020-2100 is from the publication "CO2 Emission per GDP Forecast 2020-2100" [7].

Chart 3 - CO2 emissions per year without international transport BAU forecast 2020-2100 [MtCO2/y] [7]

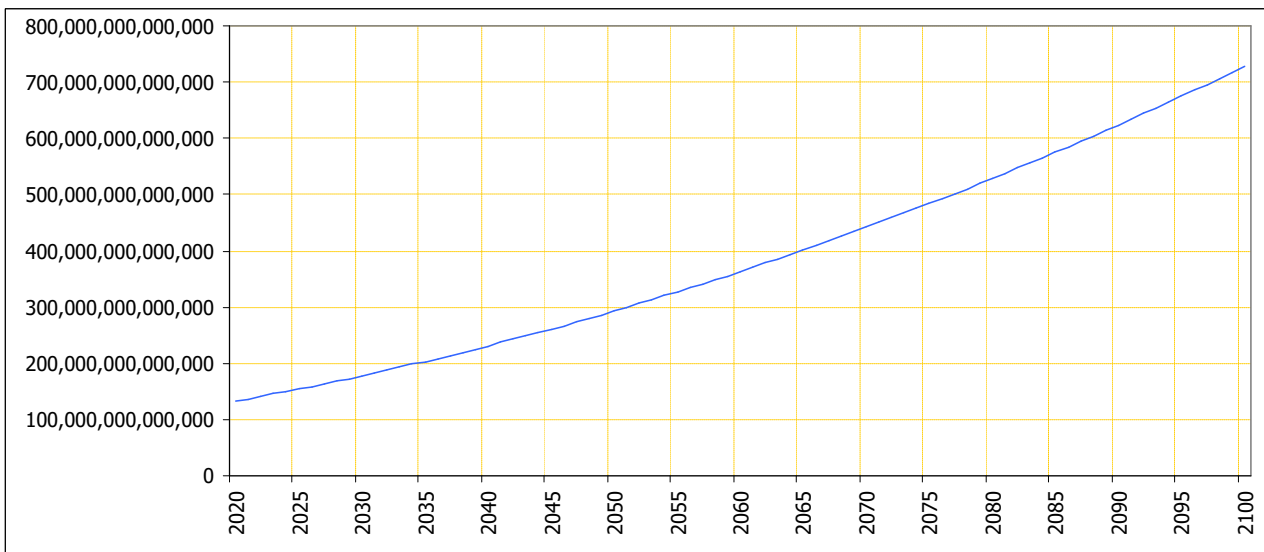


The dataset of CO2 emissions forecast for 2020-2100 is available in the publication [8].

World GDP Forecast

GDP forecast for 2020-2100 is from the publication "CO2 Emission per GDP Forecast 2020-2100" [7].

Chart 4 - World GDP/y forecast 2020-2100 [7]



The dataset of the world GDP forecast for 2020-2100 is available in the publication [8].

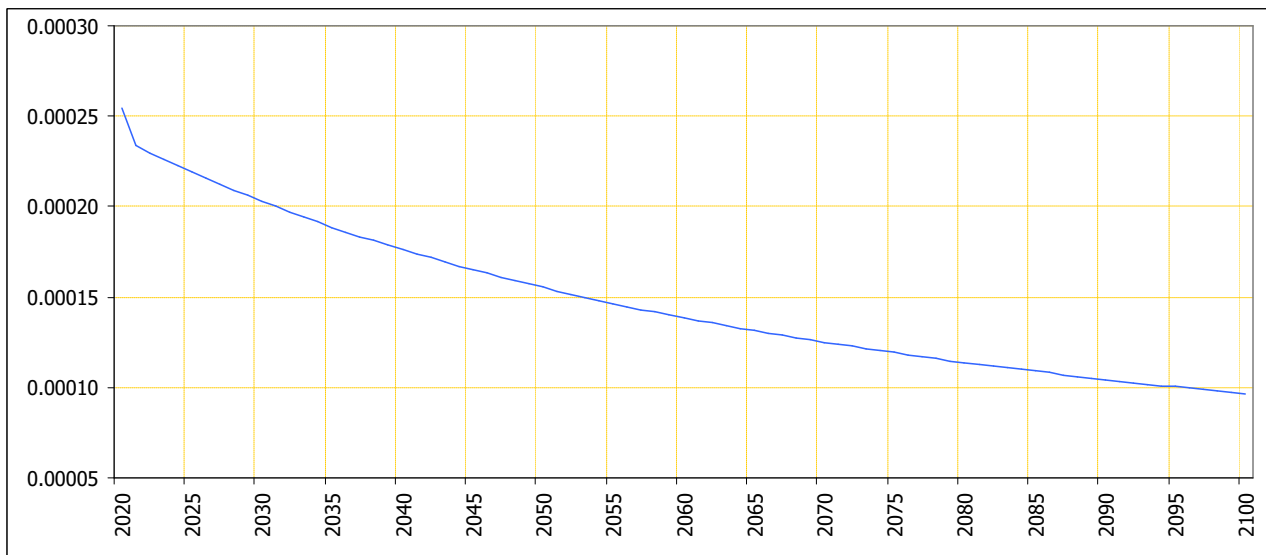
CO2 Emissions per GDP forecast

CO2 Emissions per GDP are calculated by dividing the CO2 emissions without international transport per year, by GDP in the same year.

Table 6 - CO2 emissions per GDP forecast

		1990	2020	2100
CO2 emissions per year without international transport	tCO2/y	22,191,664,636	33,803,026,586	70,191,421,088
World GDP	\$GDP/y	51,241,010,872,505	126,318,951,010,345	728,126,523,404,062
CO2 emissions per GDP	tCO2/\$GDP	0.000433	0.000268	0.000096

Chart 5 - CO2 emissions per GDP 2020-2100 [tCO2/\$GDP]



The dataset of CO2 emissions per GDP forecast for 2020-2100 is available in the publication [8].

BAU Average Annual Change in Cp\$

Table 7 - BAU average annual change in Cp\$

		1990	2020
CO2 emissions per year	tCO2/y	22,191,664,636	33,803,026,586
GDP	\$GDP/y	51,241,010,872,505	126,318,951,010,345
Cp\$	tCO2/\$GDP	0.000433	0.000268
average annual change in Cp\$	%/year		-1.592%

Business as Usual Forecast for 2025

It is assumed in this work that the CO2 mitigation measures additional to BAU will not start before the end of 2025.

Table 8 - BAU forecast for 2025 [5]

Year	without International Transport				International Transport MtCO2/y	Global	
	GDP	Cp\$	CO2/y	CCO2 BL1875		CCO2 BL1875 MtCO2	GW BL1850-1900 °C
		tCO2/\$GDP	MtCO2/y	MtCO2			
2020	132,918,157,185,392	0.000254	33,803	1,613,287	1,004	1,656,988	1.235
2021	137,023,952,204,136	0.000233	31,995	1,645,282	1,024	1,690,007	1.260
2022	141,214,160,123,108	0.000230	32,444	1,677,726	1,044	1,723,495	1.285
2023	145,488,780,942,308	0.000226	32,894	1,710,619	1,065	1,757,454	1.310
2024	149,847,814,661,735	0.000223	33,345	1,743,964	1,086	1,791,885	1.336
2025	154,291,261,281,390	0.000219	33,797	1,777,761	1,108	1,826,789	1.362

Necessary Annual Change in CO2 Emissions per GDP to Reach 1.5°C Global Warming Limit in 2100

Table 9 - Years to Global Warming 1.5°C

$\Delta Cp\$/y$	year	$\Delta CO_2/y$	$\Delta CO_2/y$	$\Sigma \Delta CO_2/y$	$\Sigma \Sigma \Delta CO_2/y$	GW in 2100
%/y	GW=1.5°C	2026	2026	2100	2026-2100	BL1850-1900
		%/y	MtCO2/y	MtCO2/y	MtCO2/y	°C
-1.592%	2031	+1.296%	+438	14,069	780,971	+3.837
-10%	2033	-7.359%	-2,487	-33,738	-2,126,985	+1.669
-15%	2037	-12.506%	-4,227	-33,796	-2,301,846	+1.539
-17%	2042	-14.564%	-4,922	-33,797	-2,338,698	+1.512
-18%	2085	-15.594%	-5,270	-33,797	-2,353,587	+1.500

$\Delta Cp\$/y$ average annual change in Cp\$ 2025-2100, %/y
 year GW=1.5°C year when Global Warming will reach 1.5°C
 $\Delta CO_2/y$ 2026 change in CO2 emissions per year in 2026
 $\Sigma \Delta CO_2/y$ cumulative change in CO2 emissions per year in 2100
 $\Sigma \Sigma \Delta CO_2/y$ sum of cumulative (2026-2100) change in CO2 emissions per year
 GW in 2100 Global Warming in 2100 above 1850-1900 baseline

Necessary Annual Change in CO2 Emissions per Capita to Reach 1.7°C Global Warming Limit in 2100

Table 10 - Years to Global Warming 1.7°C

ΔC_p /y	year	Countries	ΔCO_2 /y	$\Sigma \Delta CO_2$ /y	$\Sigma \Sigma \Delta CO_2$ /y	GW in 2100
%/y	GW=1.7°C	ΔCO_2 /y	2026	2100	2026-2100	BL1850-1900
		%/y	MtCO ₂ /y	MtCO ₂ /y	MtCO ₂ /y	°C
-1.592%	2031	+1.296%	+438	14,069	780,971	+3.837
-5%	2042	-2.212%	-5,270	-30,393	-1,469,069	+2.160
-9%	2066	-6.329%	-5,270	-33,662	-2,062,239	+1.718
-9.340%	2099	-6.679%	-5,270	-33,695	-2,086,161	+1.700

year GW=1.7°C

year when Global Warming will reach 1.7°C

Necessary Annual Change in CO2 Emissions per Capita to Reach 2.0°C Global Warming Limit in 2100

Chart 6 - Years to Global Warming 2.0°C

ΔC_p /y	year	Countries	ΔCO_2 /y	$\Sigma \Delta CO_2$ /y	$\Sigma \Sigma \Delta CO_2$ /y	GW in 2100
%/y	GW=2.0°C	ΔCO_2 /y	2026	2100	2026-2100	BL1850-1900
		%/y	MtCO ₂ /y	MtCO ₂ /y	MtCO ₂ /y	°C
-1.592%	2031	+1.296%	+438	14,069	780,971	+3.837
-5%	2042	-2.212%	-5,270	-30,393	-1,469,069	+2.160
-5.910%	2100	-3.149%	-1,064	-32,143	-1,684,038	+2.000

year GW=2.0°C

year when Global Warming will reach 2.0°C

Scenarios of Annual Change in Cp\$

Chart 7 - Maximum CO2 emissions per GDP (Cp\$) [tCO2/GDP]

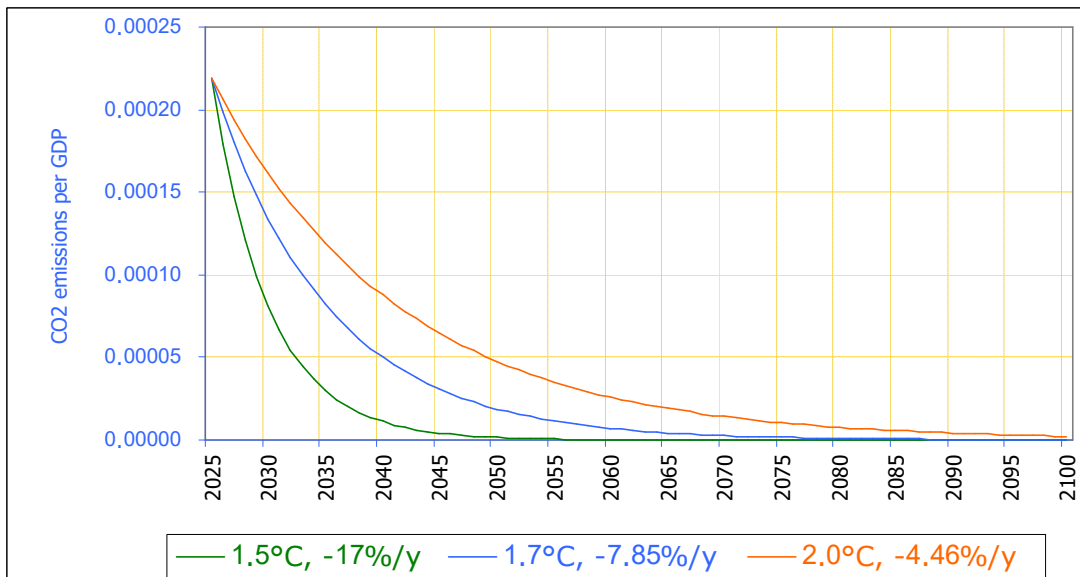


Chart 8 - Cumulative emissions reduction per year in scenarios of average annual change in Cp\$ [MtCO2/y]

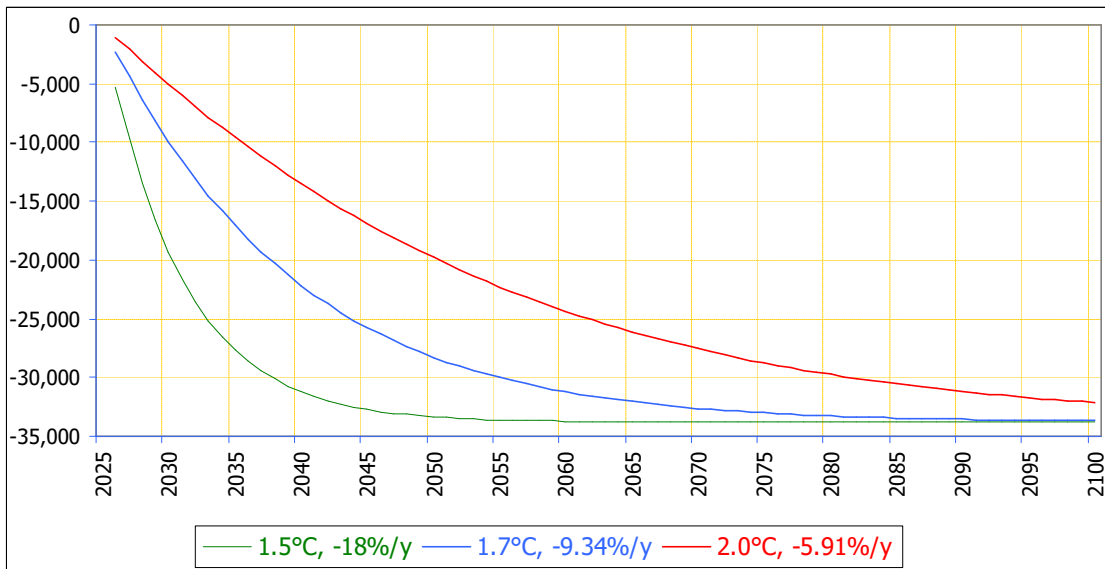


Chart 9 - Cumulative emissions reduction per period (2025-2100) in scenarios of average annual change in Cp\$ [MtCO2/period]

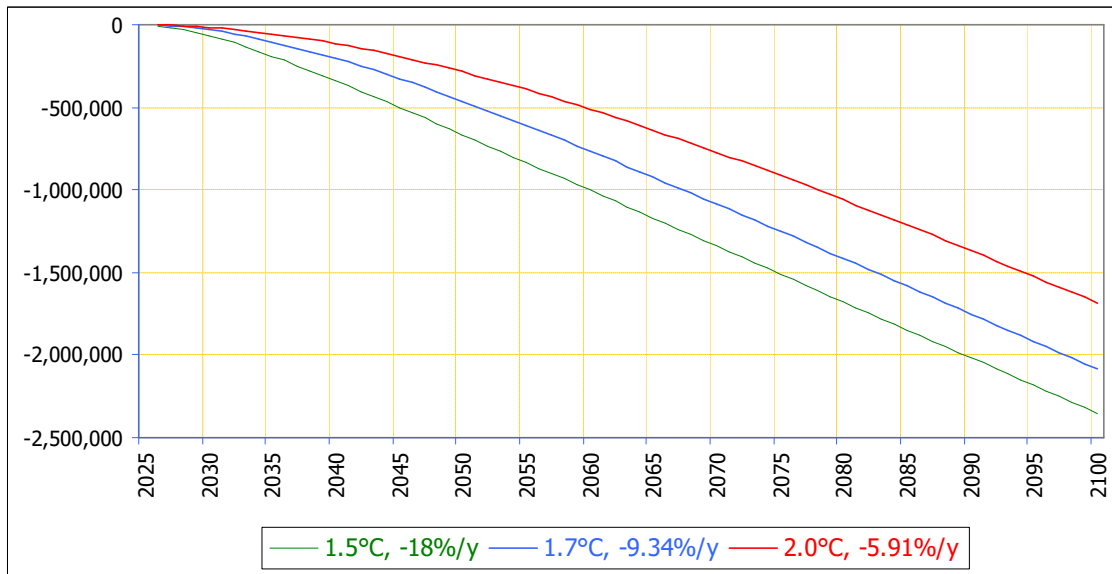


Chart 10 - Global Warming in scenarios of annual change in Cp\$ [°C]

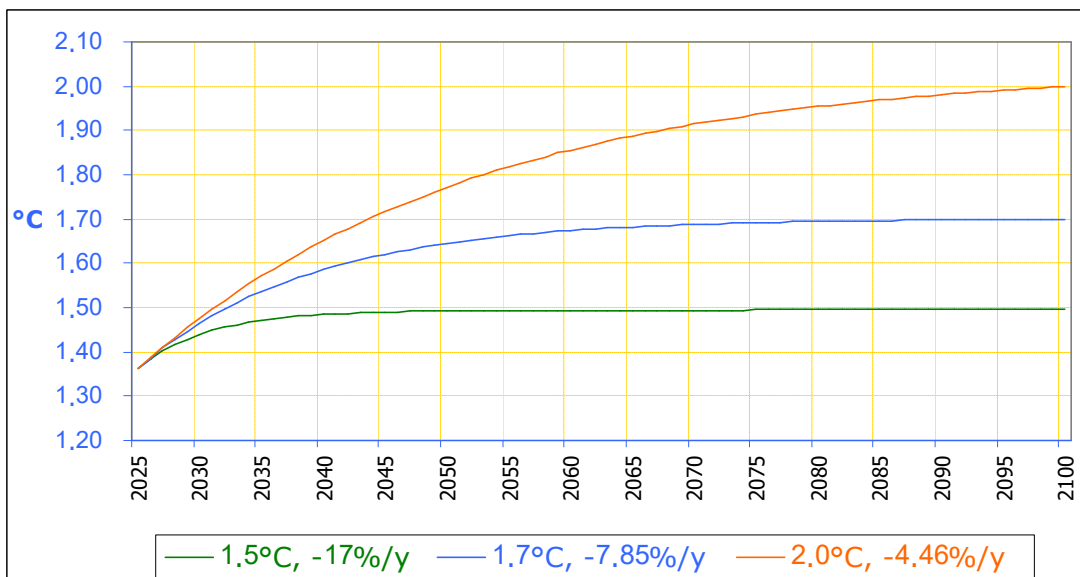


Table 11 - Maximum CO2 emissions per GDP (Cp\$) to reach 1.5°C-2.0°C Climate Change limit in 2100

Target	2.0°C	1.7°C	1.5°C
ΔCp\$/y	-4.46%	-7.85%	-17.00%
	%/y	%/y	%/y
2020	0.00025431	0.00025431	0.00025431
2021	0.00023350	0.00023350	0.00023350
2022	0.00022975	0.00022975	0.00022975
2023	0.00022609	0.00022609	0.00022609
2024	0.00022252	0.00022252	0.00022252
2025	0.00021905	0.00021905	0.00021905
2026	0.00020610	0.00019859	0.00017962
2027	0.00019392	0.00018004	0.00014729
2028	0.00018246	0.00016322	0.00012078
2029	0.00017168	0.00014798	0.00009904
2030	0.00016153	0.00013416	0.00008121
2031	0.00015198	0.00012163	0.00006659
2032	0.00014300	0.00011027	0.00005461
2033	0.00013455	0.00009997	0.00004478
2034	0.00012660	0.00009063	0.00003672
2035	0.00011912	0.00008217	0.00003011
2036	0.00011208	0.00007449	0.00002469
2037	0.00010545	0.00006753	0.00002024
2038	0.00009922	0.00006123	0.00001660
2039	0.00009336	0.00005551	0.00001361
2040	0.00008784	0.00005032	0.00001116
2041	0.00008265	0.00004562	0.00000915
2042	0.00007776	0.00004136	0.00000751
2043	0.00007317	0.00003750	0.00000615
2044	0.00006884	0.00003400	0.00000505
2045	0.00006478	0.00003082	0.00000414
2046	0.00006095	0.00002794	0.00000339
2047	0.00005734	0.00002533	0.00000278
2048	0.00005396	0.00002297	0.00000228
2049	0.00005077	0.00002082	0.00000187
2050	0.00004777	0.00001888	0.00000153
2051	0.00004494	0.00001711	0.00000126
2052	0.00004229	0.00001552	0.00000103
2053	0.00003979	0.00001407	0.00000085
2054	0.00003744	0.00001275	0.00000069
2055	0.00003522	0.00001156	0.00000057
2056	0.00003314	0.00001048	0.00000047
2057	0.00003118	0.00000950	0.00000038
2058	0.00002934	0.00000862	0.00000031
2059	0.00002761	0.00000781	0.00000026
2060	0.00002598	0.00000708	0.00000021

target	2.0°C	1.7°C	1.5°C
ΔCp\$/y	-4.46%	-7.85%	-17.00%
	%/y	%/y	%/y
2061	0.00002444	0.00000642	0.00000017
2062	0.00002300	0.00000582	0.00000014
2063	0.00002164	0.00000528	0.00000012
2064	0.00002036	0.00000478	0.00000010
2065	0.00001915	0.00000434	0.00000008
2066	0.00001802	0.00000393	0.00000006
2067	0.00001696	0.00000356	0.00000005
2068	0.00001596	0.00000323	0.00000004
2069	0.00001501	0.00000293	0.00000004
2070	0.00001413	0.00000266	0.00000003
2071	0.00001329	0.00000241	0.00000002
2072	0.00001250	0.00000218	0.00000002
2073	0.00001177	0.00000198	0.00000002
2074	0.00001107	0.00000179	0.00000001
2075	0.00001042	0.00000163	0.00000001
2076	0.00000980	0.00000147	0.00000001
2077	0.00000922	0.00000134	0.00000001
2078	0.00000868	0.00000121	0.00000001
2079	0.00000816	0.00000110	0.00000000
2080	0.00000768	0.00000100	0.00000000
2081	0.00000723	0.00000090	0.00000000
2082	0.00000680	0.00000082	0.00000000
2083	0.00000640	0.00000074	0.00000000
2084	0.00000602	0.00000067	0.00000000
2085	0.00000566	0.00000061	0.00000000
2086	0.00000533	0.00000055	0.00000000
2087	0.00000501	0.00000050	0.00000000
2088	0.00000472	0.00000045	0.00000000
2089	0.00000444	0.00000041	0.00000000
2090	0.00000418	0.00000037	0.00000000
2091	0.00000393	0.00000034	0.00000000
2092	0.00000370	0.00000031	0.00000000
2093	0.00000348	0.00000028	0.00000000
2094	0.00000327	0.00000025	0.00000000
2095	0.00000308	0.00000023	0.00000000
2096	0.00000290	0.00000021	0.00000000
2097	0.00000273	0.00000019	0.00000000
2098	0.00000257	0.00000017	0.00000000
2099	0.00000241	0.00000015	0.00000000
2100	0.00000227	0.00000014	0.00000000

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