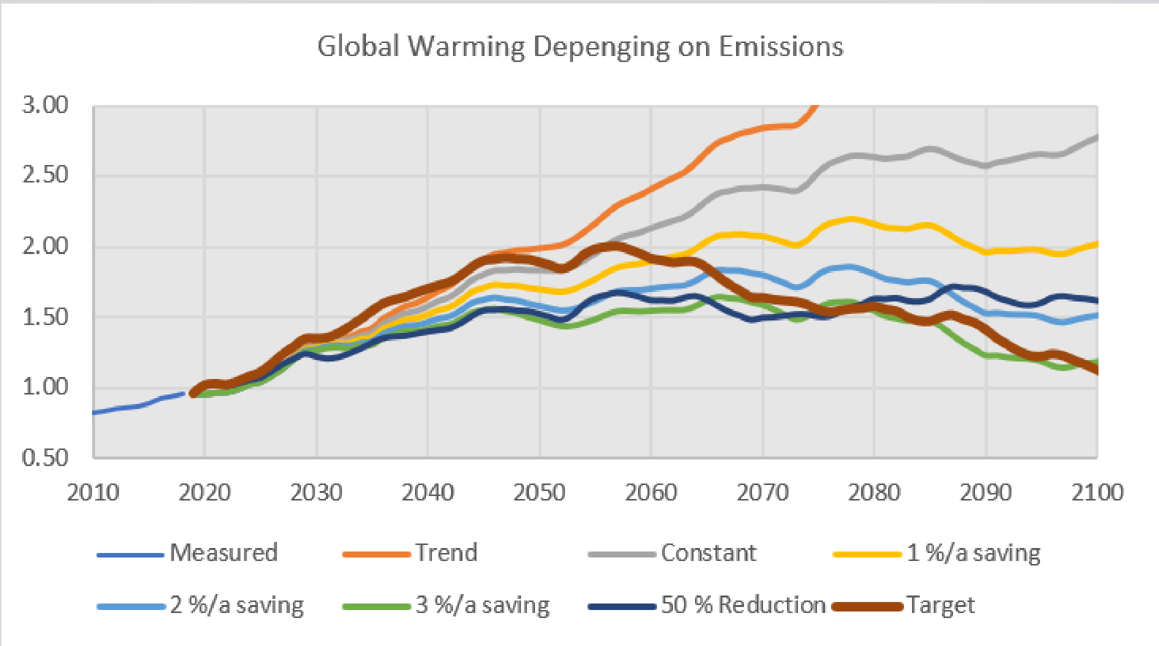
Fundamentals of Global Warming

2019 Edition

Asko Vuorinen



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Asko Vuorinen

Ekoenergo Oy

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Ekoenergo Oy is an energy service company, which established in 1979. It has been specialized in energy consulting and has published several books about energy and climate matters. The books can be found from home page at www.ekoenergo.fi

Contents

Preword 6

1 INTRODUCTION 8

2 AIR TEMPERATURES 13

2.1 Global land and sea air temperatures 13

2.2 Forecasting future warming 16

2.3 Air temperatures in Finland 19

3 SUNSPOTS AND SOLAR IRRADIANCE 29

3.1 Sunspots 29

3.2 Sunspot corrected global temperatures 32

3.3 Solar irradiance and global warming 36

3.4 Solar irradiance and temperature changes 42

3.5 Long term temperature measurements and irradiance 46

4 CARBON DIOXIDE 49

4.1 Concentration of CO_2 49

4.2 CO_2 emissions from fuels 51

4.3 CO2 emissions of forests and cement production 54

4.4 Forecasting CO_2-concentration using a linear model 59

4.5 Mass balance model 62

4.6 Forecasting CO_2 concentration using mass balance model 67

4.7 Forecasting CO_2 concentration until the year 2500 73

4.8 Radiative forcing by CO_2 74

4.9 Temperature rise using CO2 concentration as a variable 81

5 MODELLING GLOBAL WARMING USING TSI, CO_2 AND SO_2 84

5.1 Sulphur dioxide emissions 84

5.2 Influence of aerosols to global warming 86

5.3 Forecasting future global warming using the model 88

5.4 Comparing the model with IPCC models 95

6 CHANGES IN SEA WATER 100

6.1 Temperature rise in seawater 100

6.2 Atlantic Multidecadal Oscillation (AMO) 104

6.3 North Atlantic Oscillation (NAO) 106

6.4 Pacific Decadal Oscillation (PDO) 112

6.5 El Nino South Oscillation (ENSO) 114
7 CHANGES IN ICE CONDITIONS AND SEAWATER RISE 119
7.1 Declining of ice cover 119
7.2 Seawater rise 119
7.3 Temperature and sea level in the past 122
7.4 Future seawater rise 124
8 MILANKOVITCH CYCLES 125
8.1 Introduction 125
8.2 Climate changes in the past 130
8.3 Changes in earth's orbit in the future 134
8.4 Next ice age 137
9 TARGET PLAN FOR 2050 141
9.1 Targets 141
9.2 Action plans 143
9.3 Targets for individual countries 145
10 DECARBONIZE ELECTRICITY 149
10.1 World Electricity generation 149
10.2 CO2 emissions from electricity generation 151
10.3 Investments in new technologies 152
11 DECARBONIZING TRAFFIC 158
11.1 Consumption of light distillate oil 158
11.2 Cars on the roads 158
12 DECARBONIZING HOUSEHOLDS 163
12.1 Energy used by households 163
12.2 Zero emission log houses 165
13 INCREASING CARBON SINKS 169
13.1 Forests 169
13.2 Production of saw wood 171
13.3 Growing wood for energy and carbon sink 173
14 SCENARIOS FOR COUNTRIES 174
14.1 Targets for EU 174
14.2 Targets for USA 178
14.3 Targets for China 182
14.4 Targets for India 186

14.5 Targets for Middle East 191
14.6 Targets for Africa 195
14.7 Targets for other countries 199
14.8 Targets for Finland 203
15 ECOLOGICAL LIVING 208
15.1 CO2 emissions in a family 208
15.2 Ecological eating 210
15.3 CO2 emissions of a family 211
16 SUMMARY AND CONCLUSIONS 212

Preword

It seems to me that Global Warming is the biggest threat to the mankind and it has been very poorly understood. This is, why I started to describe global warming from the basic facts which can be found from any sources. After studying the subject my understanding is that immediate actions are needed to limit warming to 2.0 degrees by the year 2200.

One of the biggest reasons to write this book has been the disinformation, which has been spreading from many official and commercial sources. There are several "paid scientists", who speak as they have been paid to do. There are several groups, which want spread disinformation. One of them is the coal, oil and gas industries, which want to continue their businesses without any taxes or limitations.

There are also politicians, who spread disinformation to get votes for Presidential election: *"The concept of global warming was created by and for the Chinese in order to make U.S. manufacturing non-competitive",* was tweeted by Donald Trump November 2016. He said also that *the weather has been changing and will be changing*. This is true, but mankind has had its influence, which should be studied.

My perspective is to try to make my own analysis based on data from the main sources (Hadcrut4, GISS, and NOAA). I have no other objective than trying to understand global warming as it is happening. I have retired in 2010 from my previous companies, which were working in power plant planning. My only connection is to our own publishing company, Ekoenergo Oy.

I have studied measured temperatures and solar irradiance. This will lead to a conclusion that the changes in global temperature have been caused until 1960 mainly by the sun. After 1960 CO_2 has been the main contributor of the 0.96 deg. C increase until 2018 There is a logarithmic relationship with CO_2 concentration and temperature as well as a negative relationship with SO_2 emissions and temperature. However, the mass balance model developed by the author indicates that than global warming can be limited to 2 deg. C, if the global emissions will be reduced with 50 % by the year 2050.

This book is an e-book, which can be download free of charge from my publisher's home page at www.ekoenergo.fi. Ekoenergo is our own small publishing company which has been publishing my books since 2007, when I wrote my first book "*Planning of Optimal Power Systems*" First edition.

Espoo, November 2019

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1 INTRODUCTION

The temperature measurement data dates back only to the end of 19th century. However, some other marks of weather changes have been observed for more than 300 years. One of the things here in the North has been the time, when the ice cover has disappeared from the lakes and rivers.

Tornio River (in the border between Finland and Sweden) has lost its ice cover constantly earlier starting from the year 1700 (Figure 1.1.1).

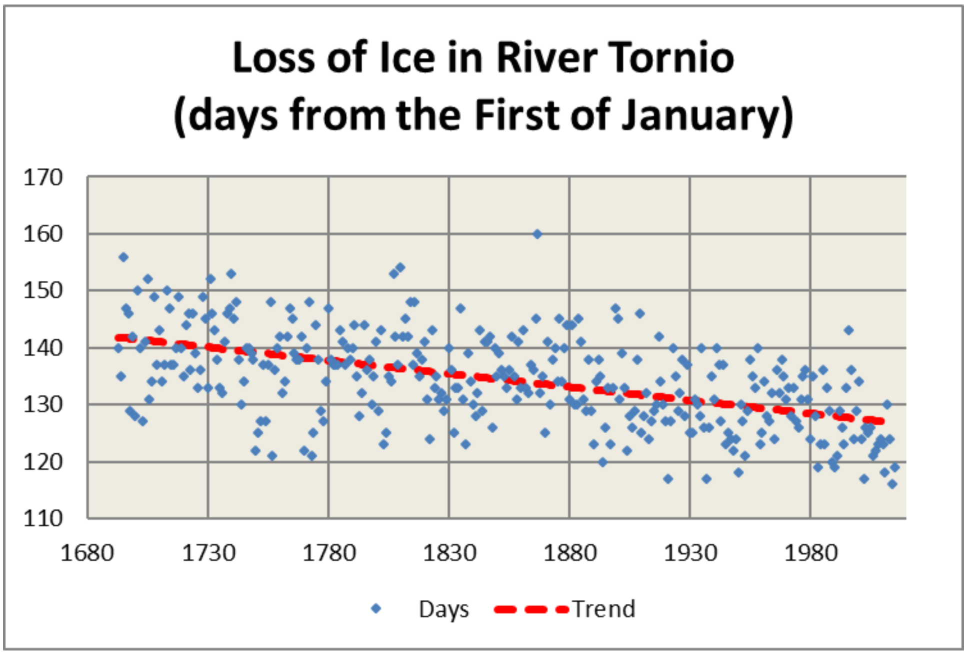

Figure 1.1.1 Days from the first of January when the ice was released from the River Tornio (Source: Esko Kuusisto, Finnish Environmental Center, SYKE).

The ice cover disappears now 14 days earlier then in the years 1700 – 1709. It is difficult to say, how large is the influence of the CO_2-emissions or any other human activity in this trend. The scientists have evaluated that the average spring temperature has increased in the Tornio area from 0.2 deg. C to 2.8 deg. C during 320-year time scale (from the year 1691 to 2011). The increase has been 2.6 deg. C or 0.88 deg. C per century.

The Little Ice Age

This temperature change has been blessing to the population of Finland. During the Little Ice Age worse years from 1695 to 1698 about 140.000 (28 %) of the Finnish 500.000 population died for hunger and diseases caused by hunger. The summer 1695 was very cold and during the summer 1996 frost game at August 19th in 1696 and hardly any crop was achieved. During the winter 1696-1697 about all of crop has been eaten and most of the cows. After cattle people stated eating horses and dogs.

The same kind of data has been found from proxies, which do not take into account tree rings (Figure 1.1.2). The weather has been warming now 300 years from the Little Ice Age. On the other hand, there was a warm period in the Middle age, when the Vikings travelled to Greenland and found America.

On the morning on 30th of January in 1658 Swedish King Charles X gave order for his troops to marc on ice over Belt in Denmark to Island of Fyn. The march continued also over the frozen Great Belt to Zealand and the main goal was arrive to Copenhagen, which was the place Danish troop. On 11th of February King and his troops arrived to Zealand. On February 28th the Treaty of Roskilde was signed and Denmark hade to give the Swedish King many parts of Denmark as result of this march.

River Thames was also freezing during the Little Ice Age years (Figure 1.1.2). The first recorded Frost Fair on the River Thames was arranged in winter 1607 – 1608. The fairs were arranged until the year 1814, whenever the river was frozen.

Figure 1.1.2 Frost fair on the river Thames in the winter 1683 – 1684.

During the Medieval years about AD 500 – 1100 the weather here in the North was much warmer than today. This was found by the fact that the scientists have found seeds of the earlier flowers and trees, which have disappeared from Finland. The Greenland got settlers from Scandinavia during years 980 – 1400. The last ship sailed from Greenland to Iceland in about 1410. The Little Ice Age had started. The population moved back to mainland.

IPCC documents

As International Panel of Climate Change started their studies they made estimates of historical temperatures using proxies. Their studies concluded that the temperature variation was similar than Figure 1.1.3 with high temperatures during AD 600 – 1200 and lower temperatures during years 1400 – 1900.

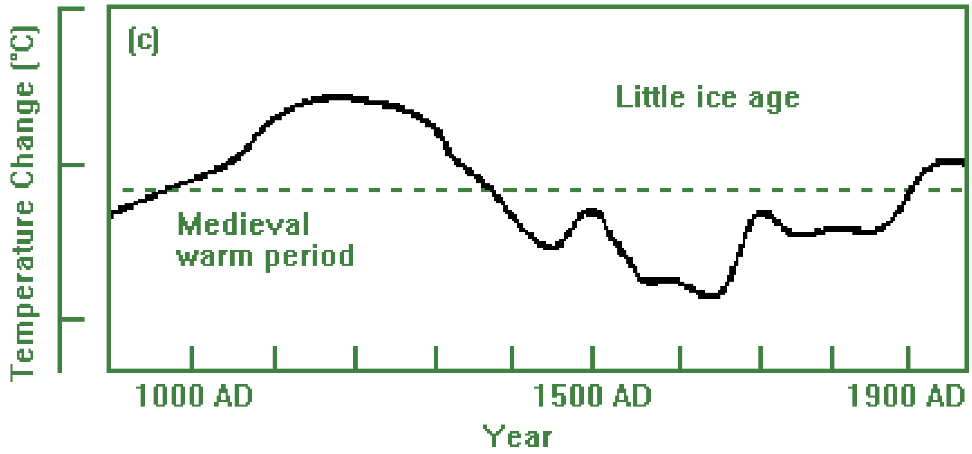

Figure 1.1.3 Temperature changes during the last 2000 years (The First IPCC report).

But in the third assessment report of IPCC from the year 2001 a hockey stick like curve was introduced (Figure 1.1.4). It indicated that the climate had becoming colder continuously until the year 1900 and after this the temperature has been rising constantly.

It seems that the hockey stick was discovered to prove the manmade warming after the year 1900. It was actually, man-made warming as it was based on reconstructed curve by **Michael E. Mann** et. al. Even the “instrumental data” (red curve in Figure 1.1.4) was behaving like the invented hockey stick. These curves showed to actual scientists that IPCC is a political organization which discovered its own “Inconvenient Truth” of the climate change. They were corrupted scientists who want to proof they opinions into the science.

Later, it was really found that so called scientists were not independent but in the control of the Governments of each country. So, it was also found that this story of global warming was false. The whole story should be re-evaluated and rewritten again. The first thing to find is the real temperature records, which correspond to the history records. They should also notice the warm period during medieval years 1000 – 1300 and very cold period during Little Ice Age years 1650 – 1700.

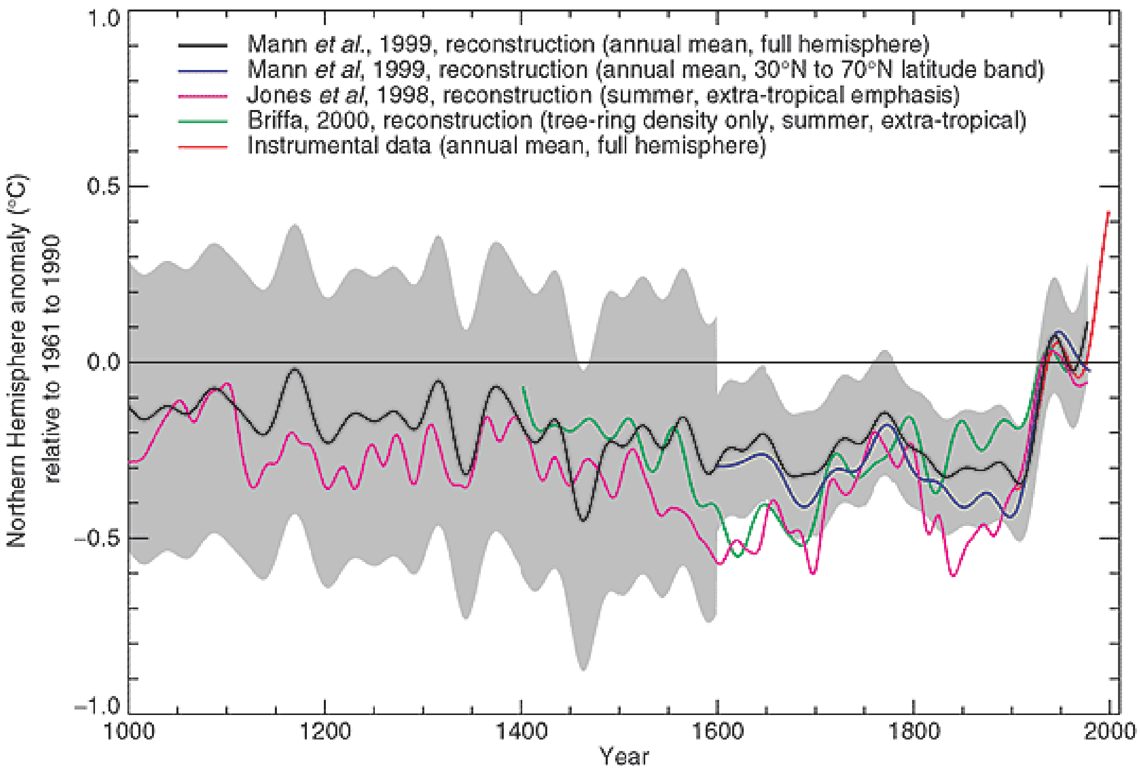

Figure 1.1.4 Hockey stick curve from IPCC third report from the year 2001. (http://www.grida.no/publications/other/ipcc_tar/?src=/climate/ipcc_tar/wg1/index.htm)
.

After studying the global temperature development, it seems that hockey stick curve like warming is really happening. It has not happened after 1850 but rather after 1980. The warming of global temperature has been caused until the year 1980 mainly because of the solar irradiance, which increased global temperature by about 0.3 deg. C in the years 1915 – 2004 (see Figures 3.2.5 and 3.4.8).

Other sources of disinformation

Many organizations are spreading disinformation for their own reasons. One source is studies funded by oil, coal and gas companies. These studies have been mainly funded to prove that the global warming has not been caused by carbon dioxide. Their main goal is to make profits with fossil fuels. Money talks!

Another source is politics, which want to get more votes to be elected as a president. On November 6, 2012 **Donald Trump** tweeted:

"The concept of global warming was created by and for the Chinese, in order, to make U.S. manufacturing non-competitive"

There are several sources of disinformation, which called as trolling. There is a hook for any kind of story, which is suitable for you.

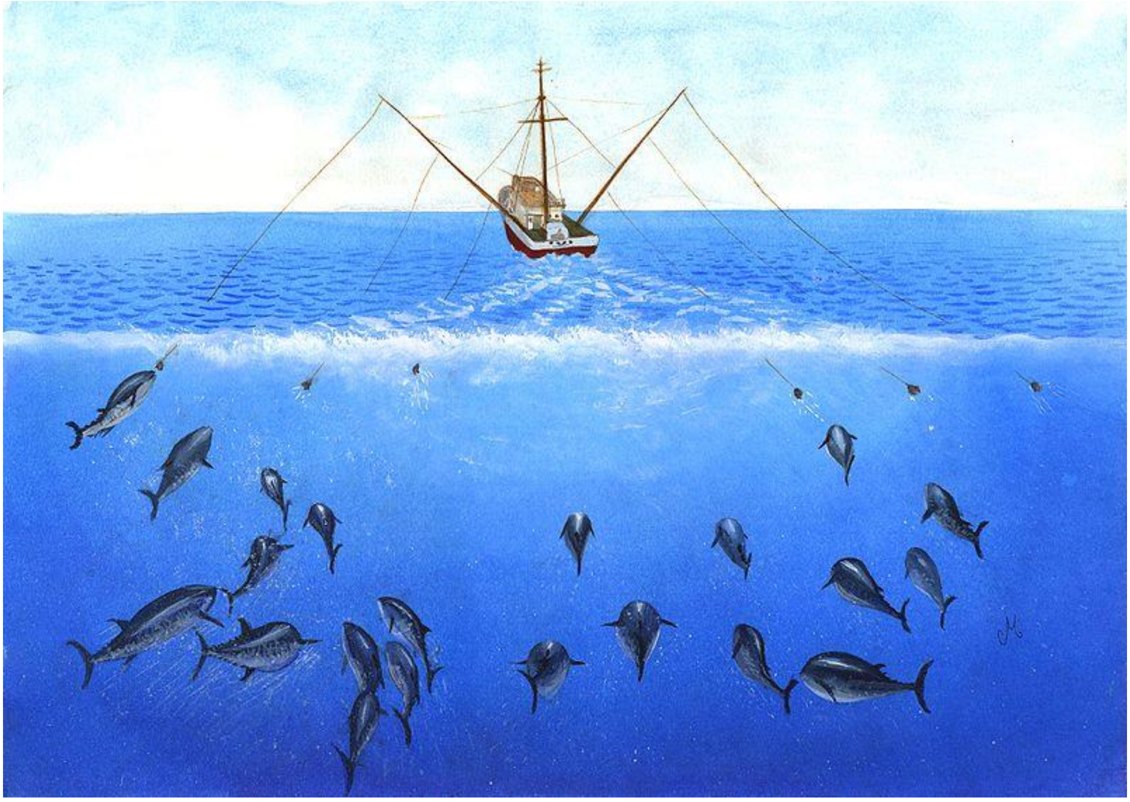

Figure 1.1.5 Trolling term comes from fishing.

2 AIR TEMPERATURES

2.1 Global land and sea air temperatures

I have used the temperature data collected by UK institutes (HadCRUT4), NOAA (National Oceanic and Atmospheric Administration from US Department of Commerce’s) and GISS (Nasa’s Goddard Institute of Space Studies). All of them use different methods in measuring and evaluating global temperature data. The annual values of the measured data have quite a large variance (Figure 2.1.1). The average temperature of these three in 2018 was 1.04 deg. C higher than the average temperature in years 1901-1930.

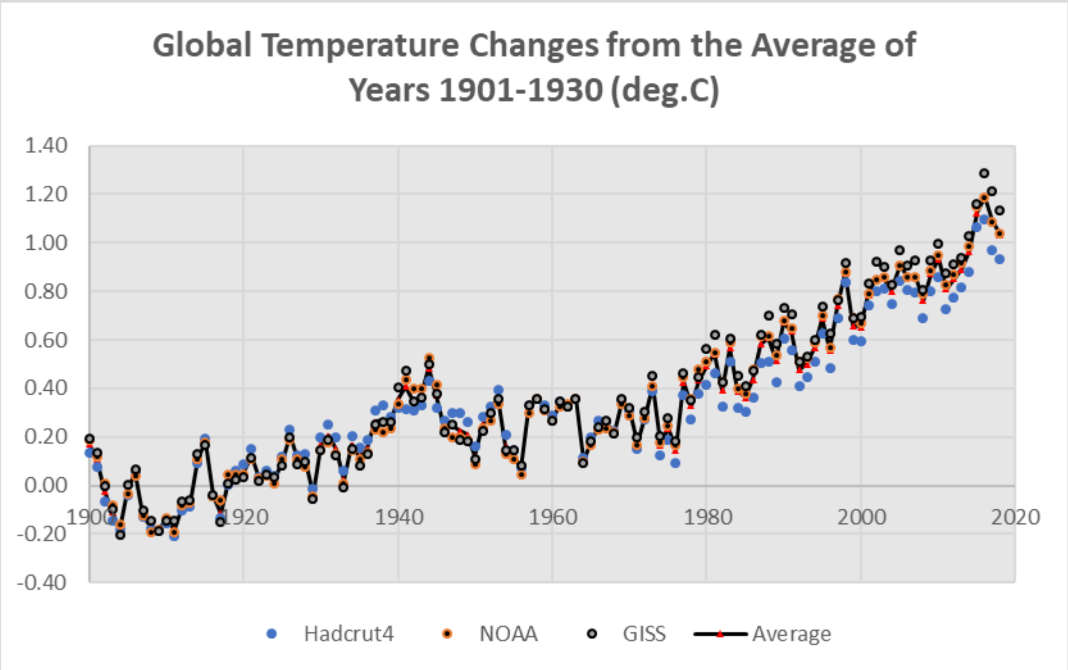

Figure 2.1.1 Annual values of global temperatures by the main institutes.

However, they are quite close of each other, if 11-year average values are combined (Figure 2.1.2). The 11-year average temperature was 0.96 deg. C higher in 2018 than in years 1901-1930.

The differences of three temperature data records are compared with the average values (of the three institutes) in Figure 2.1.3. We can find that Hadcrut4-values start lower than others and end lower than others. GISS-values start higher than others and end higher than others. NOAA-values are in the average in the beginning and in the average in the end. NOAA values seem to follow most accurately the average and the differences are about 0.01 deg. C.

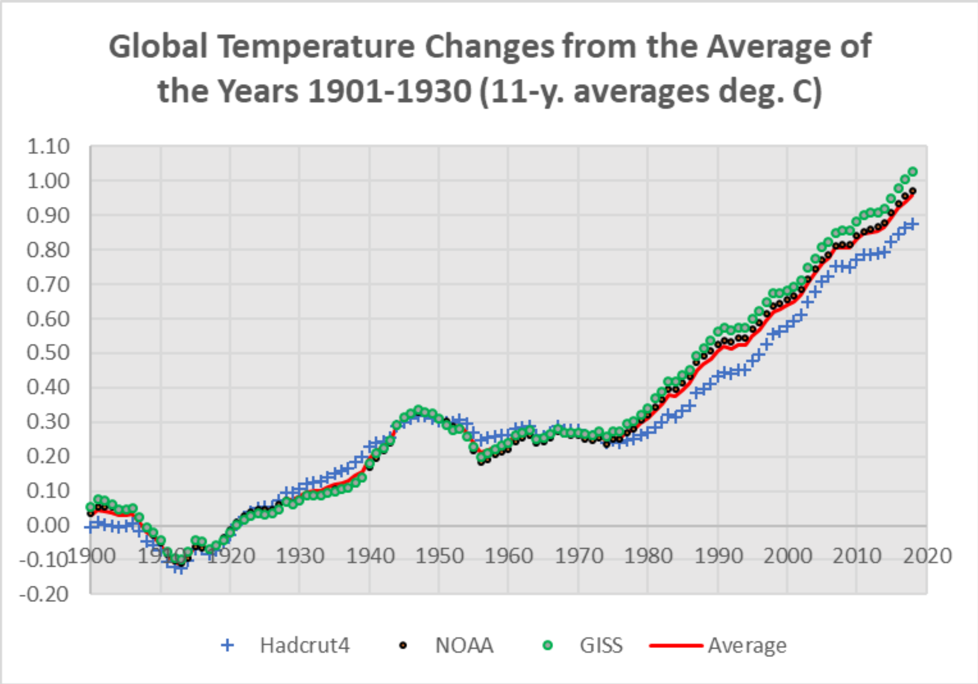

Figure 2.1.2 Global temperature data of HadCRUT4, GISS and NOAA.

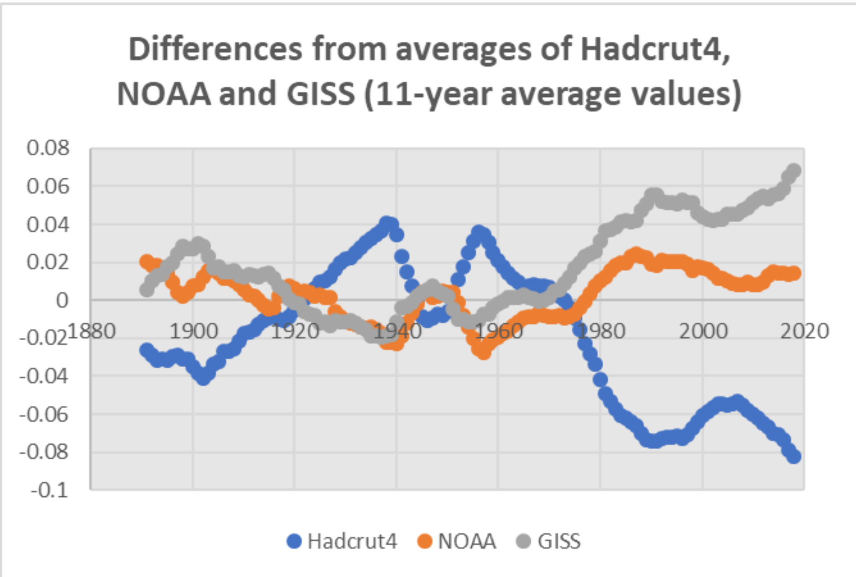

Figure 2.1.3 Differences in 11-year average values of Hadcrut4, GISS and NOAA.

Thus, the best way to avoid errors is to use the average values of these three institutes (Figure 2.1.4). We can find that the values of NOAA are very near the average of the three institutes or practically the same.

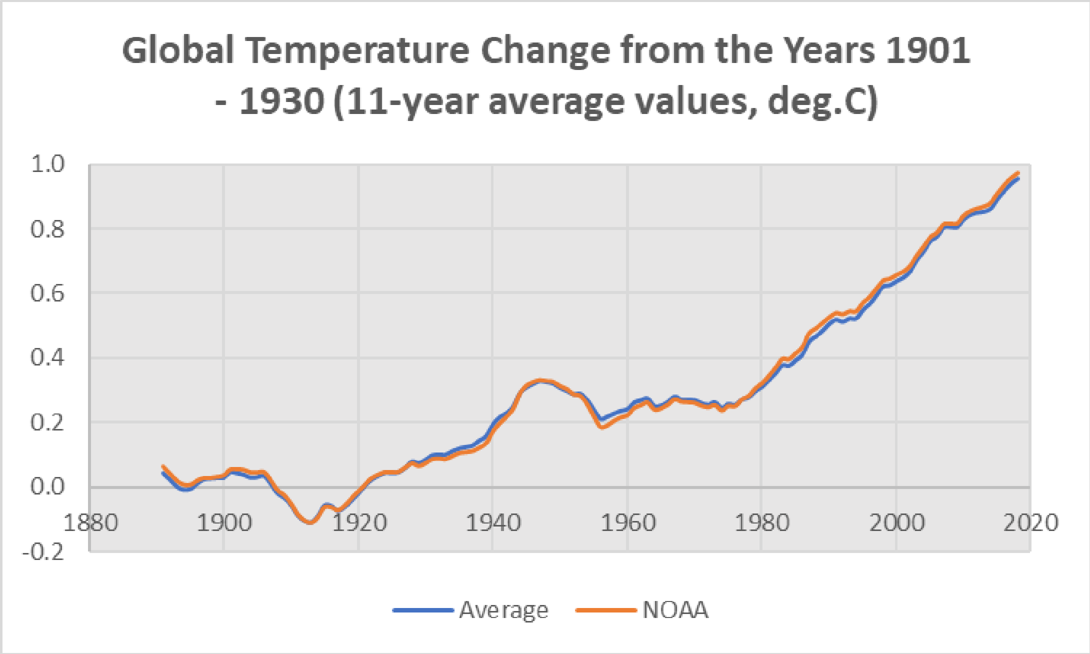

Figure 2.1.4 11-year average values of the three (Hadcrut4, GISS and NOAA) and 11-year average values of NOAA.

The variation of annual temperature values from the trend are given in Figure 2.1.5. We can find that in 2017 the temperature was at the maximum limit of 95 % probability value (+ 2 x standard deviation, STD). The 95 % confidence limit value has been calculated assuming, that the distribution of deviations from the trend are normally distributed (Figure 2.1.6).

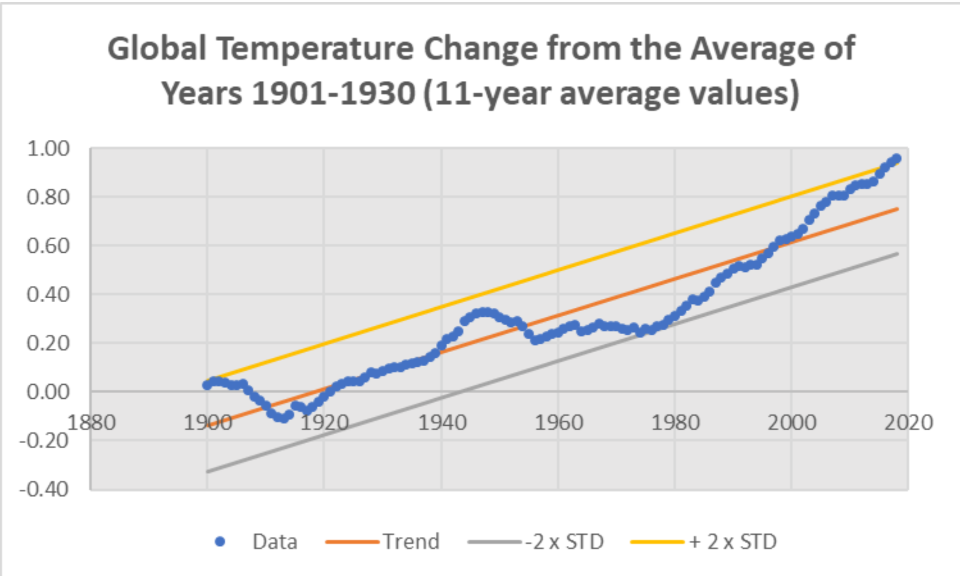

Figure 2.1.5 Variation of annual values from the trend.

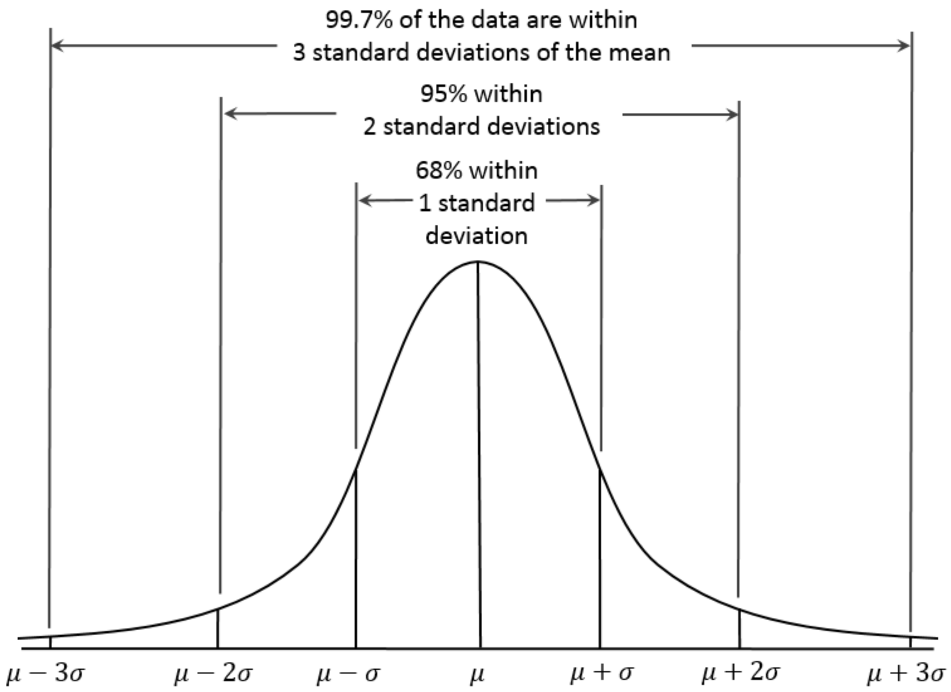

Figure 2.1.6 With 95 % confidence the variation is about 2 x standard deviation (2 x STD).

2.2 Forecasting future warming

The data of past temperature measurements can be used to forecast future. Simplest method of forecasting is studying the trend of the known measurements. If we calculate the trend based on the average annual values of temperatures of Hadcrut4, GISS and NOAA, the result is given in Figure 2.2.1. It is indicating that the temperature has increased from -0.05 deg. C in 1910 to 0.96 deg. C by 2018. The temperature trend has been 0.76 deg. C in a century. With this trend global temperature will rise to about 1.5 deg. C by 2100 and to about 2.25 deg. C by the year 2200.

We can also calculate the standard deviation (STD) of deviation of the measurements from the trend. STD is 0.094 deg. C. If we want to give 95 % contingency values, then the deviation from the trend should be less than 2 x STD or 0.19 deg. C.

If we add the 95 % confidence limits to the trend line the values can deviate from the trend line +/- 0.19 deg. C. The temperature change from the years 1901 – 1930 will be in the year between 1.2 and 1.7 deg. C by the year 2100 with 95 % confidence. In the year 2200 temperature will be between 2.0 – 2.4 deg. C higher.

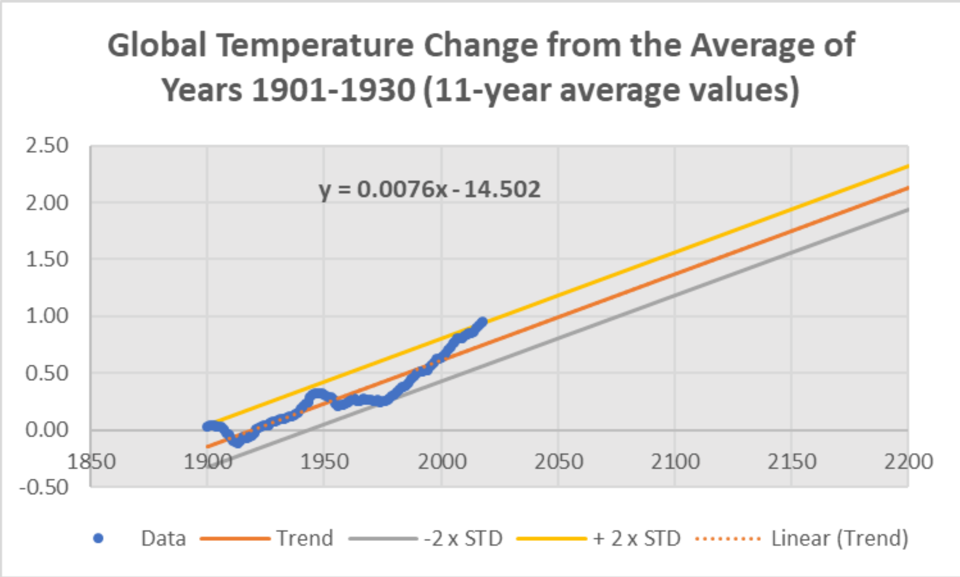

Figure 2.2.1 Global temperature trend with 95 % confidence (2 x STD) limits.

The global temperature has been rising after 1980 with trend of 0.17 deg. C decade (Figure 2.2.2). This would indicate that the temperature will be 1.7 deg. C warmer in 2100 than in 2000. Temperature was about 0.65 warmer in 2000 than in 1901-1930. Thus, the trend would mean that temperature would be 2.35 deg. C warmer in 2100 than in 1901-1930. The 1.5 deg. C limit will be reached by the year 2050, if this trend will continue.

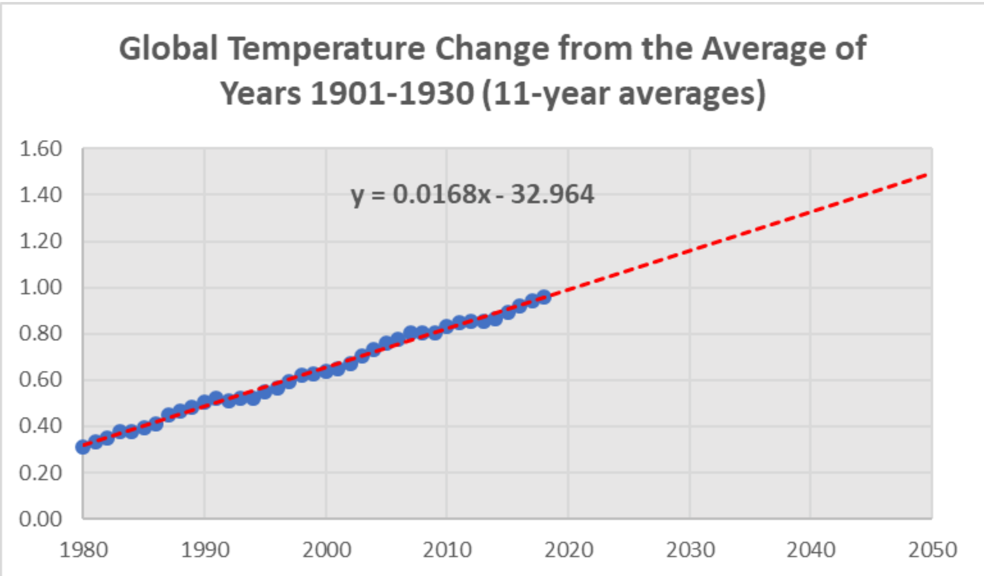

Figure 2.2.2 Trend of global warming after year 1980.

11-year and 30-year averages

Temperature changes can be better found in 11-year and 30-year moving average figures (Figure 2.2.3). I have used 11-year average because the short sunspot cycle has 11-year variation and thus this eliminates short term sunspot cycle.

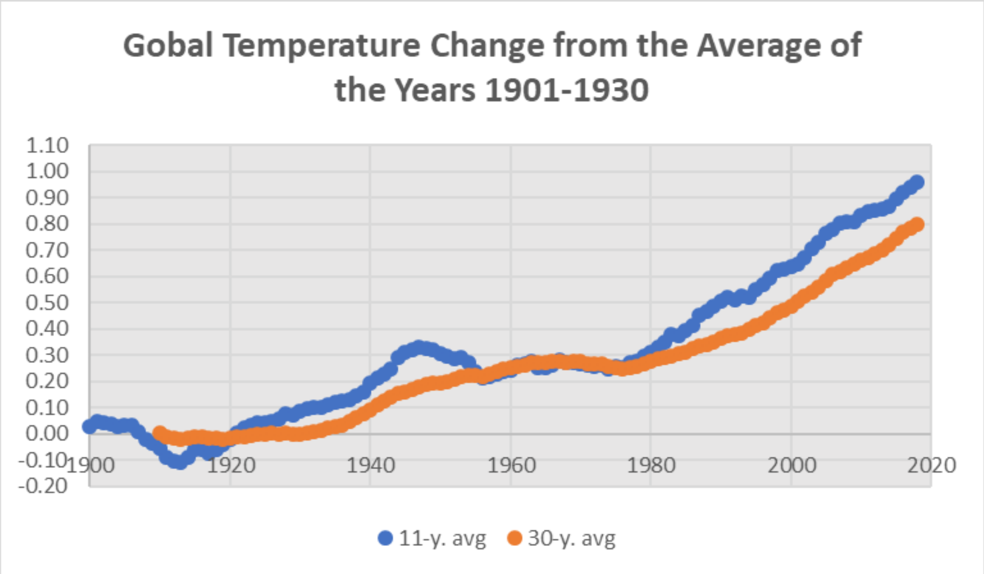

Figure 2.2.3 Temperature deviation from years 1901-1930.

Meteorological scientists consider that 30-year average values will indicate changes in climate. The global 30-year average temperatures have risen from the years 1901-1930 to years 1989 – 2018 with 0.80 deg. C (Table 2.2.1). This has happened within 88 years and average increase has been 0.91 deg. C in a century.

Table 2.2.1 Forecasted temperatures using the trend values of the 30-year averages.

Years		30-year averages		Increase (deg. C)	
From	To	From	To	Increase	per 100 y.
1930	2018	0.00	0.80	0.80	0.91
1930	1980	0.00	0.27	0.27	0.53
1980	2018	0.28	0.80	0.52	1.37

30-year average temperature has increased during the first 50-years until the year 1980 with 0.27 degrees. But from 1980 the increase has been from 0.28 deg. C to 0.80 deg. C or with 0.52 deg. C in 37 years. This corresponds 1.37 deg. C increase in a century.

2.3 Air temperatures in Finland

It has been said in many studies that the temperature rise will be faster in the northern areas than in average. One place which is far from cities is Sodankylä Observatory in Finland (67° 22' N, 26° 38' E, 180 m). The place is in Lapland where in Sodankylä municipality are less than 1 people per square kilometer.

The temperature measurements were started in 1901 and they show annual average temperatures fluctuations from -3.5 to +2.0 °C (Figure 2.3.1). The 11-year average temperatures in Sodankylä peaked in 1939 at 0.39 °C and had lowest value of -1.60 °C in the year 1986.

We can find there both warming and cooling in average values. Warming happened from 1910 to 1939 and cooling from 1939 to 1980. In 1981 warming started again and it has the peak value in 2018.

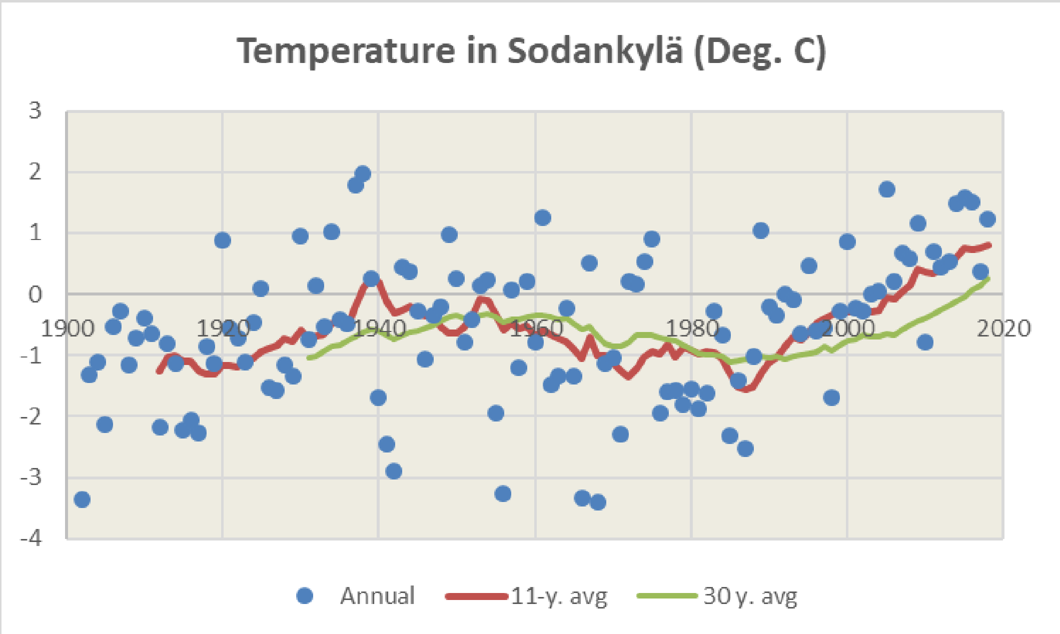

Figure 2.3.1 Measured temperatures in Sodankylä (67° 22' N, 26° 38' E, 180 m).

The deviation of temperature from the average of years 1901-1930 is indicating that 30-year average temperature has increased with 1.3 deg. C and 11-year average with 1,8 deg. C (Figure 2.3.2).

The trend of temperature change in Sodankylä from 1901 to 2018 is showing the increase of temperature of 1.1 deg. C in 100 years (Figure 2.3.3). The trend predicts that the temperature will be 2.0 deg. C higher in 2100 than the average value in years 1901-1930 (Figure 2.3.4).

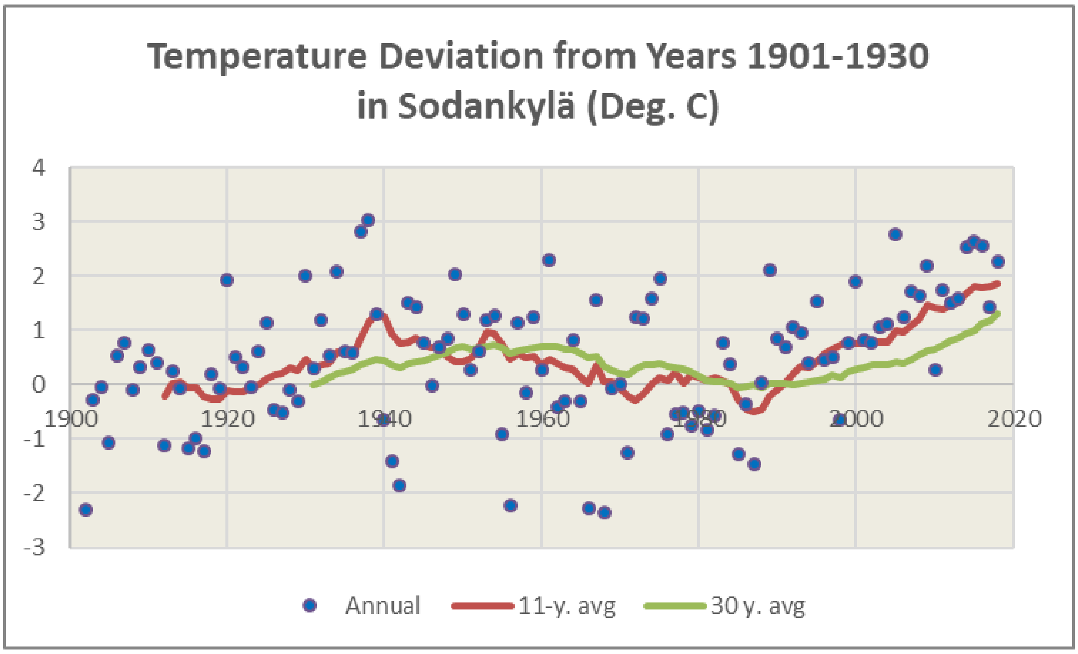

Figure 2.3.2 Temperature deviation from the average of years 1901-1930 (Deg. C).

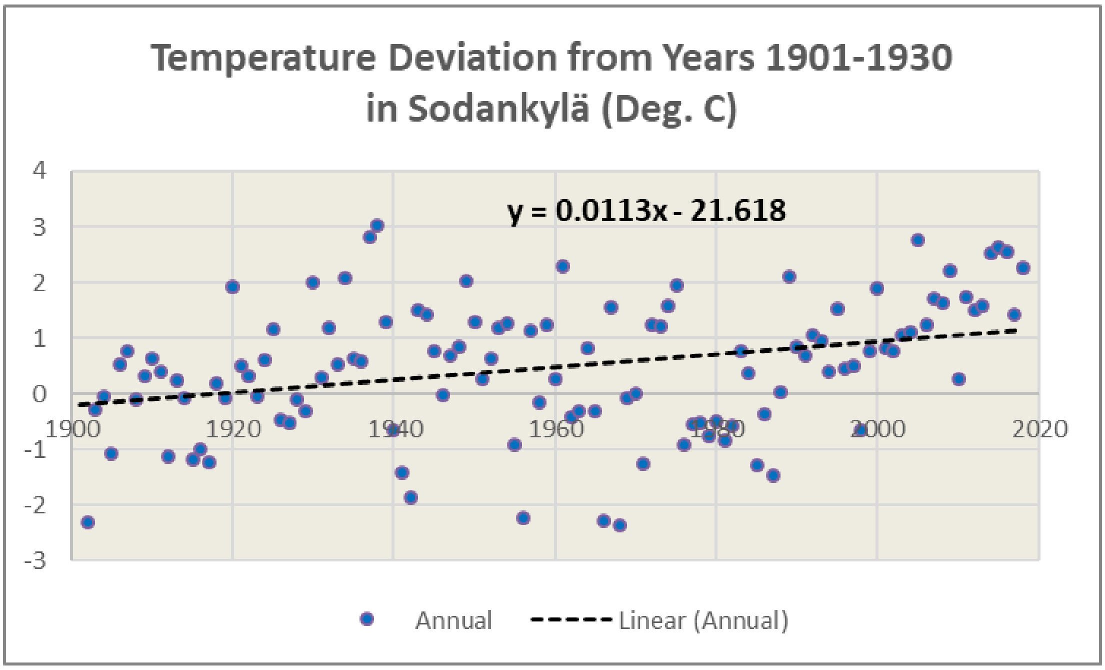

Figure 2.3.2 Temperature increase in Sodankylä from the years 1901-1930 (deg. C).

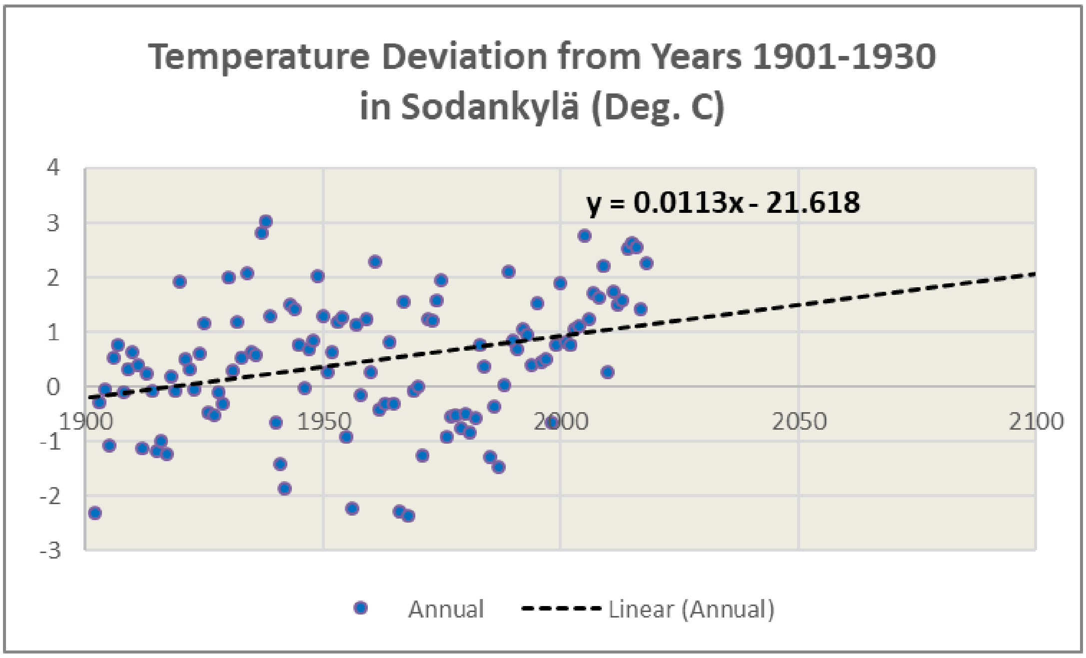

Figure 2.3.4 Temperature increase in Sodankylä from the years 1901-1930 (deg. C).

11-year and 30-year average warming

We can also make a trend analysis based on 11-year and 30-year annual averages. The 11-year average trend (Figure 2.3.5) indicates that the temperature has risen with about 1.85 deg. C from the year 1911, which was the first 11-year average.

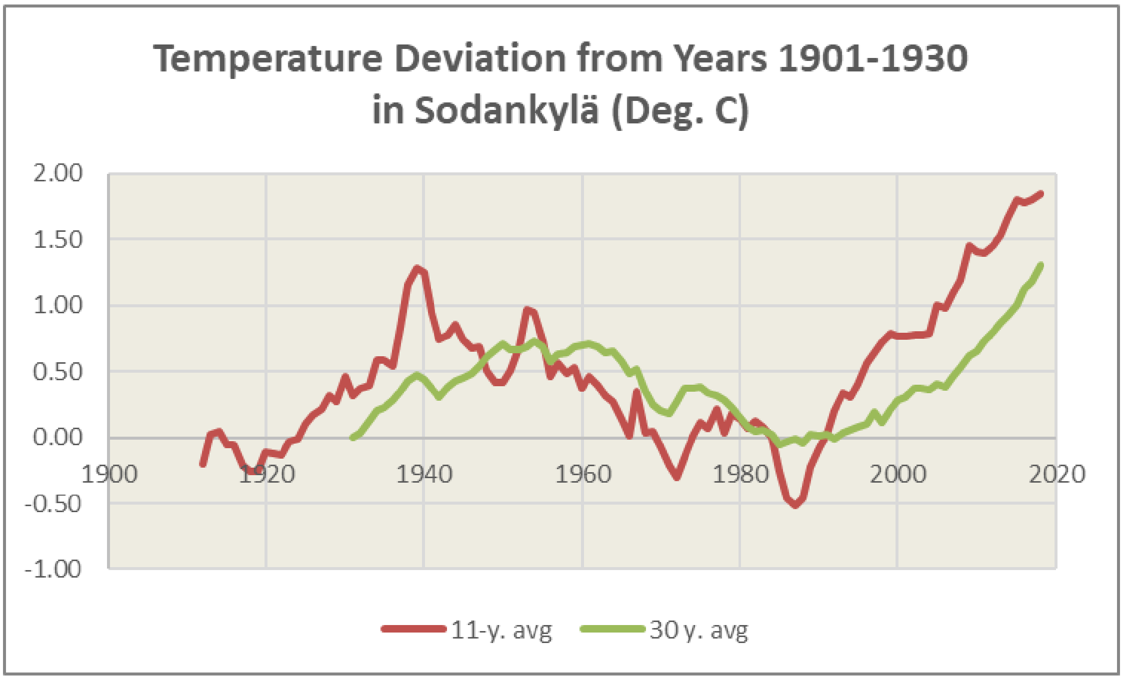

Figure 2.3.5 Warming trend in Sodankylä using 11-year and 30-year average measurements.

Climatologists consider that 30-year average temperatures are showing where climate is going to. If we look at 30-year average temperatures (Figure 2.3.5), they show a peak during the years 1950 - 1960 and another peak (1.30 deg. C) in 2018 (which may have not yet reached its peak). The fluctuation has about 65-year cycle and range of about one degree.

However, the 30-year average temperature values indicated cooling during the years from 1960 to 1980. During these years scientists were speculating that the world was cooling and a new ice age is coming. The theory comes from the possible changes from the Golf Stream.

The 30-year average temperature has been increasing with 1.30 deg. C after 1930 (Table 2.3.1). The trend has been 1.48 deg. C in century. This is faster than 0.9 deg. C warming found in global temperature in a century. However, the trend after 1980 indicates that warming will be 3.05 deg. C in a century.

Table 2.3.1 Warming trend from 30-year averages in Sodankylä, Finland.

Years		Temperature (deg.C)		Temperature (deg.C)	
From	To	From	To	Increase	per 100 years
1930	2018	0.00	1.30	1.30	1.48
1930	1980	0.00	0.15	0.15	0.29
1980	2018	0.15	1.30	1.16	3.05

Temperature change in Helsinki

Temperatures in Helsinki have been measured since 1829 (Figure 2.3.6). The 11-year average values have been rising from 4.0 deg. C in 1840 to about 6.8 deg. C in 2018 or with 2.8 deg. C. The 30-year average has risen from 4.0 to 6.4 or with 2.4 deg. C.

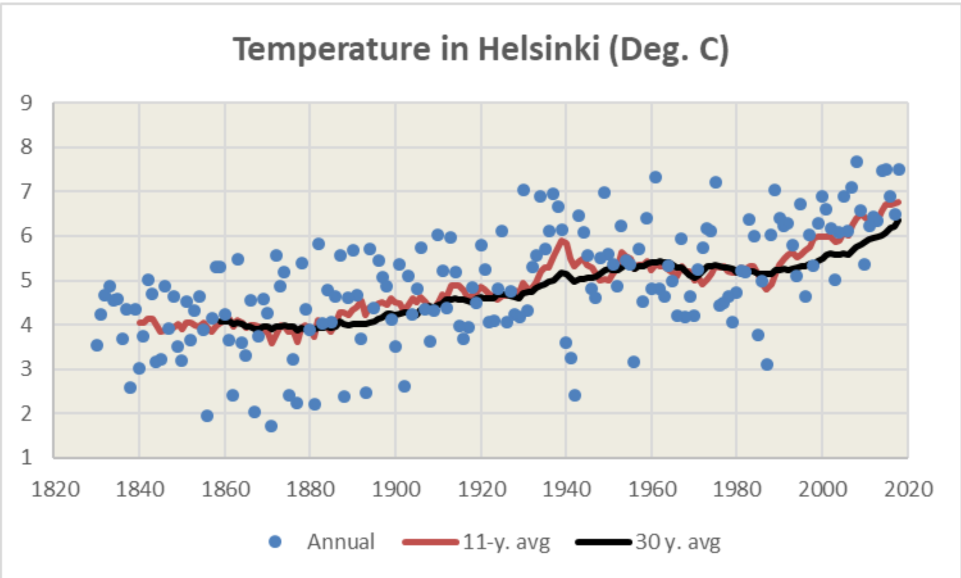

Figure 2.3.6 Annual temperatures in Helsinki

The change in temperature from average of 1901-1930 has been 1.7 deg. C until 2018 in 30-year average values (Figure 2.3.7 and 2.3.8)). This has been 0.4 deg. C higher than in Sodankylä, where the 30-year average temperature has been rising 1.3 deg. C (Figure 2.3.5). This is caused by the changes in the city, which have now more concrete buildings and asphalt roads than in the beginning of 20th century.

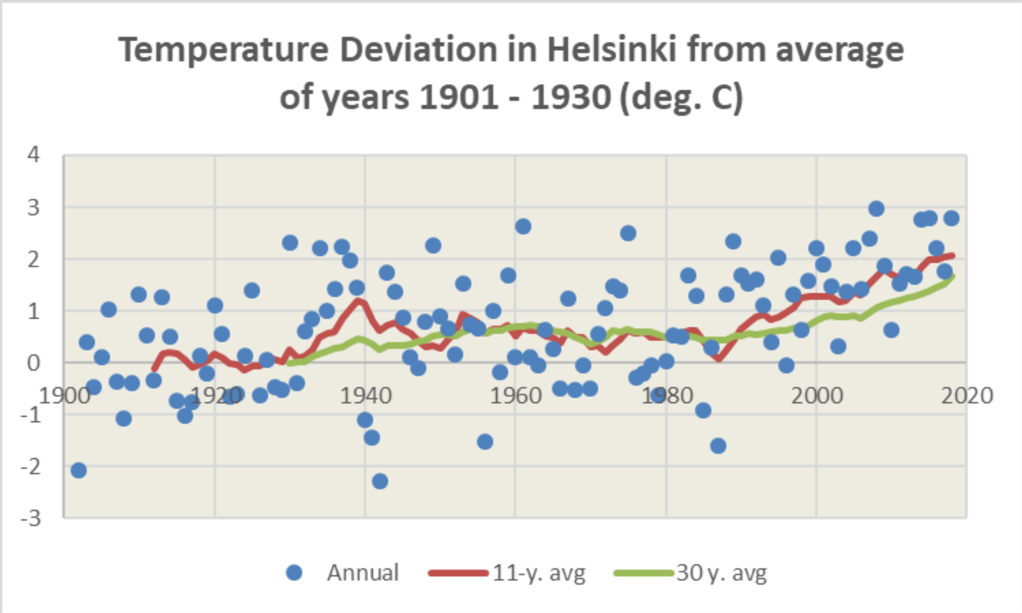

Figure 2.3.7 Change of temperature in Helsinki from the average of years 1901-1930.

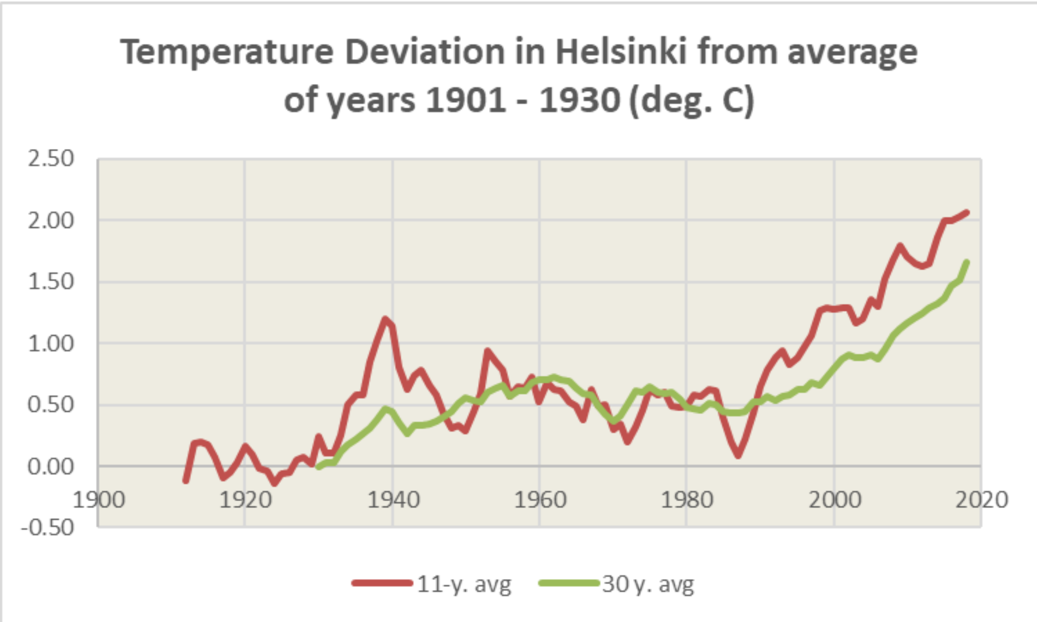

Figure 2.3.8 Change of temperature in Helsinki from the average of years 1901-1930.

The difference in 30-year average temperatures has started to increase in about the years 1970, when the automobile traffic and district heating was spreading in the city of Helsinki (Figure 2.3.9).

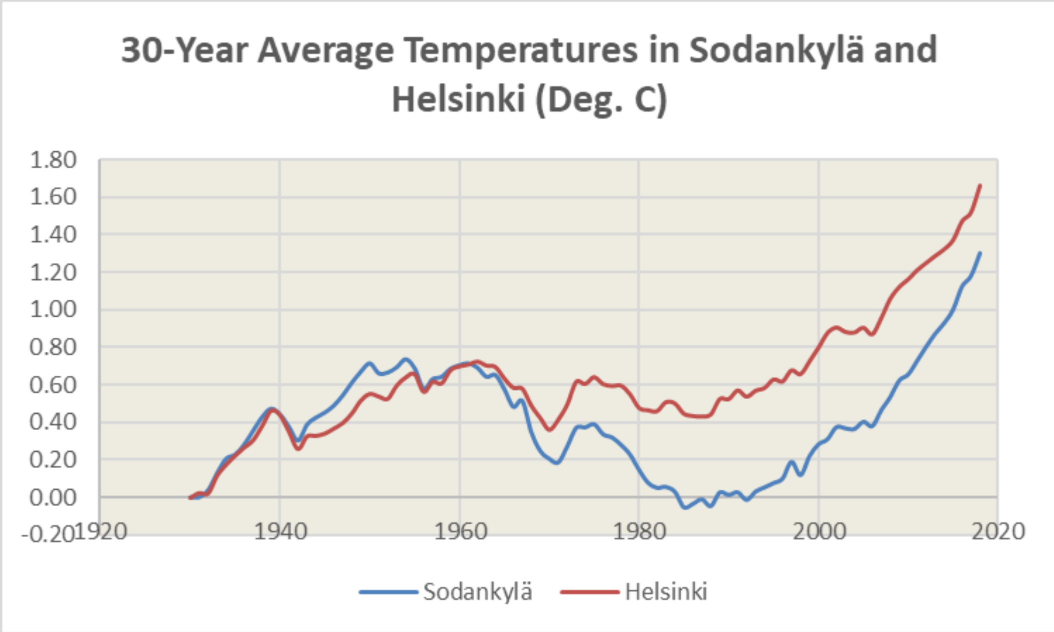

Figure 2.3.9 30-year average warming in Sodankylä and Helsinki.

Monthly warming since years 1901 - 1930

I found old Statistical Yearbooks of Finland, which has the monthly temperature measurements during years 1901-1930 at five sites (Helsinki, Tampere, Maarianhamina, Oulu and Sodankylä) and in which the measurements are made still today (Table 2.3.2).

Table 2.3.2 Monthly average temperatures during years 1901 – 1930 and 1981 – 2010 and temperature rise from the years 1901 – 1930 to years 1981 – 2010 (deg. C).

Years 1901-1930	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Helsinki	-5,5	-5,8	-2,7	2,2	8,2	13,0	16,8	15,0	10,6	5,3	0,5	-3,4	4,57
Tampere	-6,7	-7,2	-3,4	2,1	8,6	13,5	16,9	14,4	9,8	4,2	-0,9	-4,9	3,93
Maarianhamina	-2,4	-3,4	-1,6	2,2	7,0	11,7	15,6	14,8	10,5	6,1	2,0	-0,9	5,18
Oulu	-9,0	-10,0	-5,7	0,0	5,9	11,8	15,7	13,2	8,2	2,0	-3,3	-7,4	1,85
Sodankylä	-13,5	-13,8	-8,9	-2,5	4,0	10,6	13,8	10,8	5,7	-1,2	-8,0	-11,9	-1,18
Average	-8,3	-9,1	-5,4	-0,1	5,6	11,4	15,0	12,9	8,1	2,3	-3,1	-6,7	1,95

Years 1981-2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Helsinki	-3,9	-4,7	-1,3	3,9	10,2	14,6	17,8	16,3	11,5	6,6	1,6	-2,0	5,94
Tampere	-6,4	-6,9	-2,8	3,3	9,7	14,1	16,9	15,0	9,8	4,6	-0,6	-4,5	4,41
Maarianhamina	-2,1	-3,1	-0,6	3,7	9,1	13,3	16,7	15,8	11,4	6,9	2,6	-0,4	6,16
Oulu	-9,6	-9,3	-4,8	1,4	7,8	13,5	16,5	14,1	8,9	3,3	-2,8	-7,1	2,72
Sodankylä	-13,5	-12,7	-7,5	-1,3	5,3	11,6	14,5	11,7	6,2	0,1	-7,1	-11,7	-0,30
Average	-8,4	-8,4	-4,3	1,3	7,4	12,8	15,9	13,9	8,8	3,4	-2,4	-6,4	2,86

Rise to 1981-2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Helsinki	1,6	1,1	1,4	1,7	2,0	1,6	1,0	1,3	0,9	1,3	1,1	1,4	1,37
Tampere	0,3	0,3	0,6	1,2	1,1	0,6	0,0	0,6	0,0	0,4	0,3	0,4	0,48
Maarianhamina	0,3	0,3	1,0	1,5	2,1	1,6	1,1	1,0	0,9	0,8	0,6	0,5	0,98
Oulu	-0,6	0,7	0,9	1,4	1,9	1,7	0,8	0,9	0,7	1,3	0,5	0,3	0,87
Sodankylä	0,0	1,1	1,4	1,2	1,3	1,0	0,7	0,9	0,5	1,3	0,9	0,2	0,87
Average	-0,1	0,7	1,1	1,4	1,8	1,4	0,9	0,9	0,7	1,1	0,7	0,3	0,91

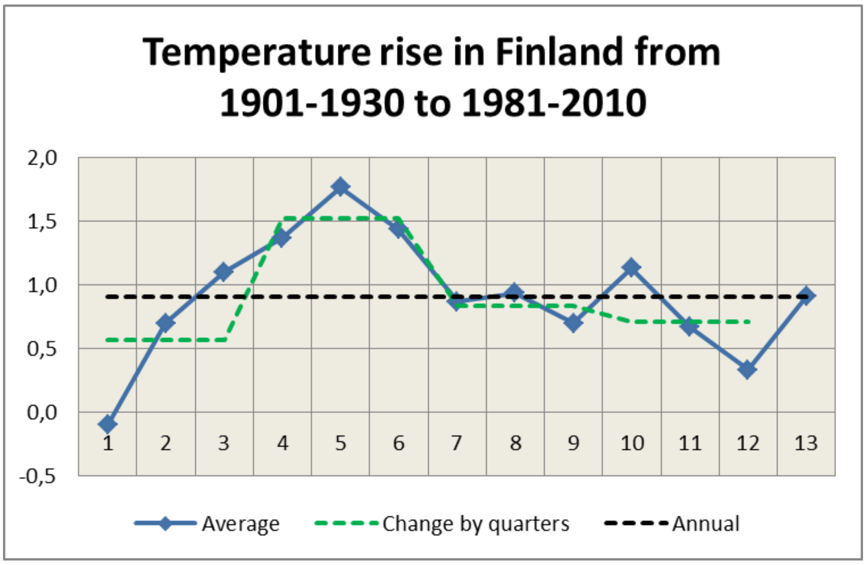

Figure 2.3.8 Warming in Finland from 1901 – 1930 to 1981 – 2010 (deg. C).

Annual warming from 1930 to 2010 has been 0.91 deg. C as measured in 30-year average temperatures or 1.14 deg. C in a century. We can notice that the warming has been the highest during spring from March to June and lowest in December and January (Figure 2.3.8). Rising of the temperatures in the spring of the year is an indication of snow and ice smelting earlier. The reflection of snow is much higher than that raw land and water in the lakes. The seas have ice cover only from January to April.

Very similar results were achieved by **Hanna Tietäväinen**, **Heikki Tuomenvirta** and **Ari Venäläinen**, who published an article *Annual and seasonal mean temperatures in Finland during the last 160 years based on gridded temperature data* (International Journal of climatology, 30: 9. November 2009).

According to the article the trend in warming per 100 years during years 1909 – 2008 have been 0.93 deg. C (Table 2.3.3).

Table 2.3.3 Warming trends in Finland per 100 years.

Years	1909-2008	1959-2008	1979-2008
Annual	0.93	1.52	2.05
MAM	1.59	1.46	0.78
JJA	0.69	0.63	1.26
SON	0.39	0.79	1.55
DJF	0.97	3.47	4.28

We can also notice that warming has been highest (1.59 der. C/100 years) in spring (MAM, March, April, May) and lowest 0.39 deg. C during autumn (SON; September, October, November). The reason for this has not been explained. One reason might be that snow is smelting earlier and thus the land is absorbing more heat during spring.

The table indicates also that the warming has been accelerating after the year 1979. The trend has been 2.05 deg. C per 100 years. The warming has been highest (4.28 deg, C/century) during winter (DJF) after the year 1979.

Conclusion:

Warming in Sodankylä has been 1.52 deg. C per 100 years after years 1901-1930. If trend continues at the same rate as before, the climate will be about 3 deg. C warmer in years 2101-2130 than during years 1901-1930.

Warming in Finland has been 0.91 deg. C during 80 years from the average from 1901 - 1930 to the average of 1980 - 2010. Highest warming has been found during spring months, March, April and May, Snow is smelting earlier and causes absorption of solar radiation will increase.

One explanation to the higher temperature rise in Finland is that the country is located inland, but the global temperature is average temperature of land and sea.

Warming in Finland since 1700

Finland has one of the longest time series which is related to annual temperatures. The loss of ice in spring in River Tornio (in Swedish border) has been measured since 1700. The days after the first of January have been continuously declining from about 141 days in 1700 to 127 days today (Figure 2.3.9).

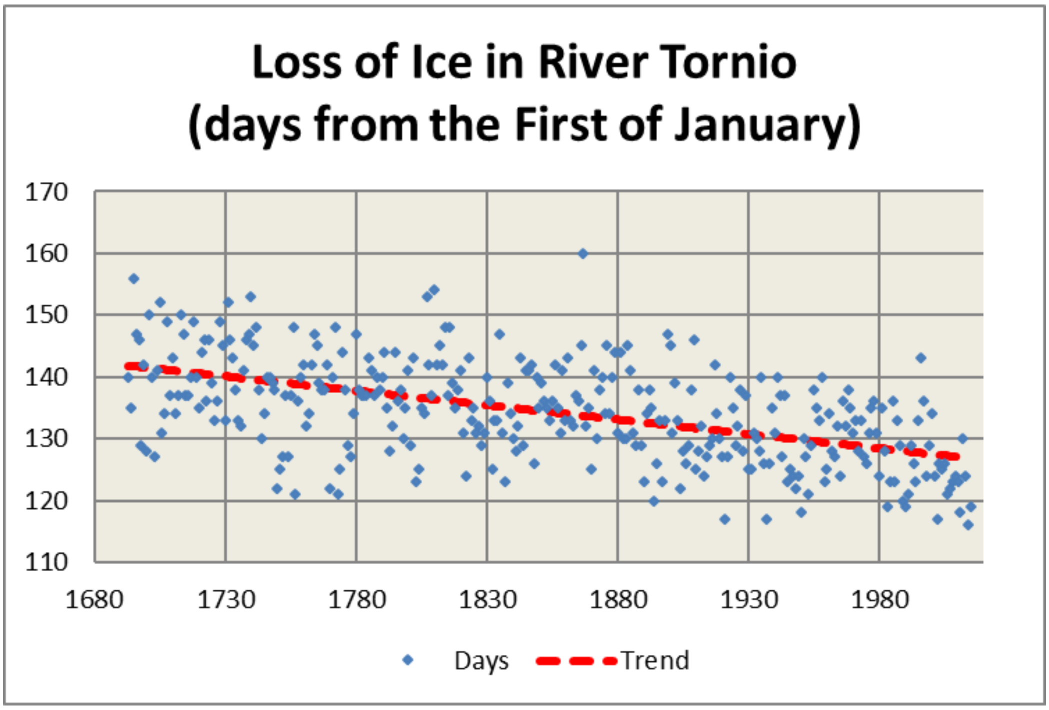

Figure 2.3.9 Loss of ice in River Tornio (days from the first of January).

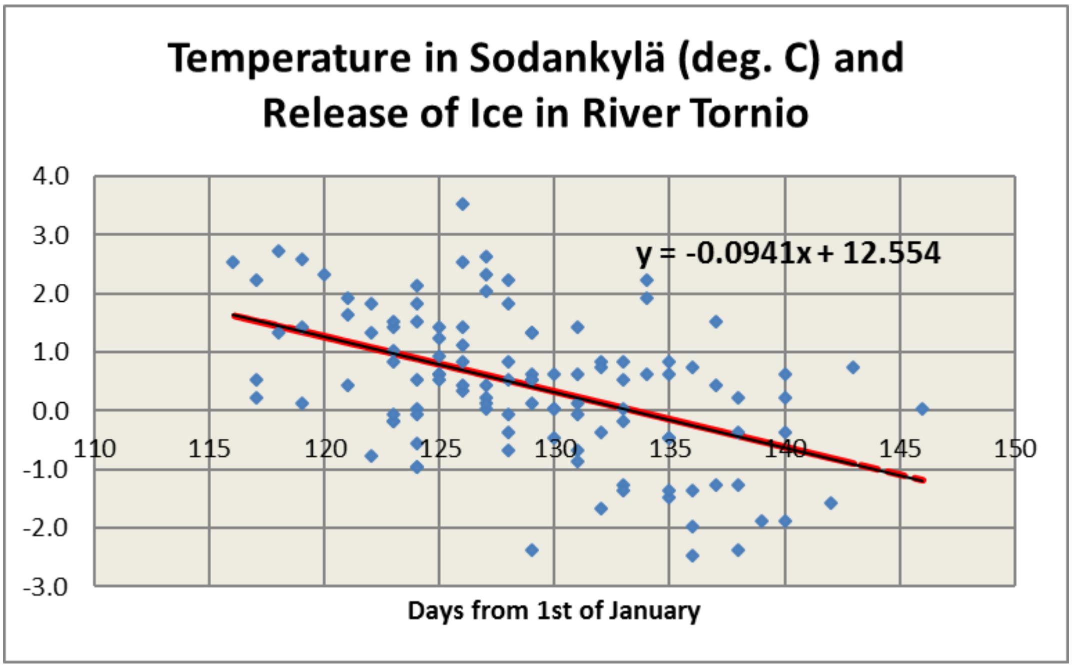

Figure 2.3.10 Temperature in Sodankylä and loss of ice are correlated.

If we combine temperature data from Sodankylä and loss of ice days from January, we can make a XY-diagram (2.3.10). It shows that change of 30 days in days in ice release date will correspond 2.8 deg. C change in temperature. Using this relationship, we can the extrapolate temperature estimates until the year 1700 (Figure 2.3.11).

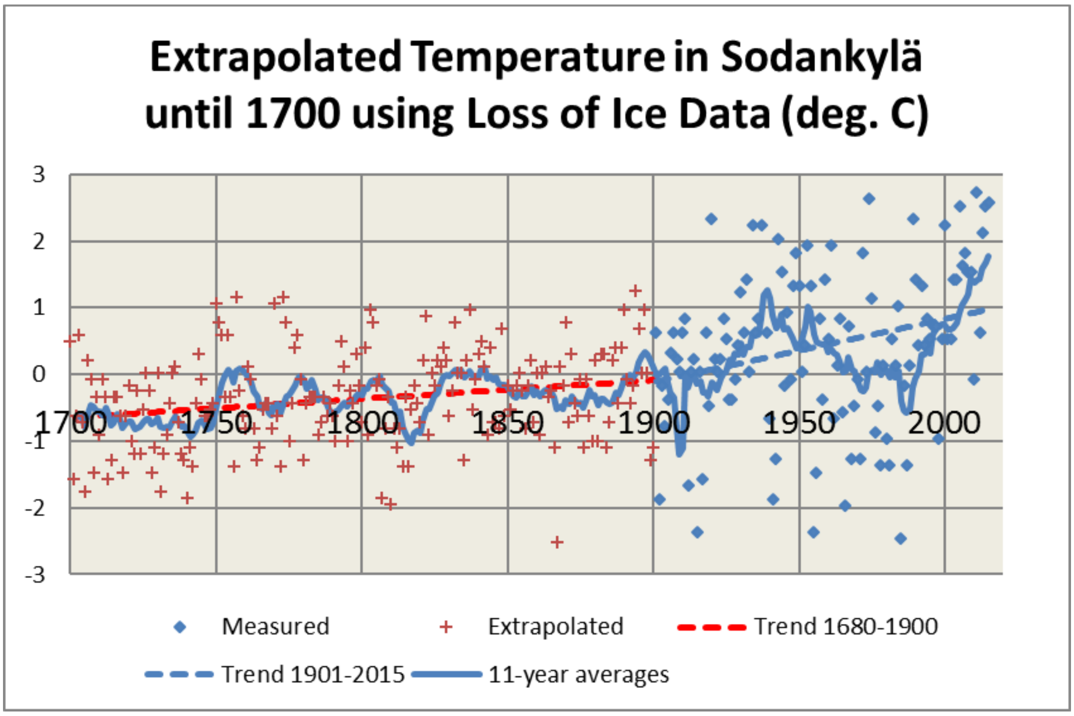

Figure 2.3.18 Extrapolated temperature in Sodankylä until the year 1700.

Summary

We can find from the data of ice smelting in the rivers that the global temperature has been rising continuously since 1700. The increase has been about 0.7 deg. C from 1700 to 1900. After 1900 the change has been about 1.0 deg. C. Thus, the total change from 1700 to 2016 has been about 1.7 deg. C.

There has not been a hockey stick curve as presented by the IPCC third report. The hockey stick is curve exists, but the anthropological warming has starts only after 1980 as can be seen from chapter 3.

Global temperature has increased about 0.80 deg. C, if measured using 30-year averages from the years 1901 – 1930 to years 1989 - 2018. The 30-year temperature in Finland has increased about 0.91 degrees from the years 1901 – 1930 to years 1981 - 2010, when the temperature was really measured in several places.

3 SUNSPOTS AND SOLAR IRRADIANCE

3.1 Sunspots

We have found that temperatures have been risen more than 300 years almost constantly from the times of Little Ice Age (LIA). LIA was happening from 1300 to 1750 during which times also River Thames had frozen and people were walking on the ice (Figure 3.1.1).

Figure 3.1.1 Frozen River Thames.

Sunspots are black points in sun, which were found because Italian scientist **Galileo Galilei** (1564 – 1642) developed better telescope. He and others found the sunspots with the better telescope which could magnify objects with factor 30. In 1610 he published a small book titled “*Starry Messenger*”, where he described his findings.

Figure 3.1.2 Invention of telescope was a key to find sunspot

Later it was found that sunspot numbers were extremely low during years 1645 - 1700 (Figure 3.1.3). This era was called as Maunder Minimum according to its inventors, **E. Walter Maunder** (1851-1928) and his wife **Annie Russel Maunder** (1868-1947), who studied sunspots by this time. Number of sunspots was only less than 10 in each decade during those years.

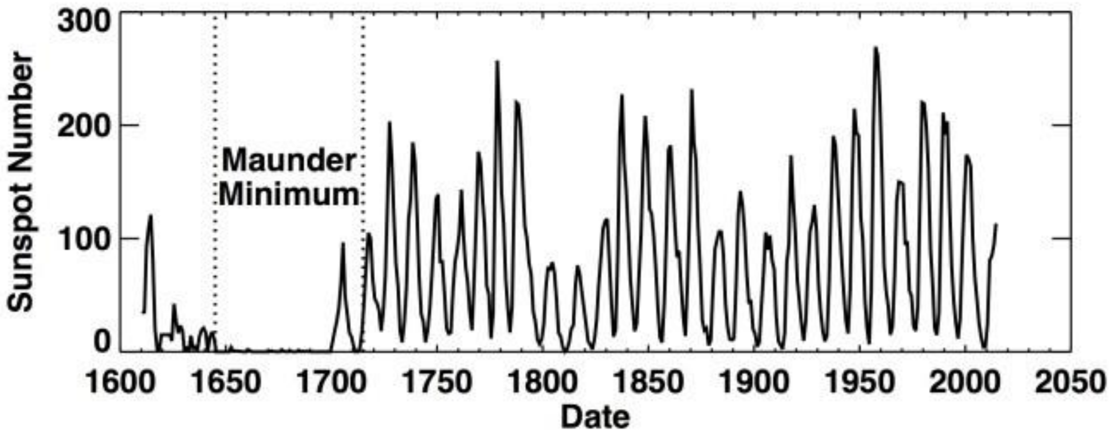

Figure 3.1.3 Maunder minimum and sunspots Numbers.

The sunspot data can be downloaded from the year 1700 to 2018 and presented as raw data and in 5- and 11-year averages (Figure 3.1.4). The 11-year cycle can be seen in 5-year averages, which has the minimum values in 1712, 1813, 1914 and 2010 of with 99-year intervals.

11-year average values will eliminate this 11-year cycle.

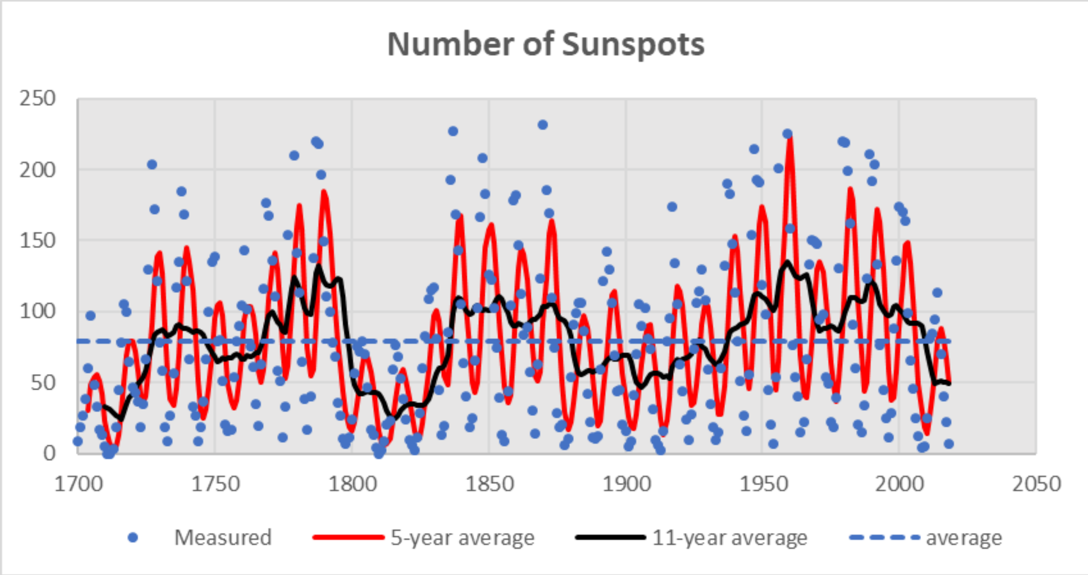

Figure 3.1.4 Sunspot data as downloaded from the file (http://www.sidc.be/silso/datafiles).

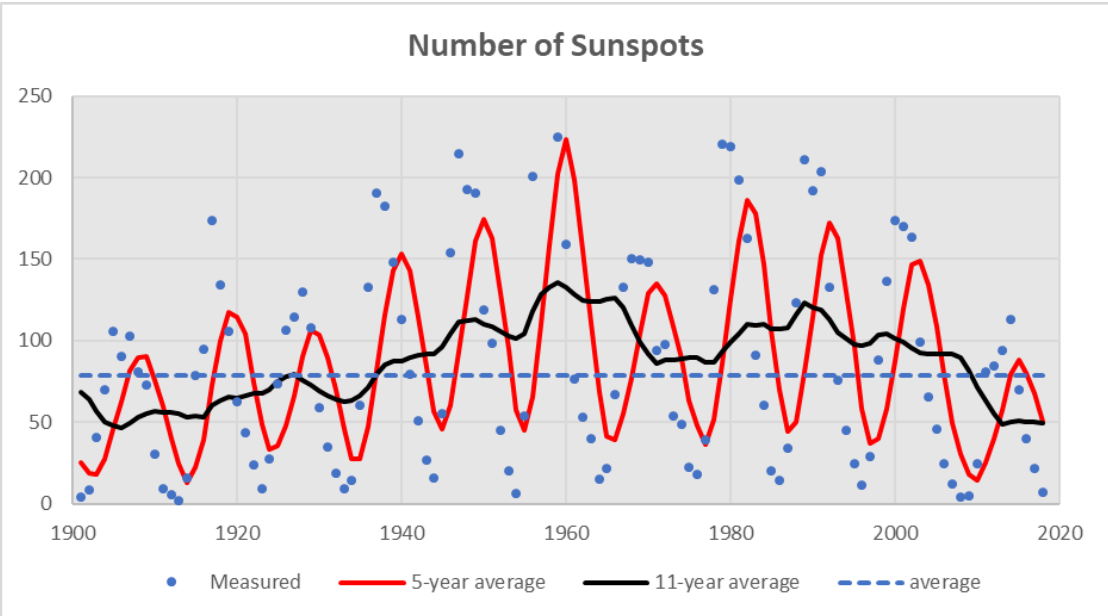

Figure 3.1.5 Sunspot data given for the years 1890 – 2017.

The temperature records given in chapter 2.1 during years 1901 - 1950 and sunspots during the same years can be presented in a XY-diagram (Figure 3.1.6). The linear trend shows that at 60 sunspots the influence is zero and at 110 sunspots level the temperature will rise with +0.33 deg. C.

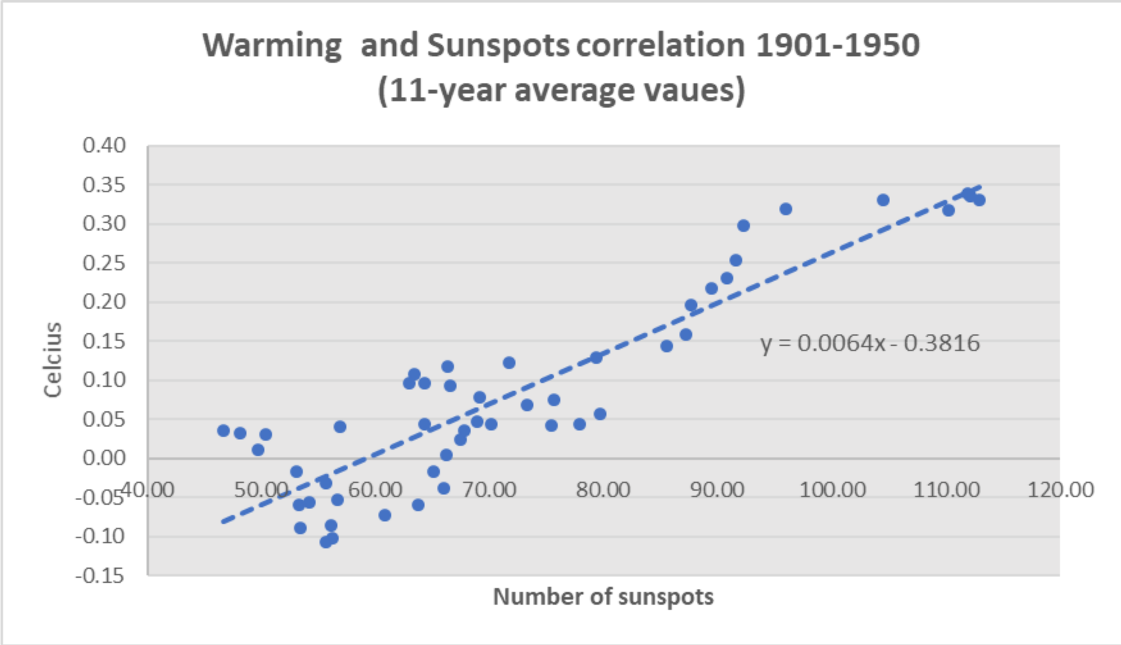

Figure 3.1.6 Influence of sunspots to global temperature (11-year average values).

Thus, we can develop following formula for sunspot influence on temperature (dT):

(3.1) $dT = 0.0064 \times SPOTS - 0.38$

Thus, we can assume that, if number of sunspots will increase to 110 will the temperature will increase with about 0.70 – 0.38 = 0.32 deg. Celsius. If the number of sunspots will drop to zero, temperature will drop by - 0.38 deg. C. Thus, the sunspots can cause -0.4 and + 0.4 deg. C fluctuation in global temperature.

3.2 Sunspot corrected global temperatures

After knowing number of sunspots and their influence of global warming (Formula 3.1), we can then calculate how much the sunspots have changes global temperatures (Figure 3.2.1). However, we will take into the account only the 11-year average values of global warming caused by the sunspots (Figure 3.2.2).

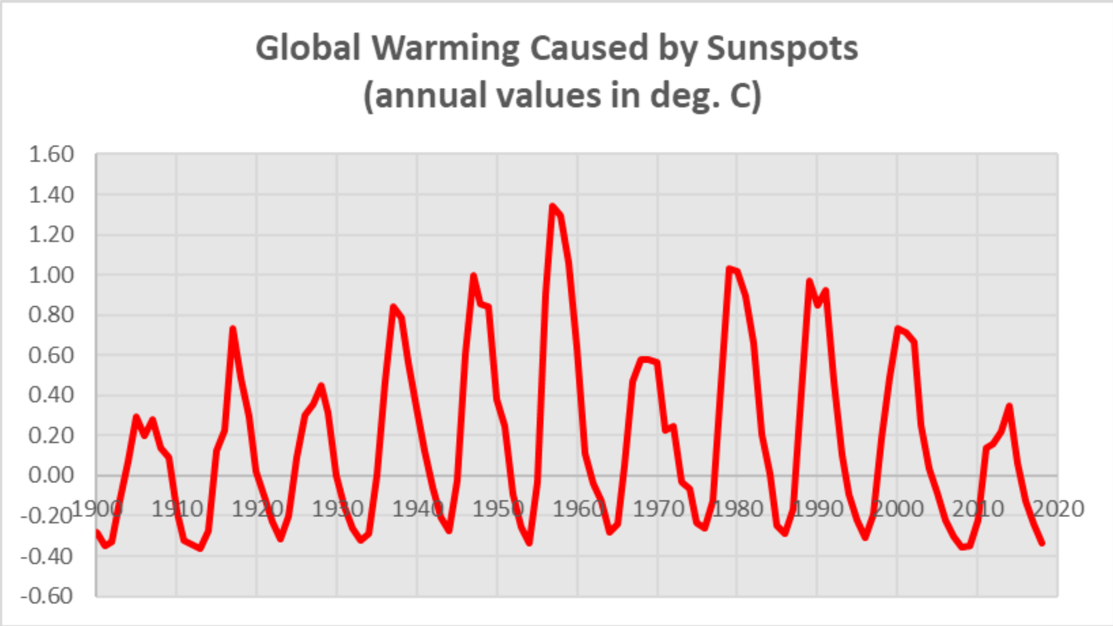

Figure 3.2.1 Sunspot caused warming using annual data.

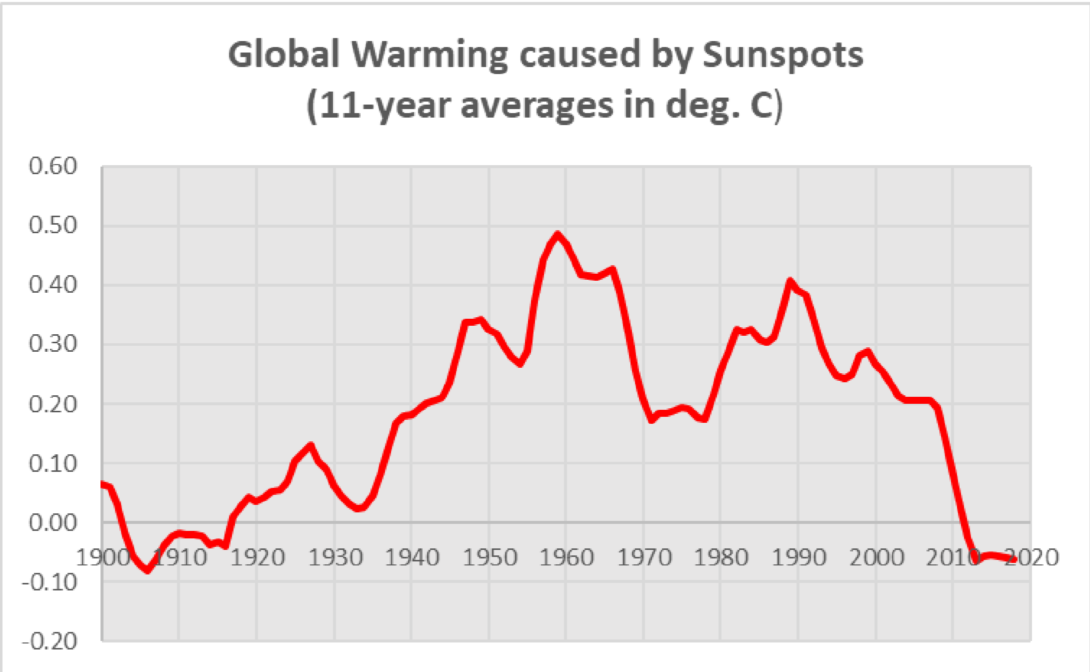

Figure 3.2.2 Sunspot caused temperature deviation has its peak influence around 1960 and 1990.

We can now separate global warming in two components, one caused by the sunspots and the other which is caused by other sources (Figure 3.2.3). The global warming was mainly caused by the sunspots until the year 1980 and by other things since 1980 (Figure 3.2.4).

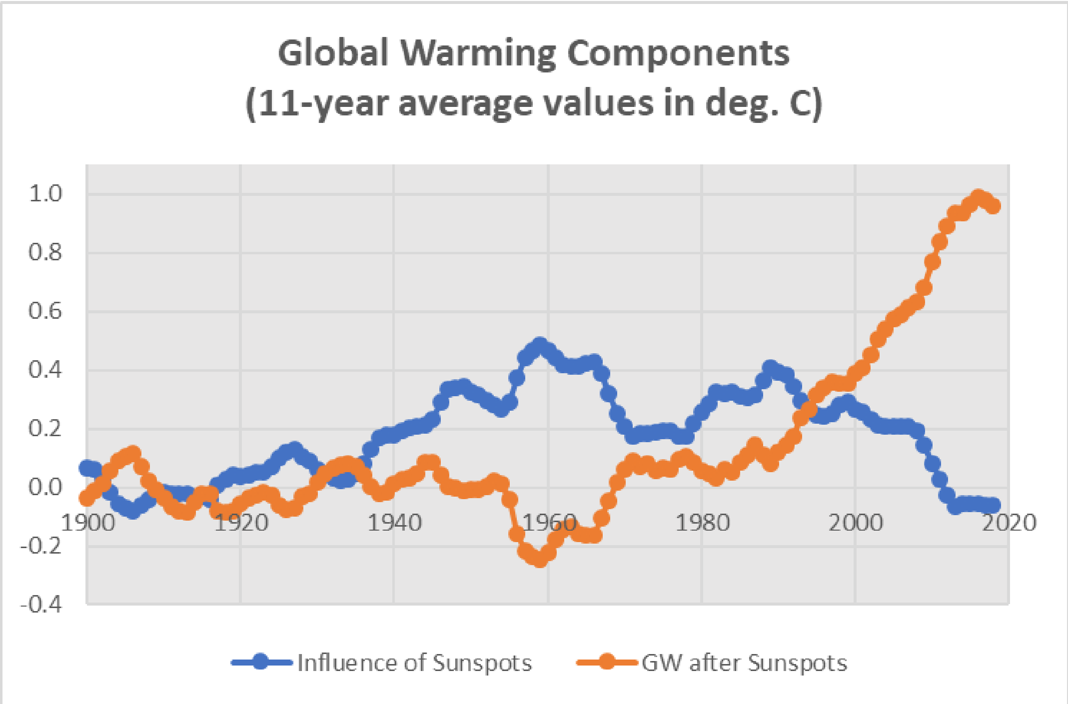

Figure 3.2.3 Global Warming caused by sunspots and other sources.

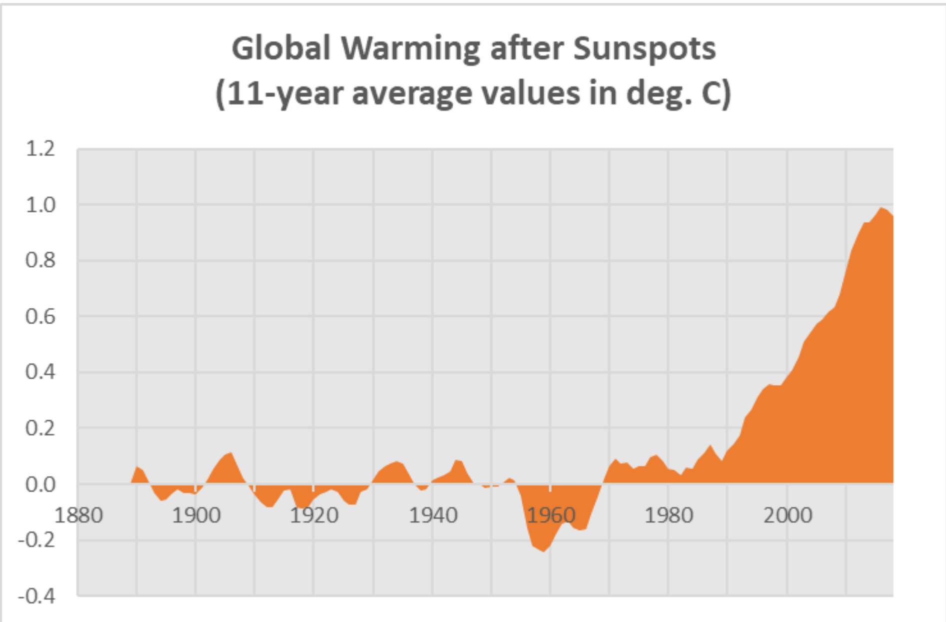

Figure 3.2.4 Global temperature deviation after influence of sunspots have corrected.

We can find (Figure 3.2.5) that the sunspot corrected temperature trend has been quite stable until the year 1985. However, after 1980 the trend is indicating increase of 2.9 deg. C per 100 years. The 2-degree limit will be achieved by the year 2050. The 1.5 deg. C limit will be achieved in the year 2035

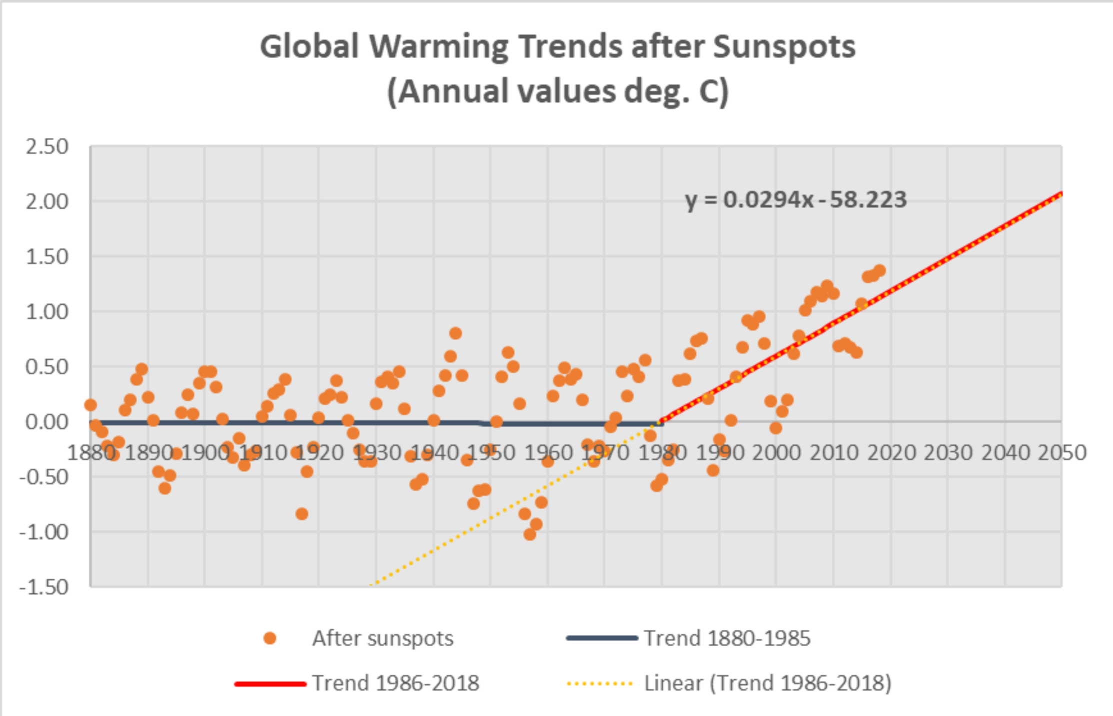

Figure 3.2.5 Global warming after elimination the influence of sunspots.

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The sunspot corrected 30-year average temperature has been rising about 0.67 deg. C from the years 1901-1930 to years 1989 – 2018 or 0.81 deg. C in 100 years (Figure 3.2.6).

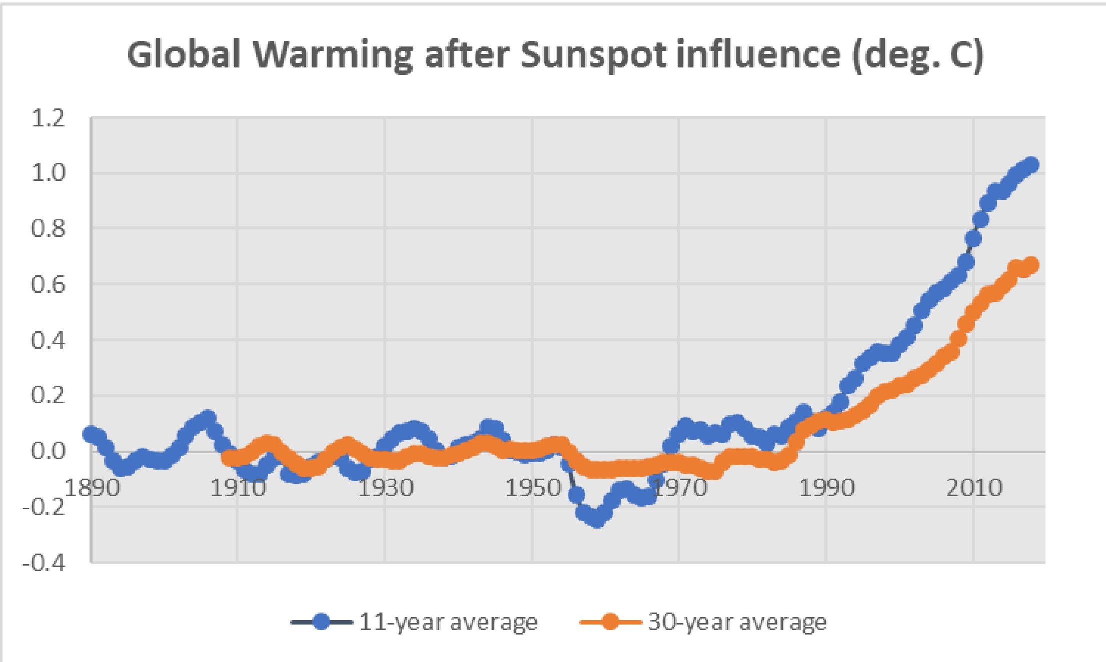


Figure 3.2.6 Sunspot corrected global warming.

If this trend from 1985 will continue, the temperature will be 2.1 deg. C warmer in 2100 than in 1985 (Table 3.2.1).

Table 3.2.1 Warming after sunspots as measured with 30-year averages.

Years		30-year averages			Increase
From	To	From	To	Increase	in 100 y.
1930	2018	-0.03	0.67	0.70	0.80
1930	1985	-0.03	-0.01	0.02	0.03
1985	2018	-0.01	0.67	0.69	2.08

The increase from 1985 to 2018 in global 30-year average temperature after sunspots has been 0.69 deg. C, which corresponds to 2.1 deg. C in a century. The trend predicts that 2.0-deg. C temperature limit will be exceeded by the year 2075.

3.3 Solar irradiance and global warming

Stefan-Boltzmann formulas

Solar irradiance in the space at the distance of the earth is almost constant. It can be calculated using Stefan-Boltzmann formula (3.3.1):

(3.3.1) $\mathbf{E = \sigma T^4}$

Where T = absolute temperature of a radiating body

σ = Stefan-Boltzmann constant = 5.67×10^{-8} $Wm^{-2} K^{-4}$

E = energy per area (W/m2) = 6.42×10^{7} W/m2

Because the surface area of the sun $A_s = 4 \times 3.14 \times R_s^2 = 4 \times 3.14 \times (6.95 \times 10^8\ m)^2 = 6.08 \times 10^{+18}\ m^2$, total power Ps transmitted by the sun

(3.3.2) $\mathbf{Ps = As \times E} = (6.08 \times 10^{+18})\ m^2 \times (6.42 \times 10^7)\ W/m^2$

$= 3.83 \times 10^{+26}$ W

Solar irradiance, Pe

Distance of the earth from the sun $D = 1.49598 \times 10^{+11}$ m and area of a sphere at this distance from the sun is $A_D = 4 \times 3.14 \times D^2 = 4 \times 3.14 \times (1.49598 \times 10^{+11})^2\ m^2 = 2.81 \times 10^{+22}\ m^2$.

Then the Total Solar Irradiance (TSI) at earths distance can be calculated as follows:

(3.3.3) **TSI = Ps/A_D** = $3.83 \times 10^{+26}$W/$2.81 \times 10^{+22}$ m^2 = 1361.7 W/m^2

TSI (1361.7 W/m^2) is also called as solar constant. However, it is not constant, but variable because of distance from the sun to earth (eccentricity) and total power of the sun (sunspots) is changing.

We can also calculate the power received by the earth (P_e):

(3.3.4) **$P_e = A_e$ x TSI**

Where A_e = area of earth's shadow in plane

$= 3.1415 \times R_e^{\ 2}$

$= 3.1415 \times (6.371 \times 10^6)^2$ m2

$= 1.275 \times 10^{+14}\ m^2$

$P_e = 1.275 \times 10^{+14}\ m^2 \times 1361$ W/m2

$= 1.735 \times 10^{+17}$ W

Irradiance of the earth, Ee

Then, we can calculate how much radiation Ee is leaving the earth.

(3.3.5) Ee = total earth irradiance = Pe/Ae

Where Ae = area of earth's surface = 4 x 3.14 x Re^2 =

$= 4 \times 3.1415 \times (6.371 \times 10^6)^2$

$= 5.10 \times 10^{+14}\ m^2$

Ee = Pe / Ae

$= 1.735 \times 10^{+17}$ W / $(5.10 \times 10^{+14}\ m^2)$

= 340.2 W/m^2

We can then look to earth's energy balance where the incoming radiation (341 W/m^2) is the same as reflected energy (102 W/m^2) + outgoing radiation (239 W/m^2) (Figure 3.3.1). Albedo is reflected energy (102 W/m^2) divided by incoming energy (341 W/m2) or about 0.3. It should be noted that albedo depends on the surface of the ground (fresh snow about 0.8 - 0.9, desert sand about 0.4, open seas and asphalt 0.05 - 0.1).

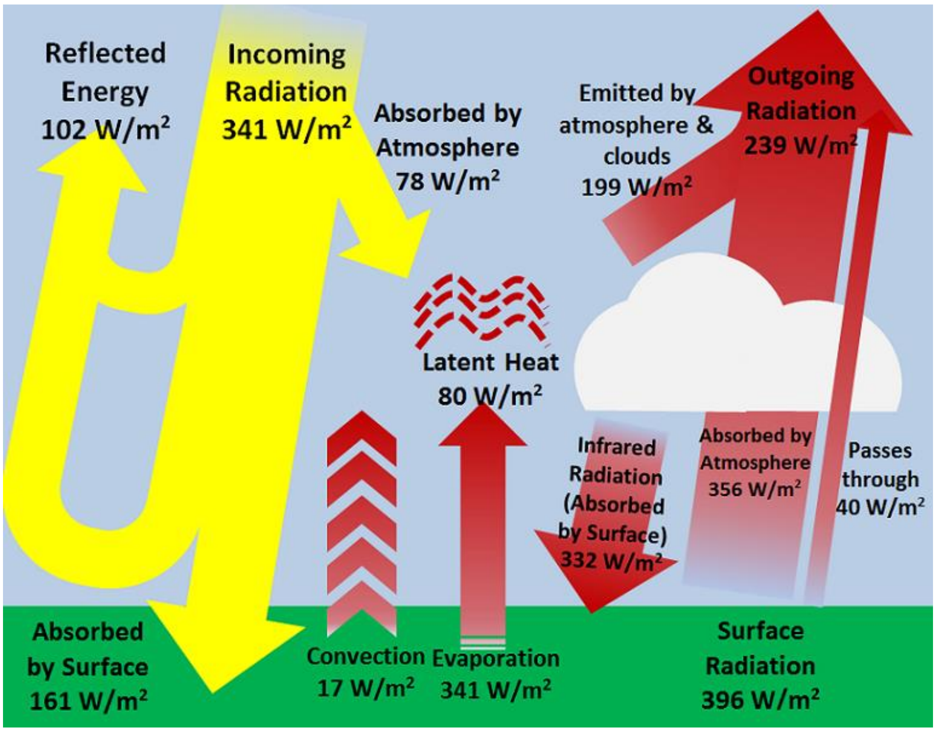


Figure 3.3.1 Earth's energy balance

(*http://energyeducation.ca/encyclopedia/Earth%27s_energy_budget*)

Climate forcing of energy production, Fep

Global energy consumption (GEC) is today about 13,500 Gtoe/a or 157,000 TWh. Year can be divided to 8766 hours and thus the energy output of energy production EP = 157,000 TWh/8766h = 1.79 x 10^{+14}W. If divided by the earth's surface, we get primary energy output per m^2 or climate forcing of energy production, Fep

(3.3.6) $\quad$ Fep = EP/A = $(17.91\text{x}10^{+12})$ W/ $(5.10 \text{ x } 10^{+14})$ m^2

$= 0.35$ W/m^2

Fep is about 0.1 % of earths irradiance Ee (340.2 W/m^2).

Effective temperature of the earth (Te)

Finally, we can solve the T from the Stefan-Boltzmann formula (3.3.1) and calculate the effective temperature of earth, Te, as follows:

(3.3.7) $\quad$ $Te = (Ee(1\text{-}\alpha) / \sigma)^{1/4}$

Where $\quad$ Ee = 340.2 W/m^2

α = albedo = 0.3

$Te = (340.2 \text{ x } 0.7 / 5.67 \text{ x } 10^{-8})^{1/4}$

= 254.6 K= 254.6-273.2 C

= -18.4 C

However, the measured temperature of the air at 1.5 m level from the ground is about 15 deg. C. Effective earth's temperature Te = - 18.4 deg. C corresponds the temperature at a higher level than 1.5 m from the ground.

Adding global energy production Fep (0.35 W/m^2) to Ee (340.2 W/m^2) in formula 3.3.7 rises global temperature by 0.065 deg. C. This has been concentrated in cities, which means that temperature in cities can be considerably higher than elsewhere.

Variation of solar irradiance

Total solar irradiance has been measured by satellites since 1976. The average of TSI has been during years 1976 – 2015 only 1360.95 W/m^2 (Figure 3.3.2).

TSI follows 11-year solar cycle and has its peaks during years 1999 – 2003 and 2011 – 2015. We can find from the figure that the last peak was much lower than the three earlier peaks. This indicates that that the 11-year average irradiance has been declining during years 2008 – 2017. This is the reason, why the measured TSI (1360.95 W/m^2) is smaller than the theoretical TSI (1361.7 W/m^2) evaluated by the formula 3.3.3.

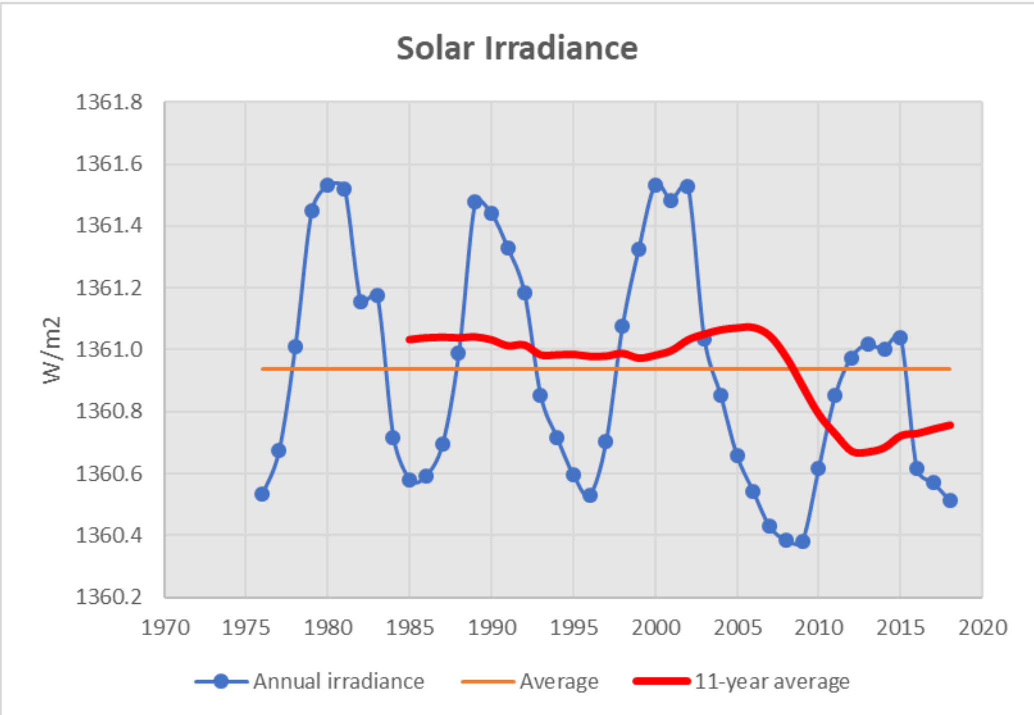


Figure 3.3.2 Solar irradiance follows 11-year solar cycle (annual average figures and 11-year averages) (irradiance data source: Virgo).

The total solar irradiance follows the same 11-year cycle as the number of sunspots (Figure 3.3.3).

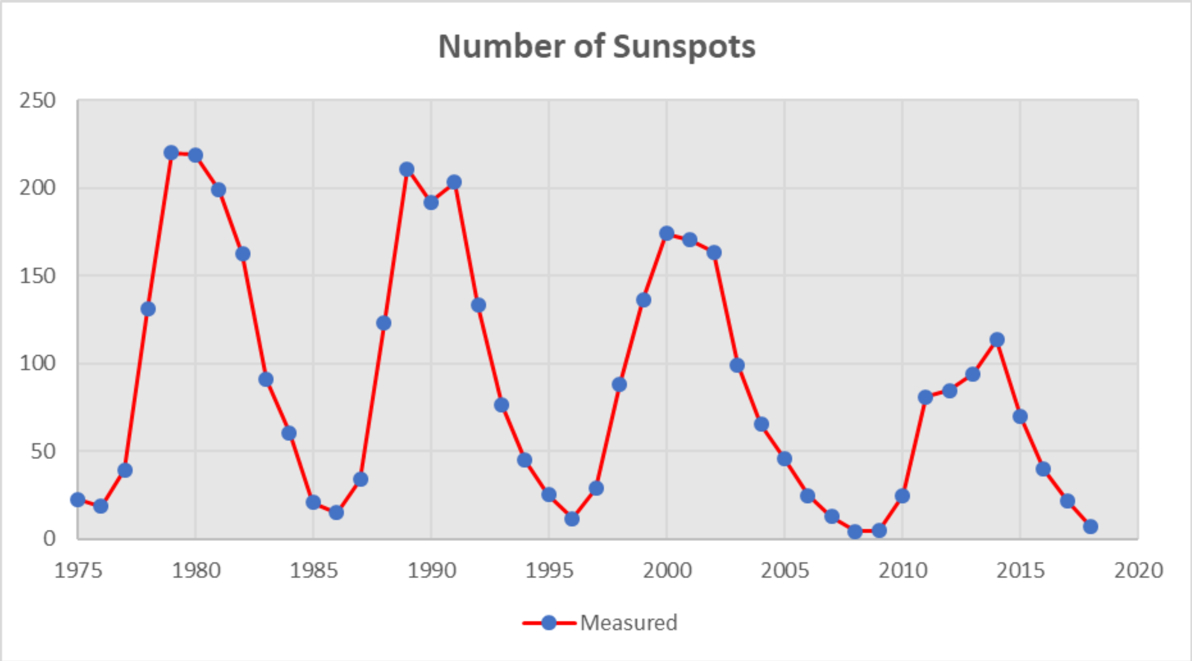


Figure 3.3.3 Sunspot-curve after year 1975 has the same form as solar irradiance.

If the number of sunspots and irradiance are combined in a XY-diagram, we can find that they have nonlinear relationship (Figure 3.3.4).

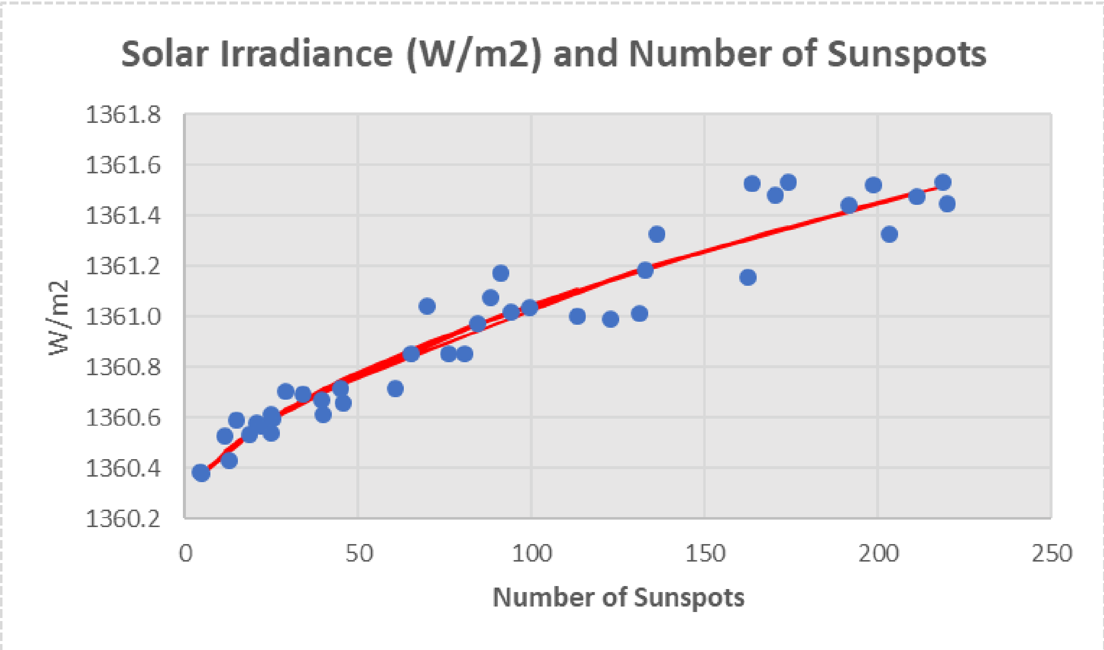


Figure 3.3.4 Solar irradiance is following sunspots with nonlinear relationship.

The total solar irradiance (TSI) follows following formula:

(3.3.8) $$TSI = 1360.202+SQRT(SPOTS/175) + 0.0009*SPOTS$$

Where TSI = Total Solar Irradiance (W/m2)

SQRT = square root (mathematical function)

SPOTS = number of sunspots (number)

The formula is proportional to the square root of sunspots. This means that, if the number of sunspots drop from 60 to zero, the irradiation will change the same amount, when the number of sunspots will change from 60 to 210.

When we know the function between sunspots and irradiation, we can then present global temperature as a function of irradiance. The irradiance for years 1890 – 1950 has been evaluated using the formula (3.3.4) and presented in a XY-diagram (Figure 3.3.5). It will show that, if irradiance is varying from 1360.75 to 1361.05 the temperature will vary from -0.10 to 0.34 deg. C.

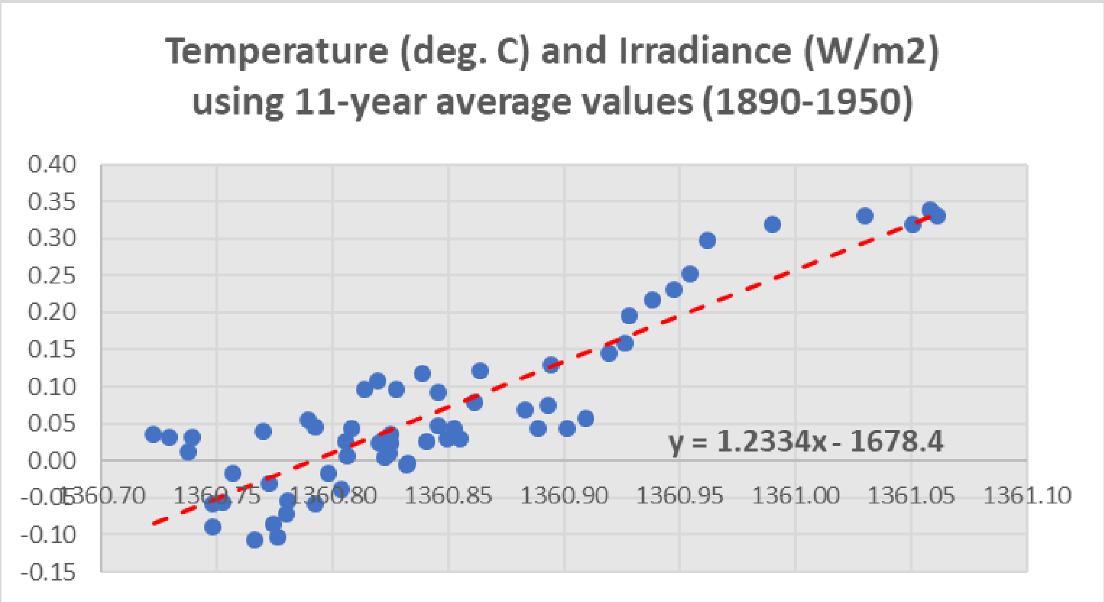


Figure 3.3.5 Temperature change as a function of irradiance (W/m^2) during years 1890 – 1950 using 11-year averages.

From the Figure 3.3.5 we will get the equation for warming caused by total solar irradiance:

(3.3.9) $$dT = 1.2334 \times TSI- 1678.4$$

$$dT = 1.2334 \times (TSI - 1678.4/1.2334)$$

$$\mathbf{dT = 1.2334 \times (TSI - 1360.79)}$$

Where dT = change in global temperature (deg. C)

TSI = total solar irradiance (W/m2)

3.4 Solar irradiance and temperature changes

We know sunspot data since the year 1700 thus it is possible to evaluate irradiance and temperature data for years 1700 – 1900. The irradiance data has been reconstructed in Figure 3.4.1. The trend in irradiance seems to be upwards with formula TSI = 0.0005 x Year + 1360. Temperature changes follow the irradiance with formula T = 0.0006 x Year – 1.022 (Figure 3.4.2).

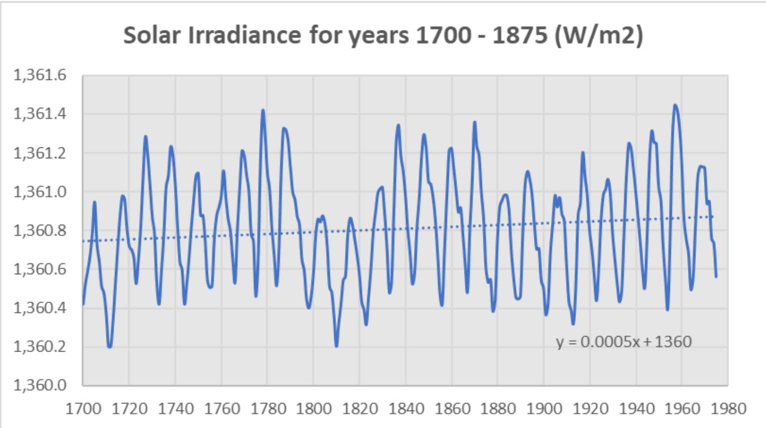


Figure 3.4.1 Reconstructed solar irradiance based on sunspot numbers.

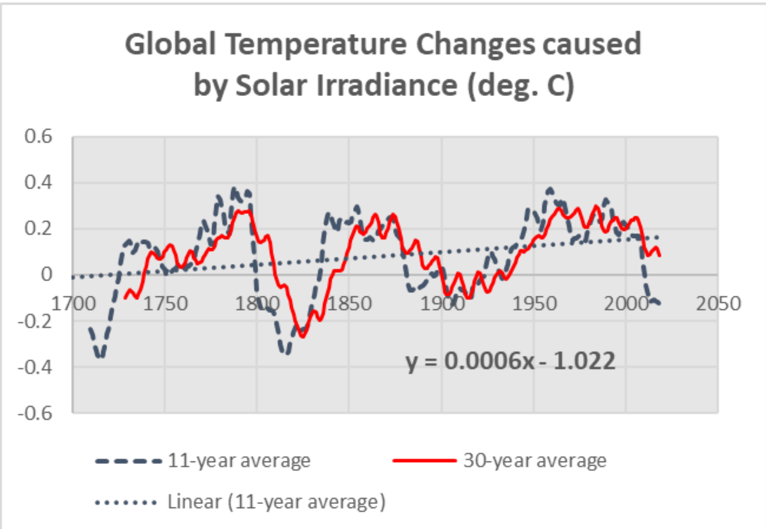


Figure 3.4.2 Global temperature as reconstructed from solar irradiance (Figure 3.4.1).

We can then separate the temperature history in two components, where one component presents solar irradiance and the other reasons (Figure 3.4.3 and Figure 3.4.4). Then we do know the influence of solar irradiance since 1710 (11-year averages) and other reasons since 1900. We can find from the Figure 3.4.4 that main reason for global warming until the year 1990 has been the solar irradiance. After 1990 the global warming has been mainly caused by the other reasons, where the anthropogenic global warming (AGW) seems to be the main reason.

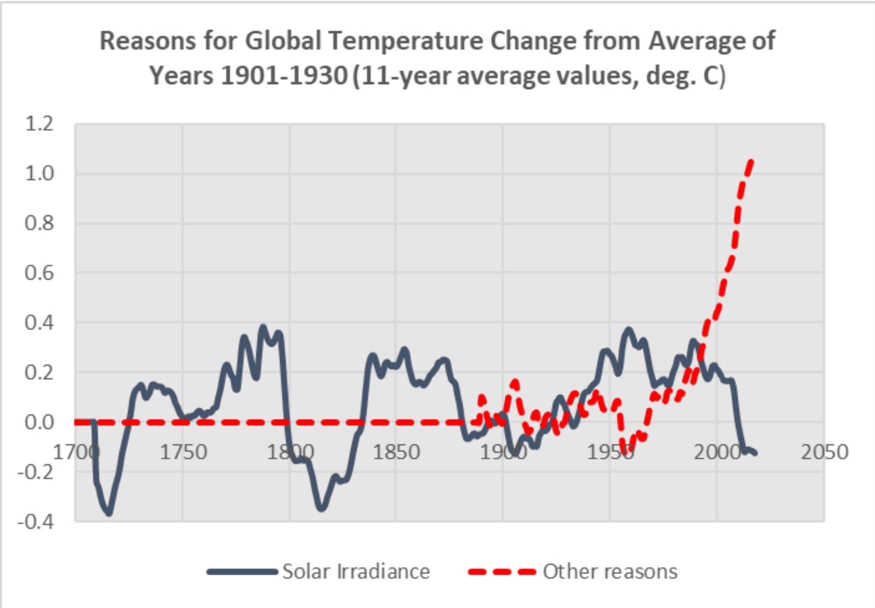


Figure 3.4.3 Reasons for global temperature changes during years 1710-2018 (11-year averages deviation from 1901-1930 average).

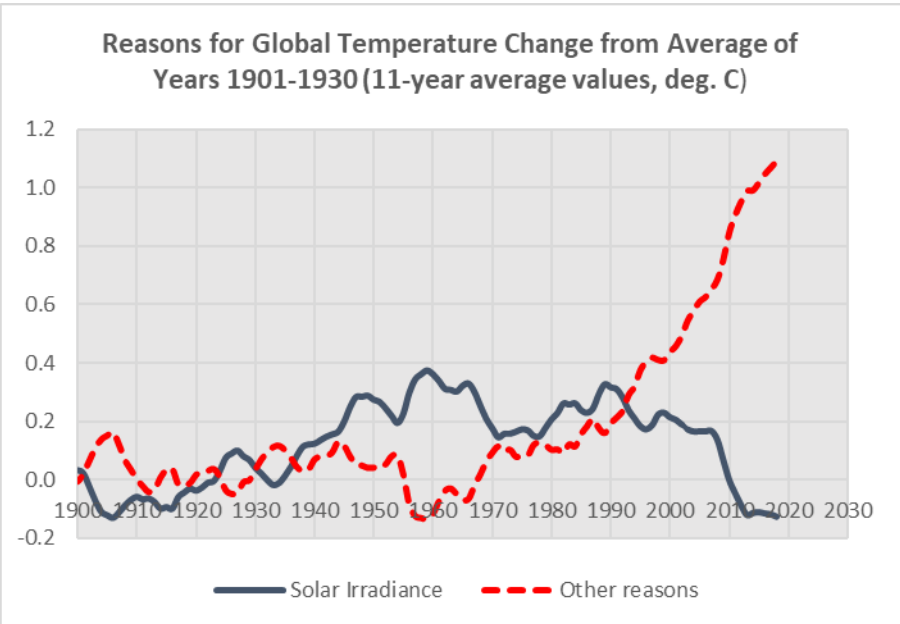


Figure 3.4.4 Reasons for global temperature changes during years 1890-2018 (11-year averages deviation from 1901-1930 average).

Very similar results have reached by Swiss scientists J. Beer et. Al. in their study (*The role of the sun in climate forcing, Quarternary Science Reviews 19. 2000 400-403*), where they have published Figure 3.4.5.

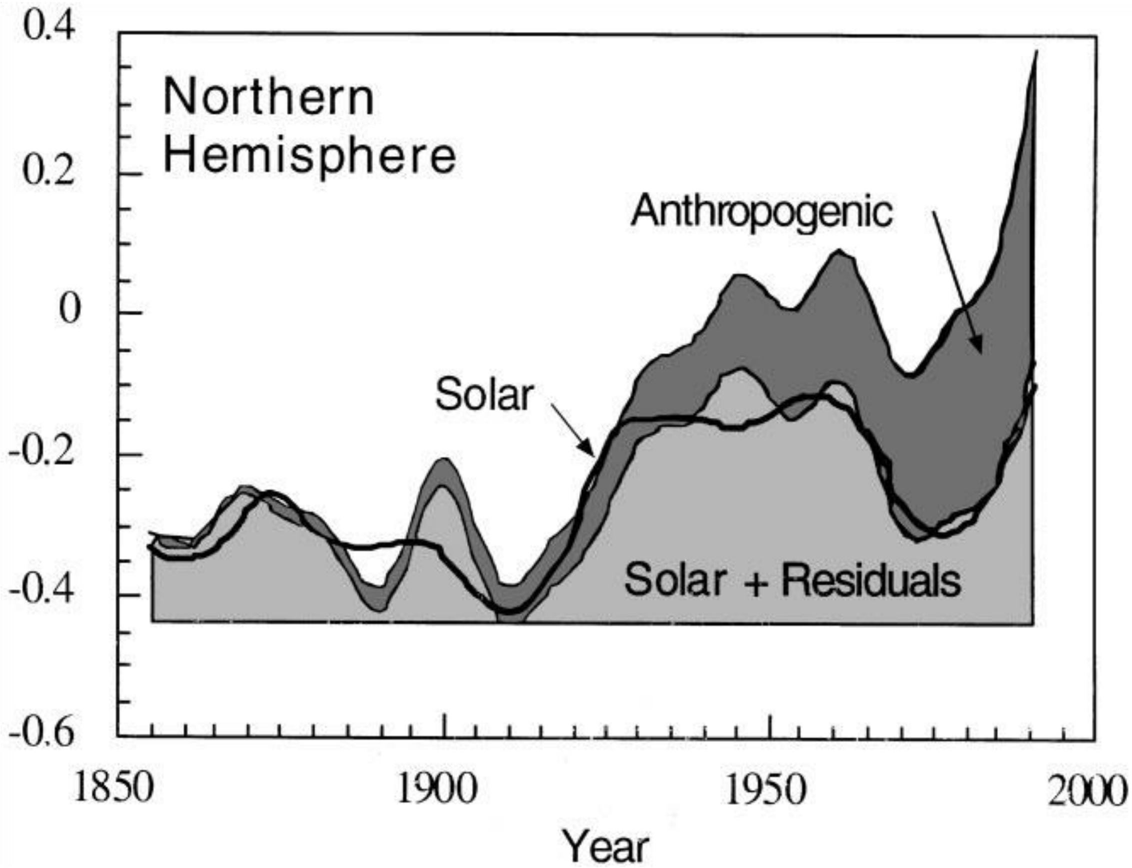


Figure 3.4.5 Reasons for warming in Northern Hemisphere (J. Beer et. Al. 2000).

We can find from the Figure 3.4.5 that sun has influenced to temperature more than other reasons combined until the year 1980. After the year 1980 anthropogenic (caused by man’s actions) reasons have been dominating. They have been summarized in the paper:

The Sun is by far the most important driving force of the climate system. But little is known what role solar variability plays in past and present climate change.

After the year 1900 influence of the sun has been evaluated to increase global temperature by trend value of 0.0017 degrees annually. This means that the temperature has been increasing about 118 x 0.0017 = 0.20 degrees (Figure 3.4.6).

However, the 11-year average temperature has been about -0.1 deg. C lower than the average temperature during years 1901-1930 and the 30-year average temperature is still about + 0,1 deg. C higher than the average during the years 1901 – 1930.

Because the solar radiation has a 99-year cycle, the temperature future temperature will probably decrease so that the long-term trend is horizontal.

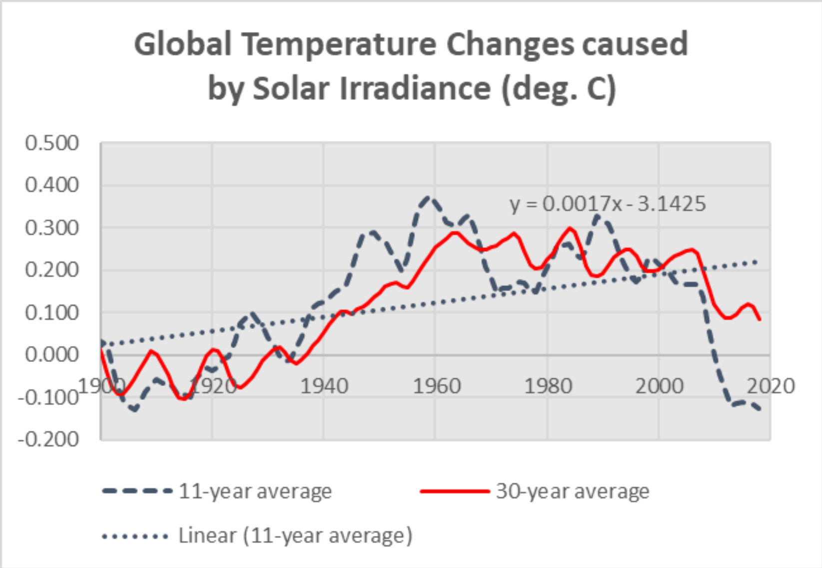


Figure 3.4.6 The global temperature change caused by solar irradiance.

If the influence of the sun will be eliminated, the other reasons for global warming will remain. This is mainly anthropogenic global warming (AGW) caused by actions of man (Figure 3.4.7). The other reasons have warmed the globe from the years 1890-1930 with about 0.1 deg. C until the year 1985 and 1.09 deg. C until the year 2018.

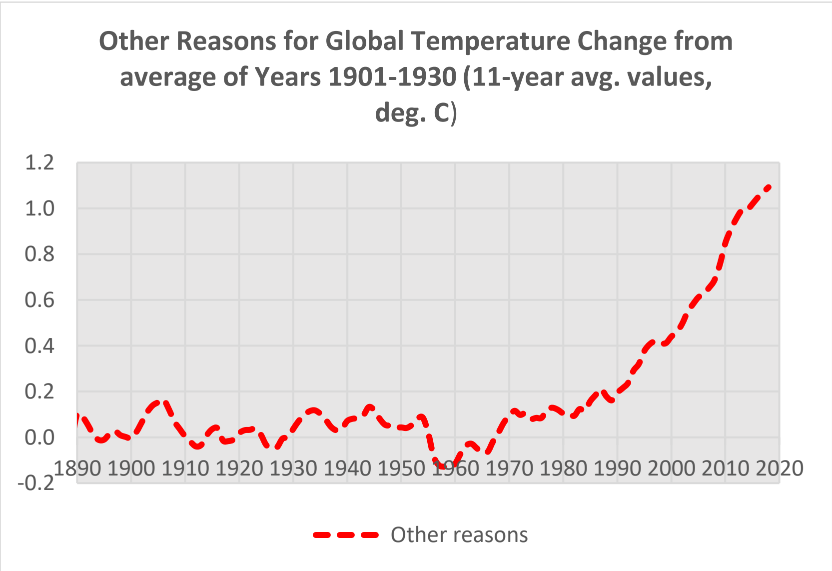


Figure 3.4.7 Global warming from 1901 – 1930 after correction of sun irradiance using 11-year average temperatures.

If we calculate trends of global warming after the year 1990 (Figure 3.4.8), we will find that the global warming trend after correction of sun irradiance follows formula (3.4.1).

(3.4.1) $$\mathbf{dT = 0.0336 \times (Year - 1985.6)}$$ (See Figure 3.4.8)

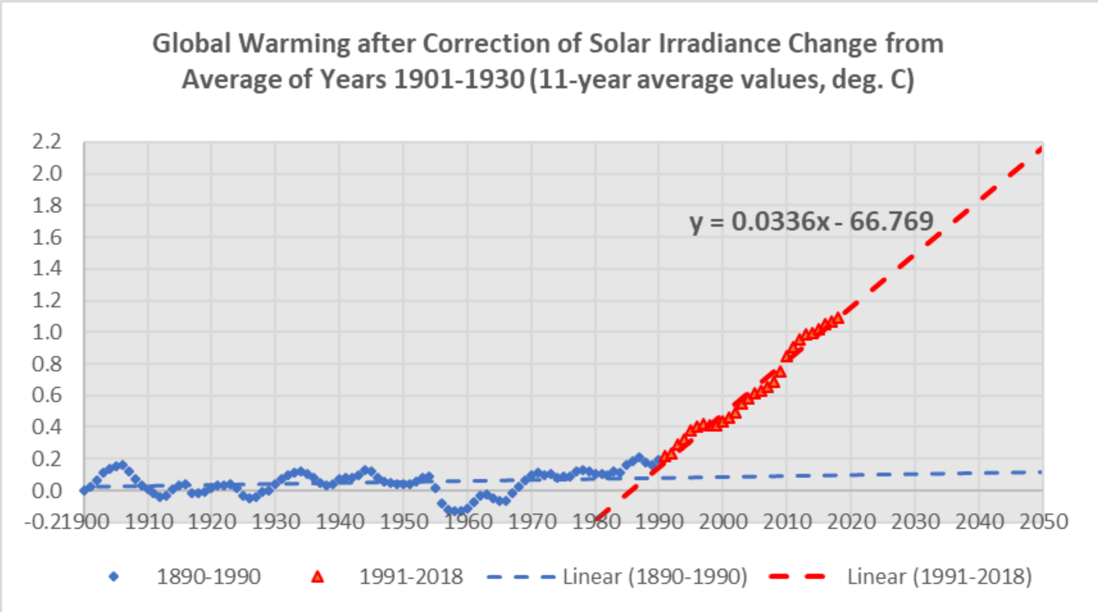


Figure 3.4.8 Global warming trends from 1901 – 1930 after correction of sun irradiance using 11-year average temperatures.

Warming trend is 0.34 degrees C in decade or 3.4 degrees C in a century. This will mean that the 1.5-degree limit will be achieved in the year 2030 and the 2.0-degree limit in the year 2045.

3.5 Long term temperature measurements and irradiance

The reconstructed global temperature can be compared with actual temperature measurements. One of them in De Bilt in Holland, where the continuous measurements were started in the year 1706. Thus, we have 30-year average measurement from this site since 1736 (Figure 3.5.1).

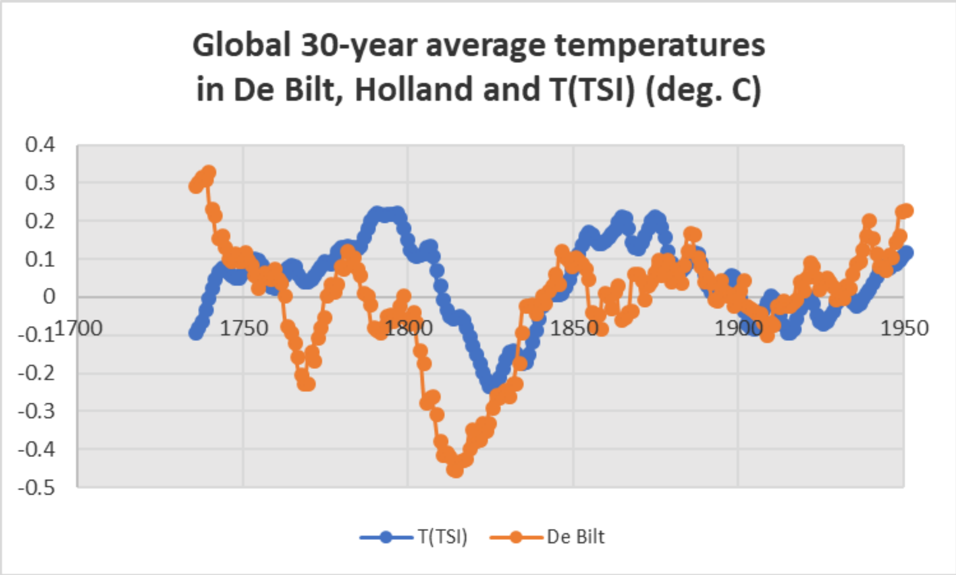


Figure 3.5.1 30-year average temperature measurements in De Bilt and reconstructed global temperature T(TSI) caused by sun irradiance.

The figure indicates that temperature on the ground level follows the fluctuation of the solar irradiance. If we put the actual 30-year average temperatures at De Bilt and reconstructed temperatures, T(TSI), in XY-diagram, we can find that T(TSI) explains about 60 % of the variation in ambient temperature in De Bilt in Holland during years 1750 – 1950 (Figure 3.5.2).

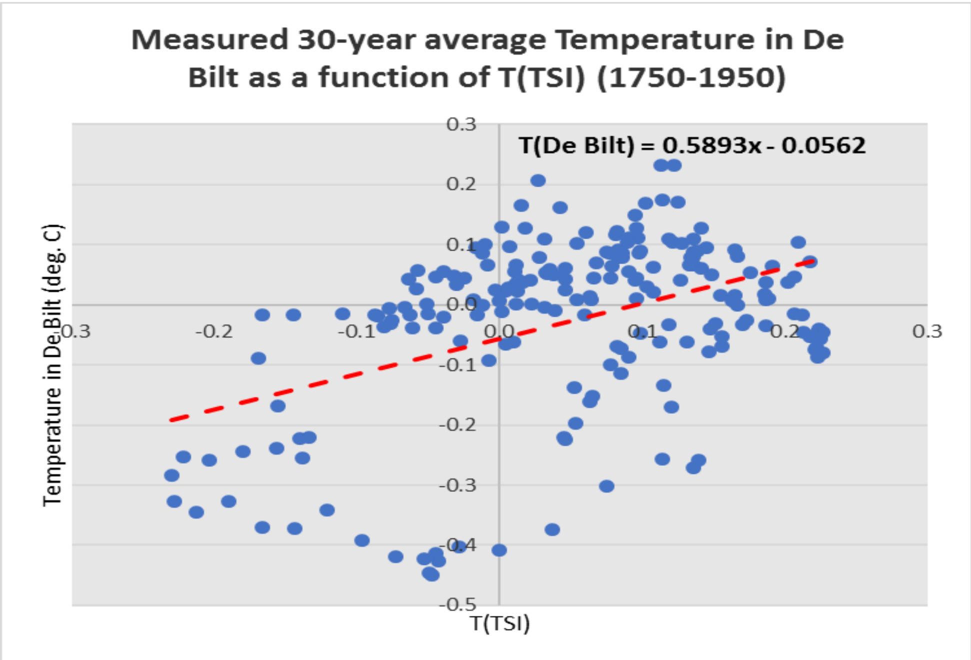


Figure 3.5.2 30-year average temperature in De Bilt, Holland as a function of reconstructed global temperature T(TSI) calculated from irradiance.

A formula for calculating temperature in De Bilt changes has the form:

(3.5.1) **T (De Bilt) = 0.59 x T(TSI) - 0.056**

Where T (De Bilt) = temperature change in De Bilt, Holland

T(TSI) = reconstructed global temperature calculated from solar irradiance (see formula 3.4.1)

The local temperature in De Bilt seems to follow very closely sun irradiance, which can explain about 60 % of the temperature changes between years 1750 – 1950.

4 CARBON DIOXIDE

4.1 Concentration of CO_2

Carbon dioxide (CO_2) is a product of burning of coal (C), when coal molecules and oxygen molecules (O_2) are forming carbon dioxide (CO_2).

Measurements of carbon dioxide in the air was started by **Charles David Keeling** (1928 – 2005) in Mauna Loa, Hawaii. He used an infrared (IR) gas analyzer, which measures strength of IR radiation at specific wavelengths, when IR radiation is transmitted thru a sample of air and then measured the strength of IR radiation after the beam has gone thru the sample. Transmittance of IR radiation depends on wave length and if CO_2 is in the gas transmittance is 80 % at 9.4 µm wave length and near zero at 2.7, 4.3 and 15 µm wave lengths (Figure 4.1.1)

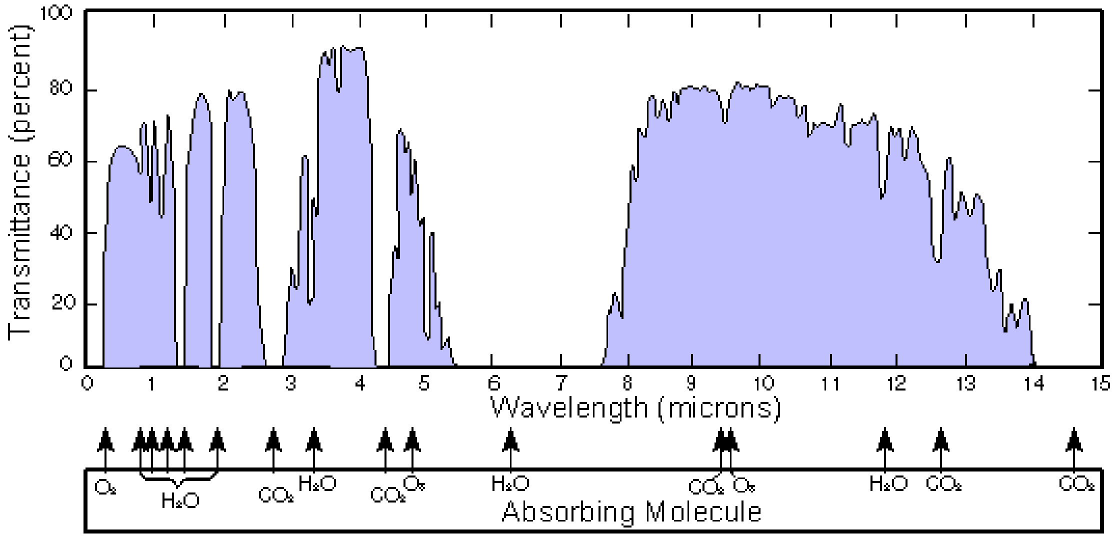


Figure 4.1.1 Transmittance of gases in IR analyzer.

Measurement of carbon dioxide concentration are being made by infrared detectors, which send infrared signal through a chamber (Figure 4.1.2) and then measuring the strength of IR-signal after it has passed through the chamber. These measurement principles should proof everybody that CO_2 is absorbing IR radiation. Those who think that carbon dioxide warming is not true, could contact Vaisala, which is a manufacturer of CO_2 detectors.

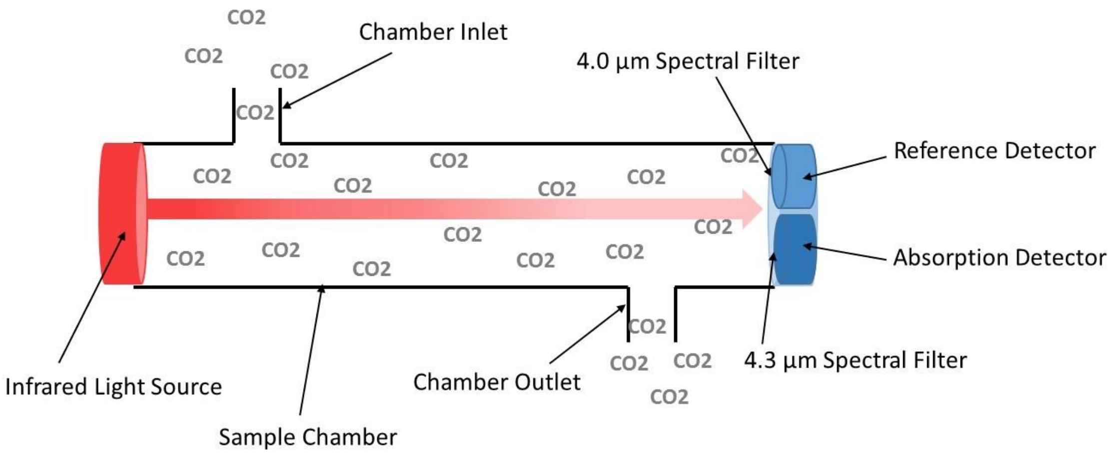


Figure 4.1.2 Measurement principle of CO_2 content in air (Source: Vaisala).

Keeling started his measurements of concentration of CO_2 in 1958 in Mauna Loa, Hawaii. His first result was 314 ppm (parts per million). The continuous measurements have been made since the and first full year was 1959, when the annual average was 316.0 ppm.

The measurements made thereafter indicate continues rising of CO_2 level in the atmosphere (Figure 4.1.3). CO_2 concentration in Mauna Loa has been rising with increasing trend. It was rising with 1 ppm annually in 1970 and about 2.3 ppm annually in 2017 (Figure 4.1.4).

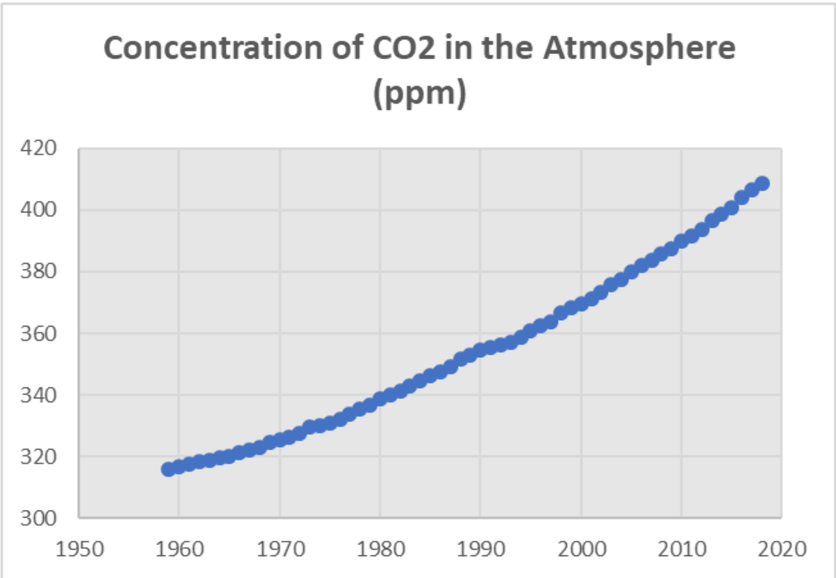


Figure 4.1.3 Concentration of CO_2 in Mauna Loa.

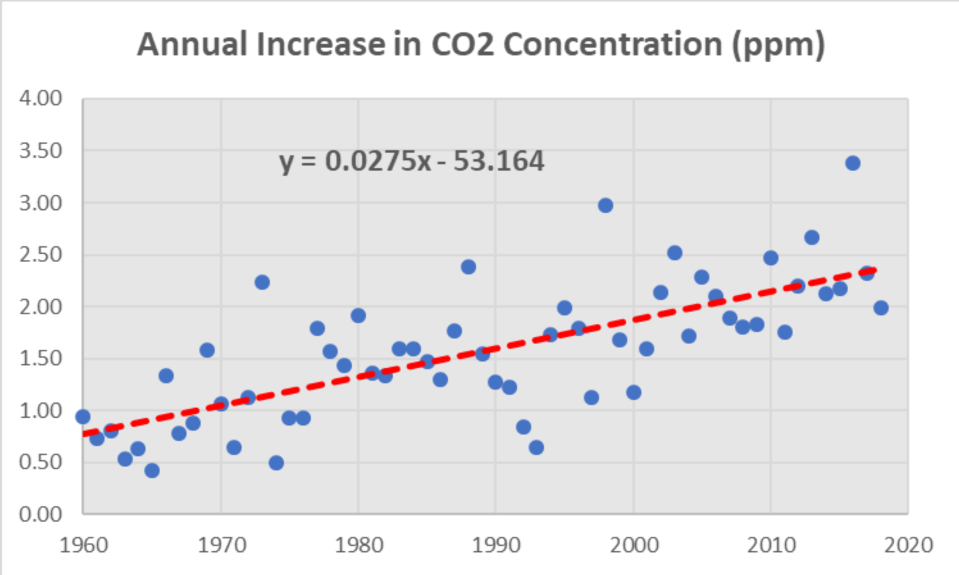


Figure 4.1.4 Concentration of CO_2 in Mauna Loa.

4.2 CO_2 emissions from fuels

Historical energy data of world since 1850 have been documented in three sources: *Die Welt in Zahlen 1850-1900, EIA Statistics 1900-1960 and BP 1960- 2018*. The primary energy was dominated by coal until the year 1960 (Figure 4.2.1).

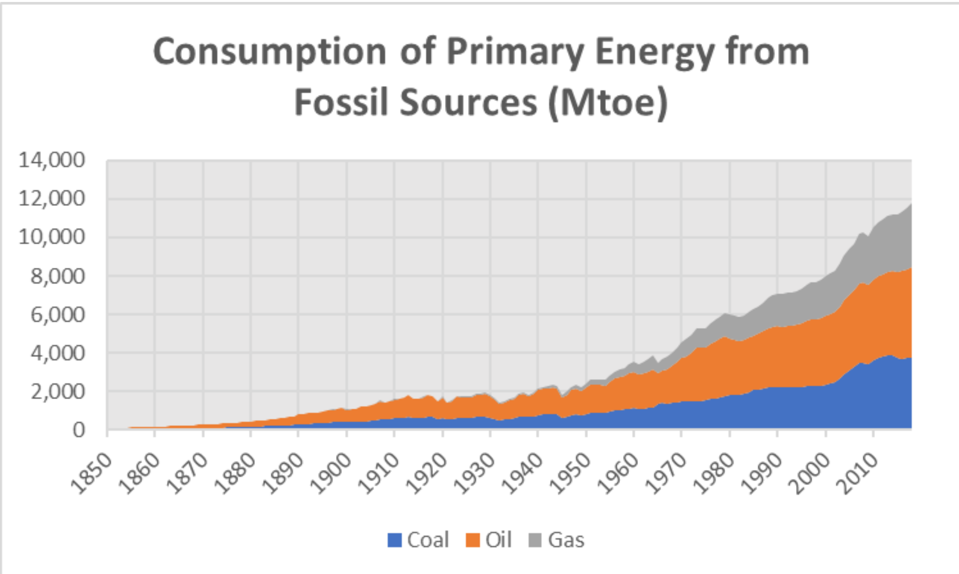


Figure 4.2.1 Consumption of primary energy in the world (Source: Die Welt in Zahlen 1850-1900, EIA Statistics 1900-1960 and BP Statistics 1960- 2018).

Using the EIA data, the CO_2 emissions have been increasing from 11 Gt/ year to about 35 Gt/a in 2018 (Figure 4.2.2). The cumulative emissions have been increasing from about 200 Gt in 1965 to about 1790 Gt in 2018 (Figure 4.2.3). The form of the curve is identical to CO_2 concentration given in Figure 4.1.3.

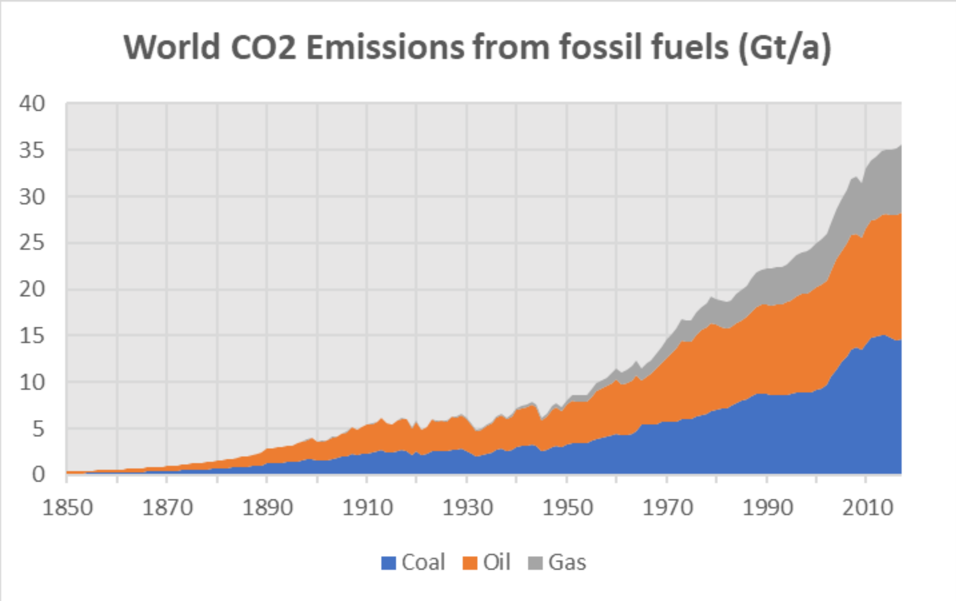


Figure 4.2.2 CO_2 emissions of fossil fuels (Source: Die Welt in Zahlen 1850-1900, EIA Statistics 1900-1960 and BP 1960- 2018).

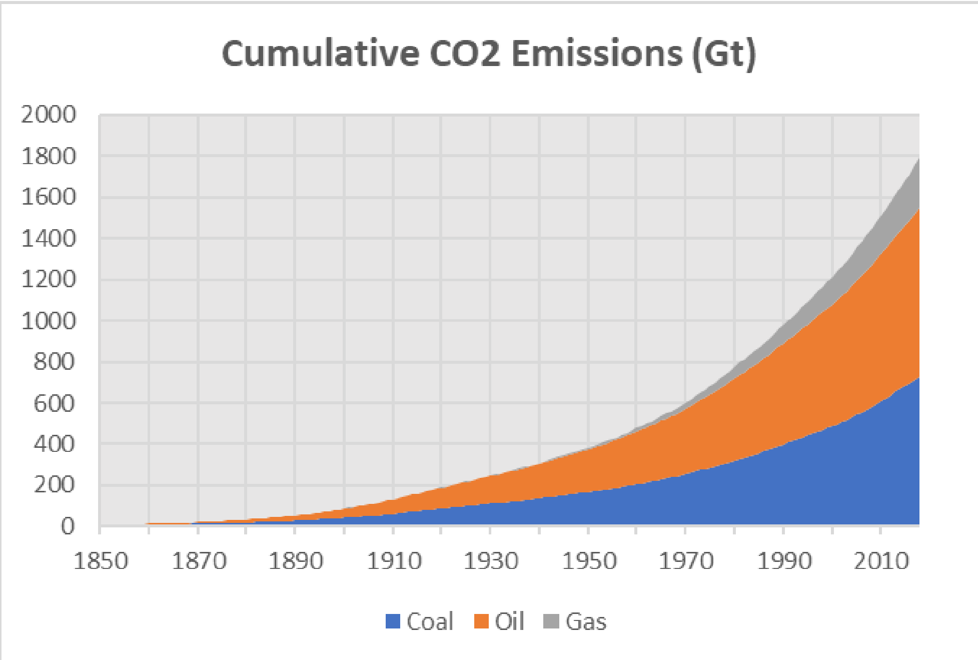


Figure 4.2.3 Cumulative CO_2 emissions of fossil fuels (Die Welt in Zahlen 1850-1900, EIA Statistics 1900-1960 and BP 1960- 2018).

However, there will be resource limits for future emissions. According the British Petroleum Statistical Yearbook 2018 the proved reserves of fossil fuels are about 1035 Gtoe (Table 4.2.1). Consumption of fossil fuels was 11.3 Gtoe in 2017. Thus, the resources will be exhausted in 91 years, if the consumption continues at present level.

Table 4.2.1 Proved reserves of fossil fuels (Gtoe, Source BP statistics 2018).

Countries	Coal	Oil	Gas	Total
USA	153.0	6.0	7.4	166.5
EU	46.5	0.6	1.0	48.1
Russia	97.8	14.5	29.6	142.0
Australia	88.3	0.4	3.1	91.8
China	84.7	3.5	4.6	92.8
India	59.6	0.6	1.1	61.2
Saudi Arabia	-	36.6	6.8	43.4
Rest of the world	101.3	177.1	110.3	388.7
Total	631.4	**239.3**	**164.0**	**1034.6**
Consumption 2017	**3.7**	**4.6**	**3.1**	**11.3**
R/C (Years)	**170.4**	**52.4**	**53.4**	**91.2**

If all fossil fuel reserves will be burned the future emissions will be about 3590 $GtCO_2$ (Table 4.2.2). The total emissions will be then cumulative emissions until present (1490 Gt) plus the emissions from fuel reserves (3590 Gt) or totally 5086 $GtCO_2$. If the remaining resources will be burned in 91 years, the emissions will be 3592 Gt/92 or 39 $GtCO_2$/year. However, the additional resource found by the will make possible the continue in this level for another hundred and fifty years.

Table 4.2.2 Potential future CO_2 emissions of world's fossil fuel reserves.

Countries	Coal	Oil	Gas	Total
USA	600	18	17	636
EU	182	2	2	187
Russia	383	45	69	497
Australia	346	1	7	355
China	332	11	11	353
India	234	2	2	238
Saudi Arabia	-	112	16	128
Rest of the world	397	543	258	1,199
Total	2474	734	384	**3,592**
Emissions until 2017	719	790	233	1,741
Total	**3193**	**1524**	**616**	**5,334**

The ultimate recoverable reserves are about three times of the known reserves. Thus, the theoretical cumulative emissions will be about 12,300 Gt (Table 4.3.3). The remaining resources will be able to emit ta todays 34 Gt/a level for the next 300 years (8547/34).

Table 4.2.3 Emissions of CO_2, ultimate fossil fuel resources will be burned.

Countries	Coal	Oil	Gas	Total
USA	1,799	55	52	1,907
EU	547	6	7	560
Russia	1,150	134	208	1,492
Australia	1,038	4	22	1,064
China	995	32	33	1,060
India	701	6	7	714
Saudi Arabia	0	337	48	385
Rest of the world	1,191	1,630	775	3,596
Total	**7,423**	**2,203**	**1,151**	**10,777**
Emissions until 2017	719	790	233	1,741
Total	**8,142**	**2,993**	**1,384**	**12,519**

4.3 CO2 emissions of forests and cement production

Additionally, forests have caused global CO_2 emissions, which have been measured properly only since 1990. "The data of world forest" has been given in a document, which I have collected from Fao data. The document can be downloaded from home page of Ekoenergo (http://ekoenergo.fi/page79.php). According to FAO statistics the net emissions caused by the forests have been changing between 2.0 and 1.1 Gt annually (Figure 4.3.1). There are countries, which were acting as carbon sinks, but more countries which were destroying forests.

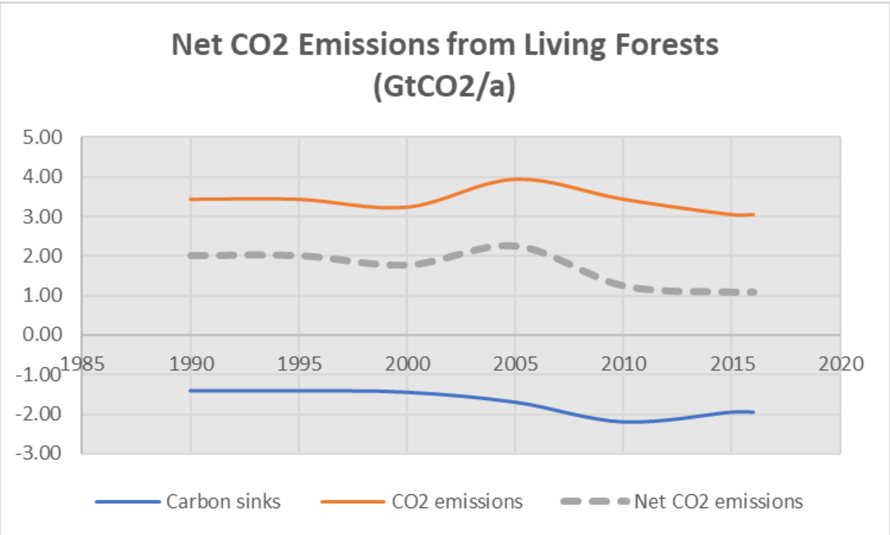


Figure 4.3.1 CO_2 emissions of forests since 1990 (Source FAO Statistics).

The top five countries in CO2 emissions of forests have been given in Figure 4.3.2. Indonesia has caused about 1 GtCO2 emissions annually. Emissions in Brazil have been decreasing, but the total these five have been remining nearly at the same level as in 1990.

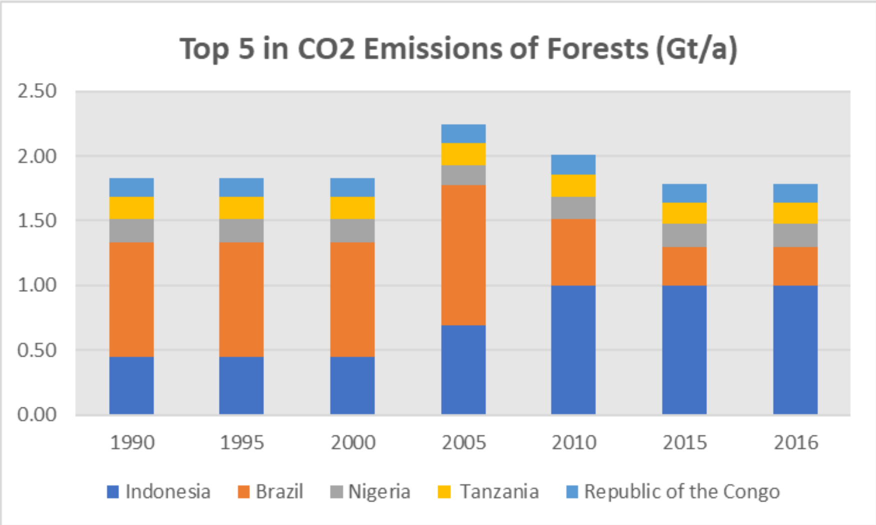


Figure 4.3.2 Largest CO2 emissions from forests (Data of World Forests).

Top five countries in carbon sinks have been given in Figure 4.3.3. They include USA, China and Russia Federation. The total sinks of these five have been remaining at level of 0,8 GtCO2/a.

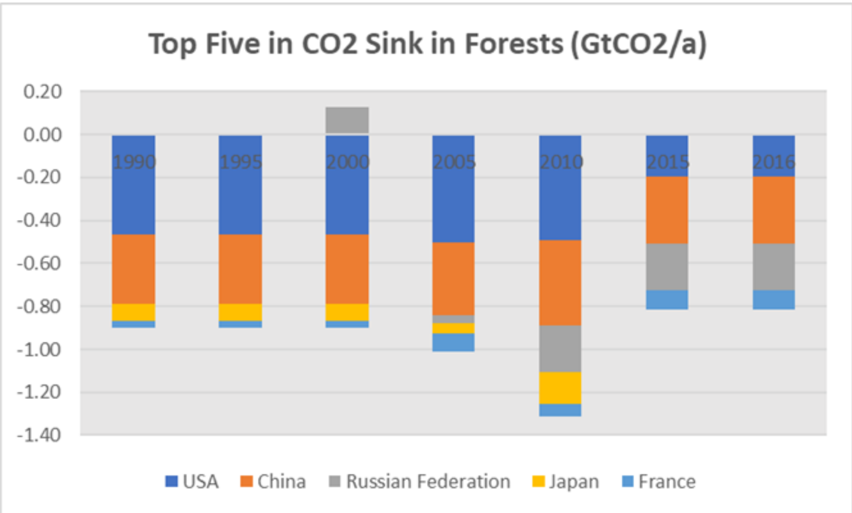


Figure 4.3.3 Largest Carbon sinks in forests (Data of World Forests).

Also cement production is causing CO_2 emissions because the raw material $CaCO_3$ has carbon. The chemical process has formula $CaCO_3 \rightarrow CaO + CO_2$. The CO_2 emissions from cement manufacturing are today about 1.5 GtCO2 annually (Figure 4.3.2).

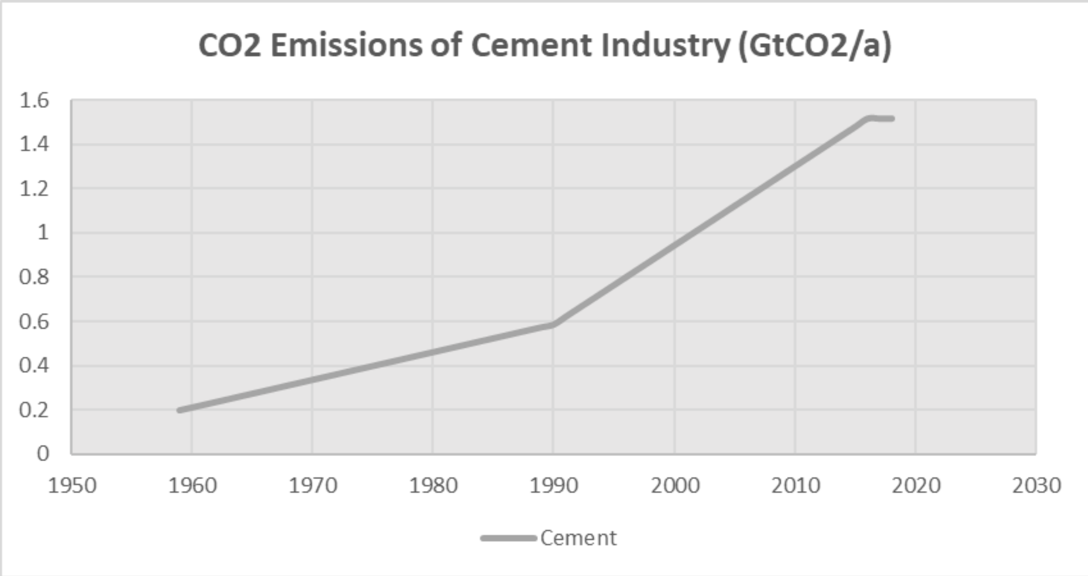


Figure 4.3.2 CO_2 emissions from cement industry.

The forest emissions have been larger than fuel emissions before 1890. (Figure 4.3.3), but the actual figures have not been published. Today, the total emissions are about 32 Gt, where forest emissions are about 1.1 Gt (3 %) and cement emissions are 1.5 Gt (4 %).

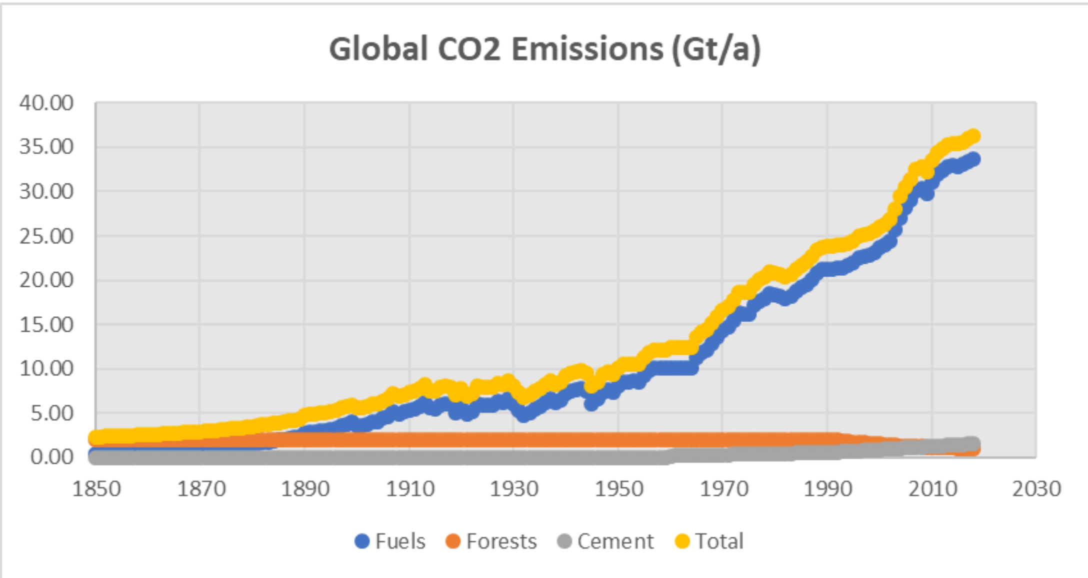


Figure 4.3.2 Annual CO_2 emissions since 1850.

The cumulative CO_2 emissions including the forest and cement sectors have increased to about 2155 Gt since 1850 (Figure 4.3.4), where emissions from fuels are 1785 Gt and forest emission about 330 Gt and cement emissions 40 Gt.

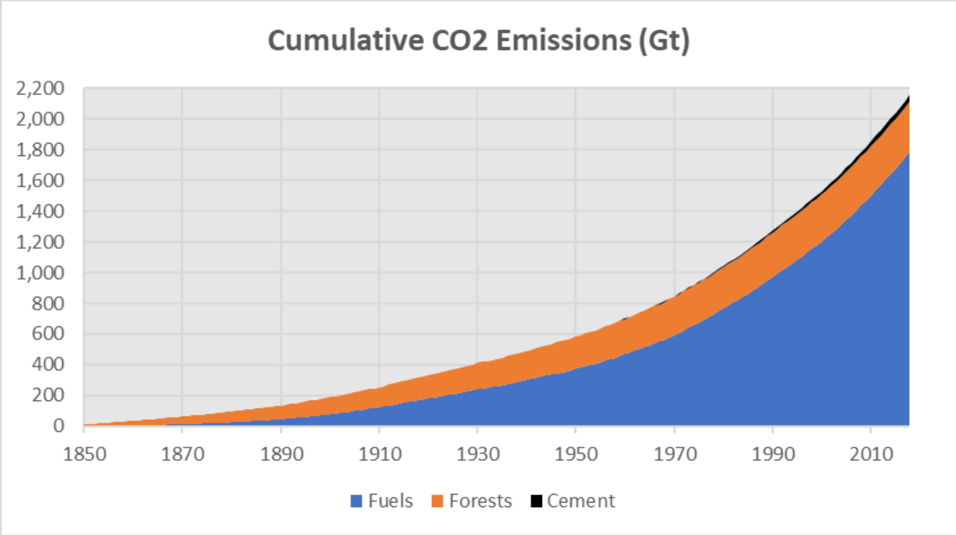


Figure 4.3.4 Cumulative CO_2 emissions of fuels, forests and cement production.

The future emissions have been estimated using six scenarios: trend (emissions continue with trend 1960-2018), constant (emissions remain at 2018 level) and saving with 1 %, 2 %, 3 % and 4 % annually and target emissions (Figure 4.3.5). With the present trend emissions will be 70 Gt by 2100 and will reduced 2%/a after 2100 because the fuels will be exhausted.

More important are the emission development until the year 2050 (Figure 4.3.6). With about 2 % annual saving the CO_2 emissions will be 18 Gt in the year 2050. The same result will be achieved, if the emissions will follow a realistic target, where the saving will start only after the year 2025.

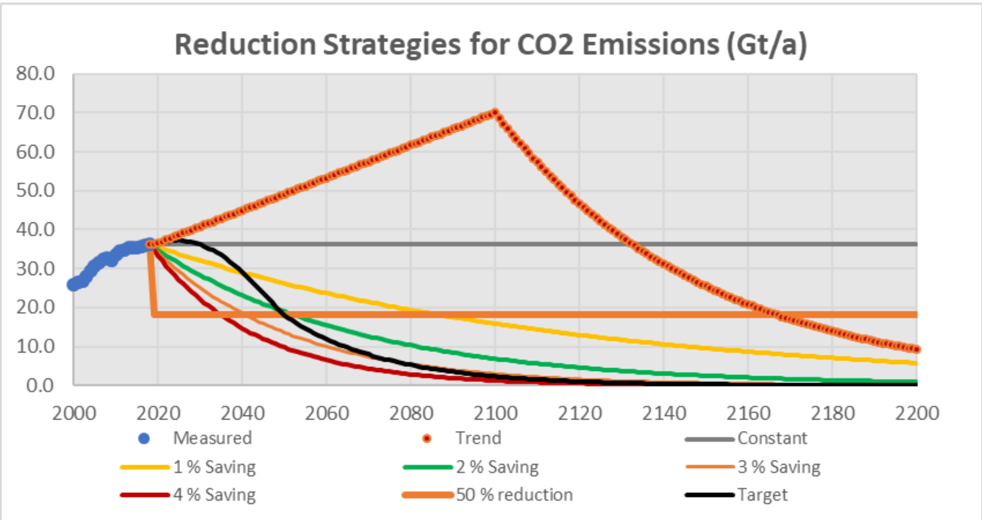


Figure 4.3.5 Reduction strategies for CO_2 emissions.

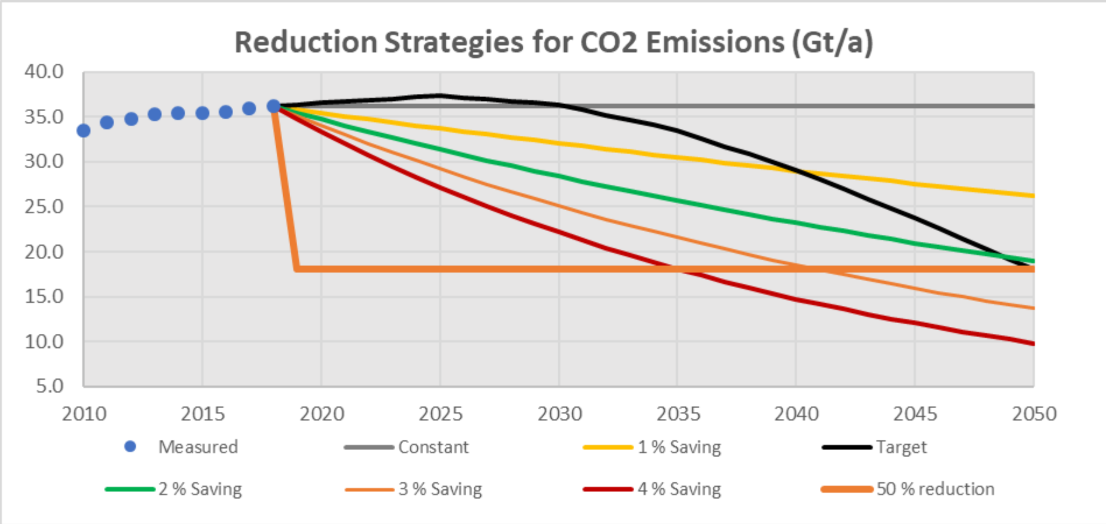


Figure 4.3.6 CO_2 emission reduction scenarios.

The cumulative emissions will be 3200 Gt by 2050 and 5000 Gt by 2100, if the emissions stay at the constant level (36.5 Gt/a) (Figure 4.3.7 and 4.3.8).

With 1 % savings	3050 Gt by 2050	4080 Gt by 2100
With 2 % saving	2900 Gt by 2050	3500 Gt by 2100
With 3 % saving	2800 Gt by 2050	3200 Gt by 2100
Target savings	3080 Gt by 2050	3460 Gt by 2100

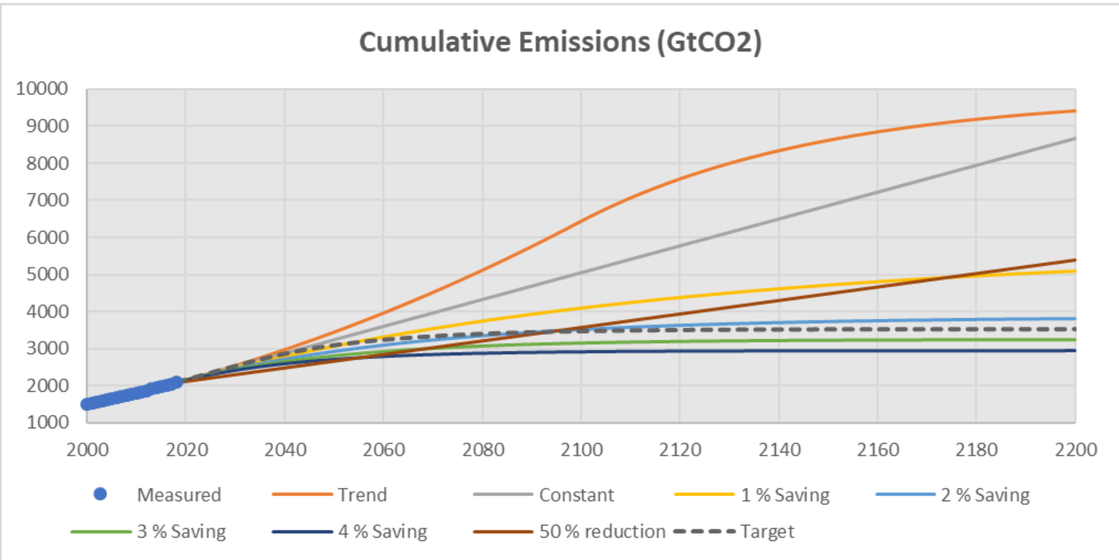


Figure 4.3.7 Cumulative emissions until 2200.

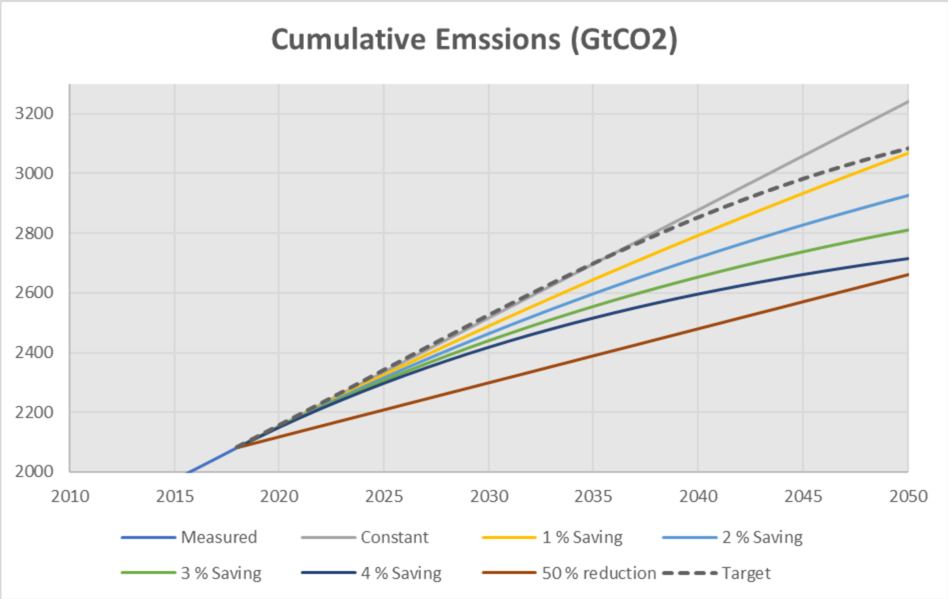


Figure 4.3.8. Cumulative CO_2 emissions until 2050 (Gt).

4.4 Forecasting CO_2-concentration using a linear model

If cumulative emissions (Figure 4.3.4) and CO_2 concentration (Figure 4.1.3) will be presented in XY-diagram, we can find that CO_2 concentration follows cumulative emissions with linear relationship (Figure 4.4.1).

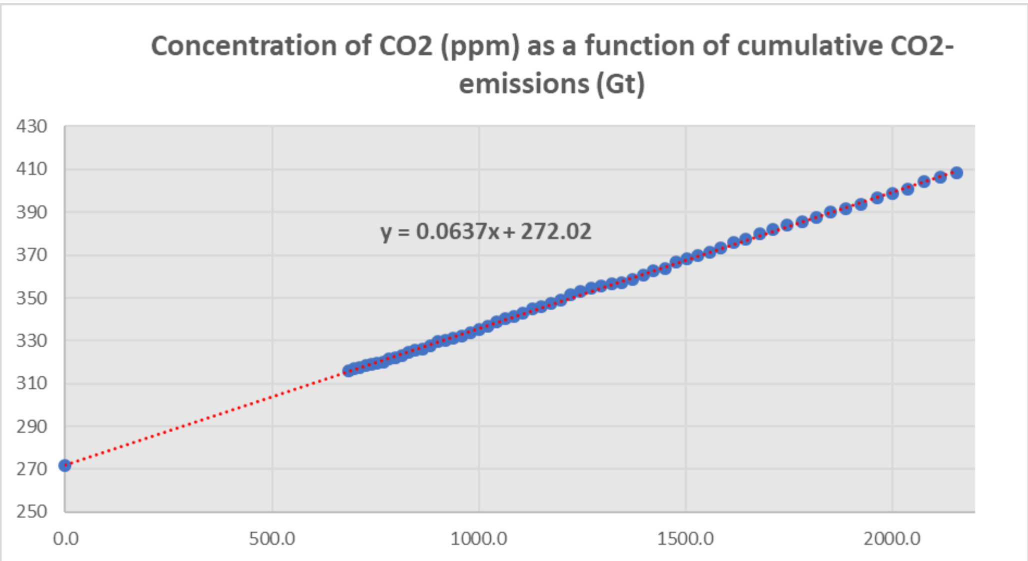


Figure 4.4.1 CO_2 concentration as a function of cumulative emissions.

We can find that the concentration has been a function of cumulative emissions by formula (4.4.1)

(4.4.1) **Concentration = 0.0637 x CE + 270.0**

Where CE = cumulative CO_2 emissions

If cumulative emissions are zero, concentration will be 270 ppm. This could be the concentration before the start of industrialization era before 1850. The critical 450 ppm level will be exceeded when the emissions will be 2830 Gt

(4.4.2) **CE = (concentration-270)/0.0637= (450-270)/0.0637= 2830 GtCO2**

The model can be used to forecast future concentration. If the emissions will be 4000 Gt, the concentration will be 527 ppm (Figure 4.4.2).

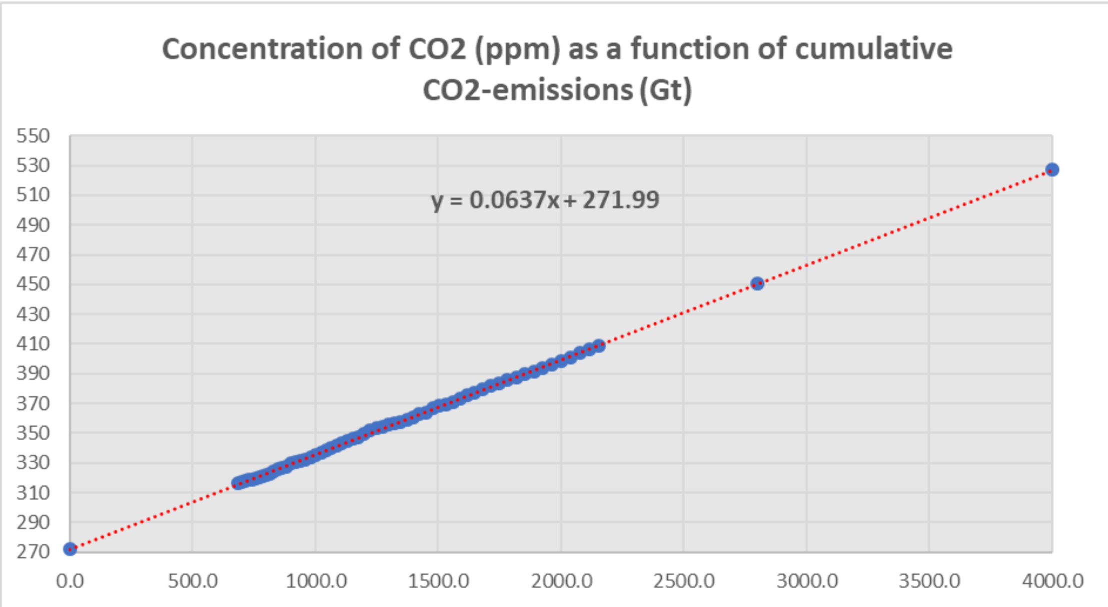


Figure 4.4.2 Mass of CO_2 in the atmosphere as a function of cumulative emissions.

With linear model the CO_2 concentration in the atmosphere will increase to 847 ppm by 2200, if the emissions will continue at constant level (Figure 4.4.3). If reduction will be 1 % annually, the concentration will be 543 ppm by 2100 (609 ppm 2200). With 2 % annual saving, the concentration will be less than 505 ppm by 2100 (524 ppm 2200).

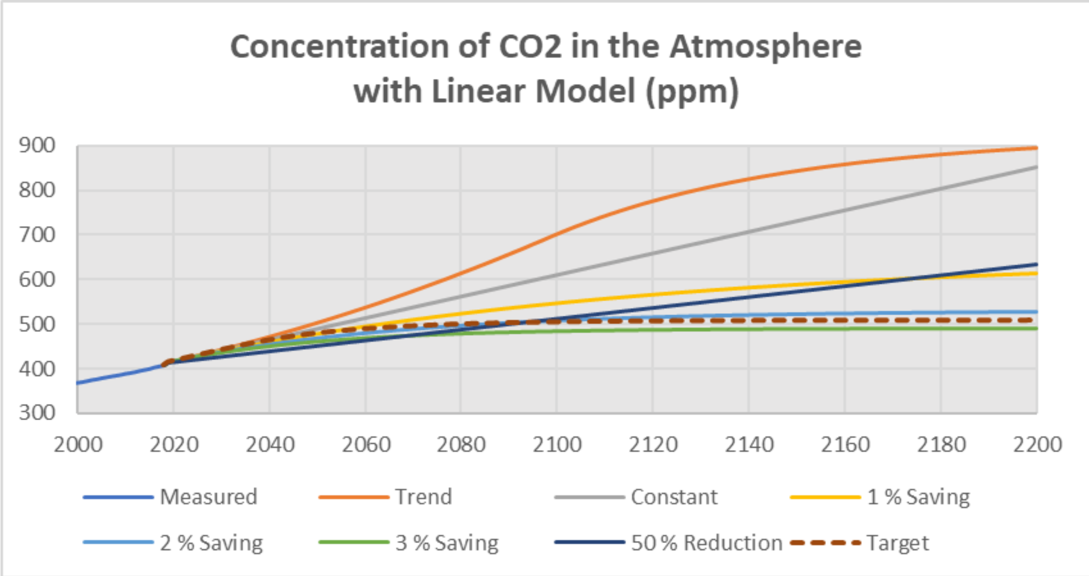


Figure 4.4.3 Concentration of CO_2 in atmosphere with linear model until the year 2200.

Until the year 2050 the target emission and 1 % annual saving plans will cause CO_2 concentration to reach 480 ppm (Figure 4.4.4). With constant emissions the concentration will be 490 ppm.

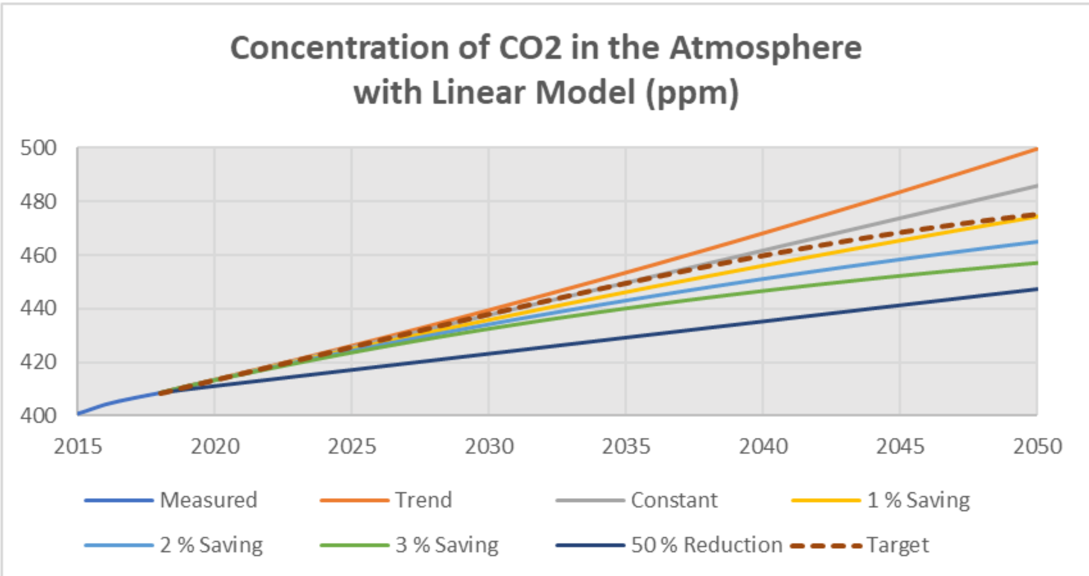


Figure 4.4.4 Concentration of CO_2 in the atmosphere with a linear model until 2050.

4.5 Mass balance model

Even if the linear formula seems to be correct, it is not. More accurate forecasting can be made by modelling the CO_2 emissions (dMCO2e), mass of CO_2 in air (dMCO2a) and seas (dMCO2s). We can in the first phase calculate the mass of CO_2 in the air (MCO2a) in 1960 and increase of mass in the air until the year 2017 simply by converting CO_2 concentration values to mass.

(4.5.1) MCO2a (1959) = Concentration (1959) x mCO2/mair x Mair

Where Concentration (1959) = 316.91

mCO2 = mole mass of CO2 = 44.0095

mair = mole mass of air = 28.97

Mair = mass of air = $5.148 \times 10^{+18}$ t

MCO2a (1959) = mass of CO2 in air in 1959

= $44.0095/28.97 \times 5.148 \times 10^{+18}$ x Concentration (1959)

= 7.8205 x 316.91 = 2478.4 Gt

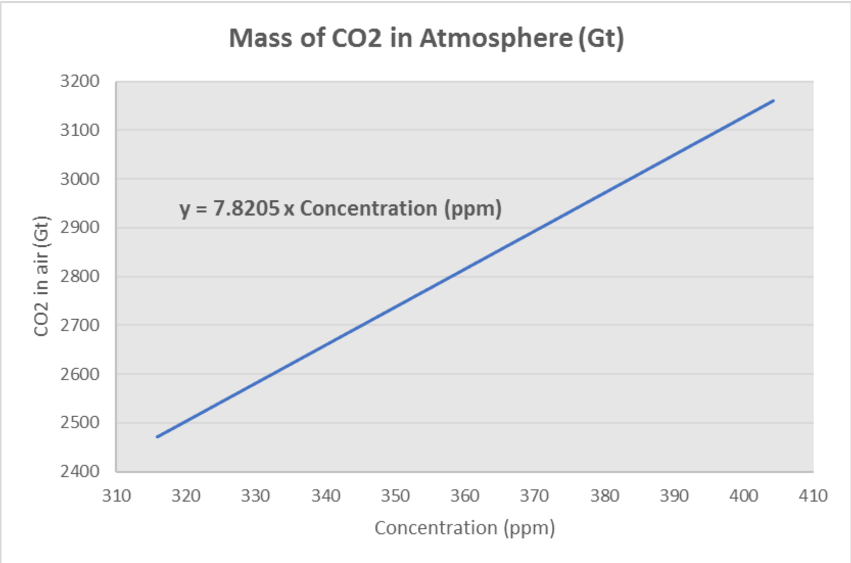


Figure 4.5.1 Mass of CO_2 in atmosphere can be calculated from CO_2 concentration in air.

We can then present the mass of CO_2 in the atmosphere in XY-diagram as a function of CO_2 concentration as a linear relationship (Figure 4.5.1). The formula for mass of CO_2 in the air (Mair) in a function of CO_2 concentration:

(4.5.2) Mair = 7.8205 x Concentration of CO_2 in air (ppm)

If we know the CO_2 emissions (dMe) and CO_2 concentration in the air, we can then calculate increase of mass of CO_2 in the air (dMa) and finally the change of the CO_2 mass in the carbon sinks (dMs)

(4.5.3) $$dMs = dMe - dMa$$

Based on the data from 1960 to 2017 the absorption of the emissions can be calculated. We can find that about 50 % of the emissions will be absorbed by the carbon sinks and about another 50 % by the atmosphere (Figure 4.5.2).

The same figure can be presented also by given carbon sinks as negative values and then the remaining emissions after sinks will present carbon dioxide which will remain in the atmosphere (Figure 4.5.3).

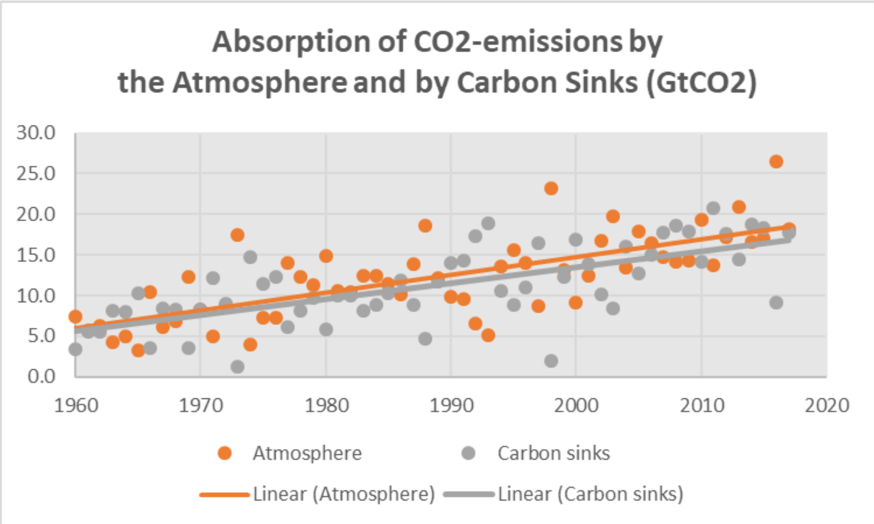


Figure 4.5.2 Absorption of CO_2 emissions by the atmosphere and the carbon sinks.

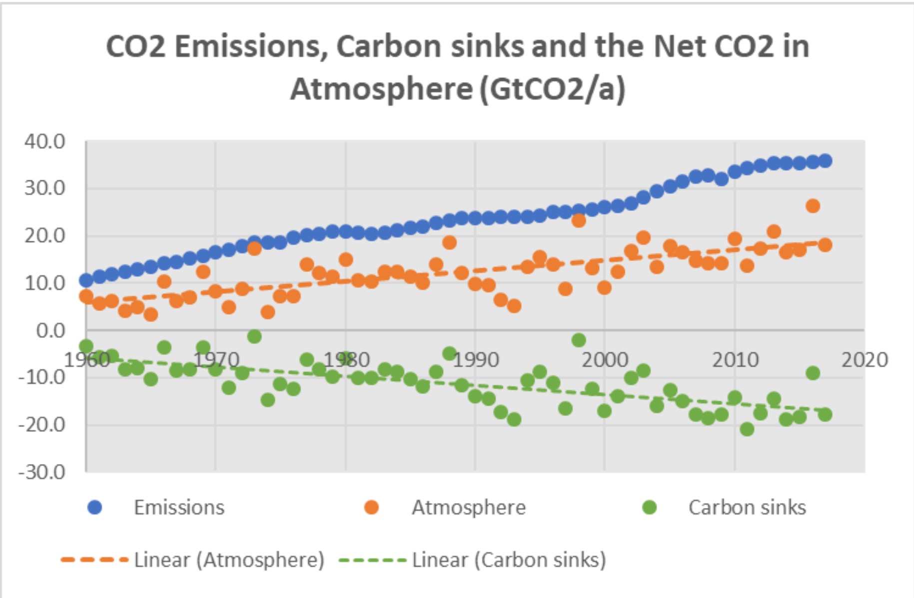


Figure 4.5.3 Emissions minus sinks is the CO_2 remaining in the atmosphere.

More exact estimation of CO_2 in the atmosphere can be found as a function of CO_2 cumulative CO_2-emissions since 1960 (Figure 4.5.4). Then we can find that 52 % (724 Gt) of the cumulative emissions (1400 $GtCO_2$) has been remaining in the atmosphere.

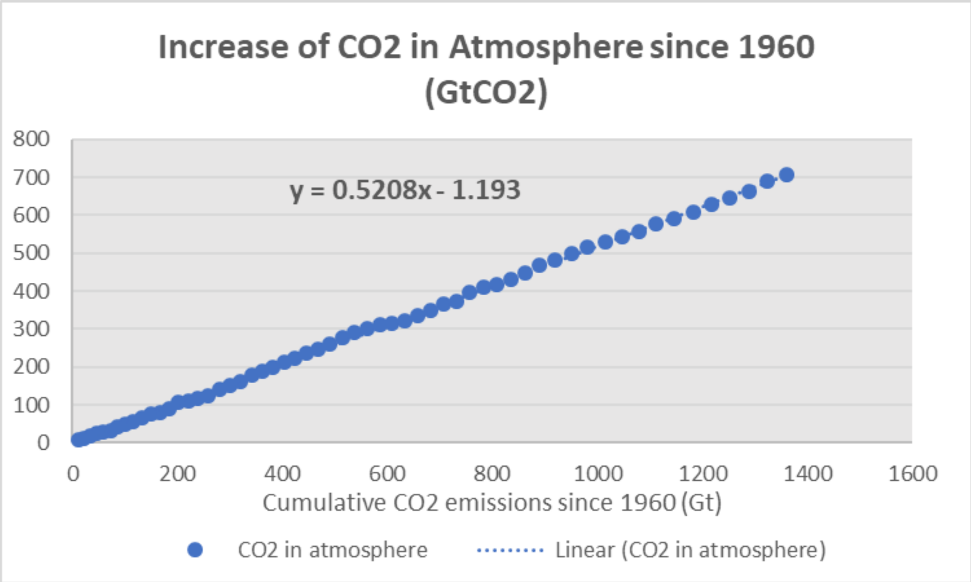


Figure 4.5.4 Increase of CO2 in Atmosphere since 1960.

The carbon sinks as a function of emissions have been presented in Figure 4.5.5, where the formula indicates that 48 % of emissions have been absorbed by the carbon sinks.

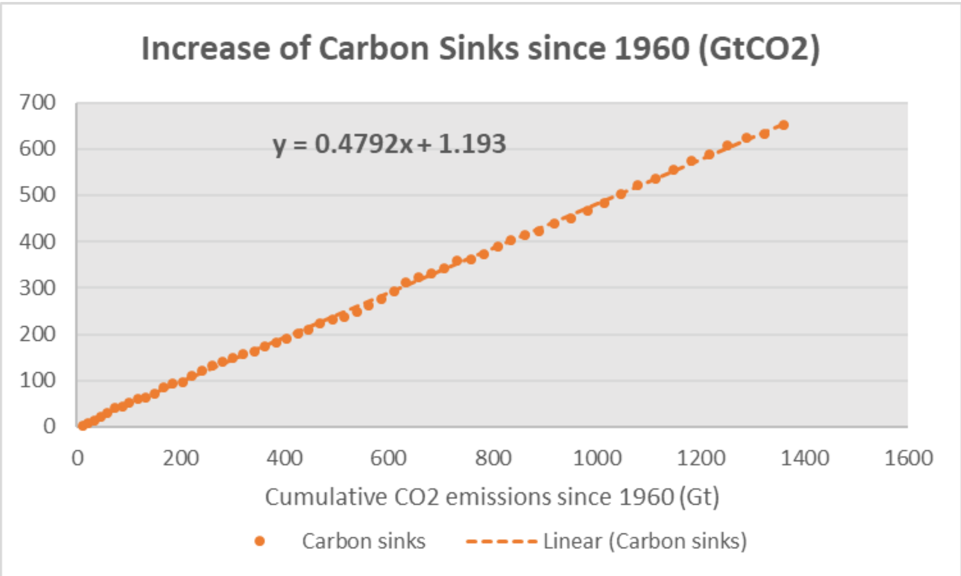


Figure 4.5.5 Increase of carbon sinks since 1960.

If we then calculate increase of mass of CO_2 in the carbon sinks (Ms) and will present the results in XY-diagram (Figure 4.5.6), we can find formulas for CO_2 absorption of the seas.

(4.5.4) dMs = 0.1257 x CCO2a- 33.245 (linear formula)

(4.5.5) dMs = 45.0 x ln (CCO2)-252.72 (logarithmic formula)

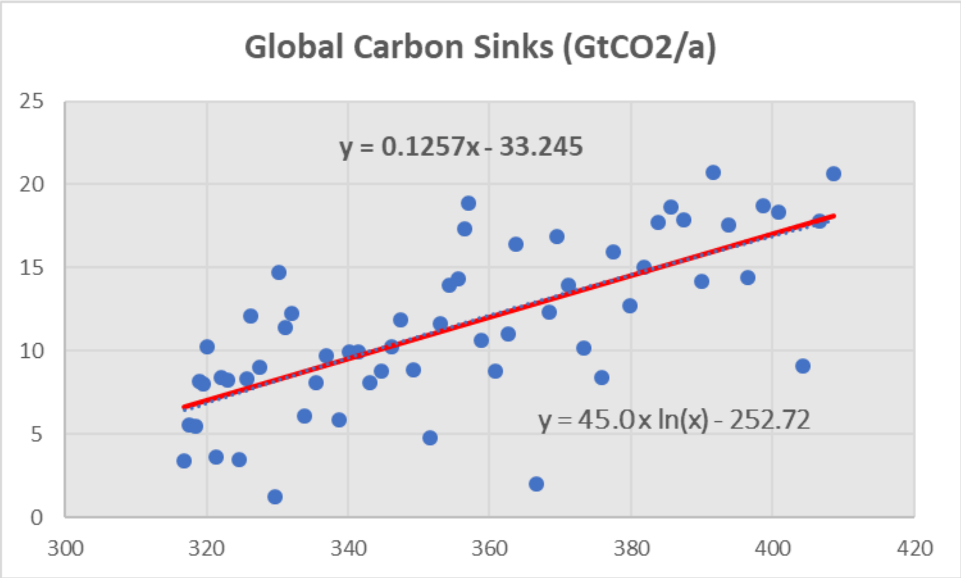


Figure 4.5.6 Linear and logarithmic models of absorption of CO_2 by carbon sinks.

IPCC 2014 version of the carbon balance has been presented in Figure 4.5.7, where the anthropogenic emissions have been indicated by red and natural emissions by black color. The figure indicates that from the 395 GtC (365 Gt fuels + 30 Gt vegetation) emitted 240 Gt (61 %) has been absorbed by the atmosphere and 155 GtC (39 %) has been absorbed by the seas (1 GtC = 3.66 $GtCO_2$).

The absorption of 155 GtC (432 $GtCO_2$) by the seas has increased to total carbon content of the seas (37.100 GtC) only with 0.4 %. If all the fossil fuel reserves will be absorbed by the seas, the mass of carbon will increase with the 2700 GtC, which is 7 % from the present mass.

Absorption of carbon dioxide by seawater is caused by the difference of partial pressure of CO_2 in the air and partial pressure of CO_2 in the seawater. The absorbed CO_2 will react with the water and form carbonic acid (H_2CO_3). This has caused acidification of seas, which has been noticed. The pH value of the seawater has decreased from about 8.179 before the industrialization years to about 8.069 in present. However, the value should be below 7.0 to indicate acidity. Neutral water has pH value of 7.0.

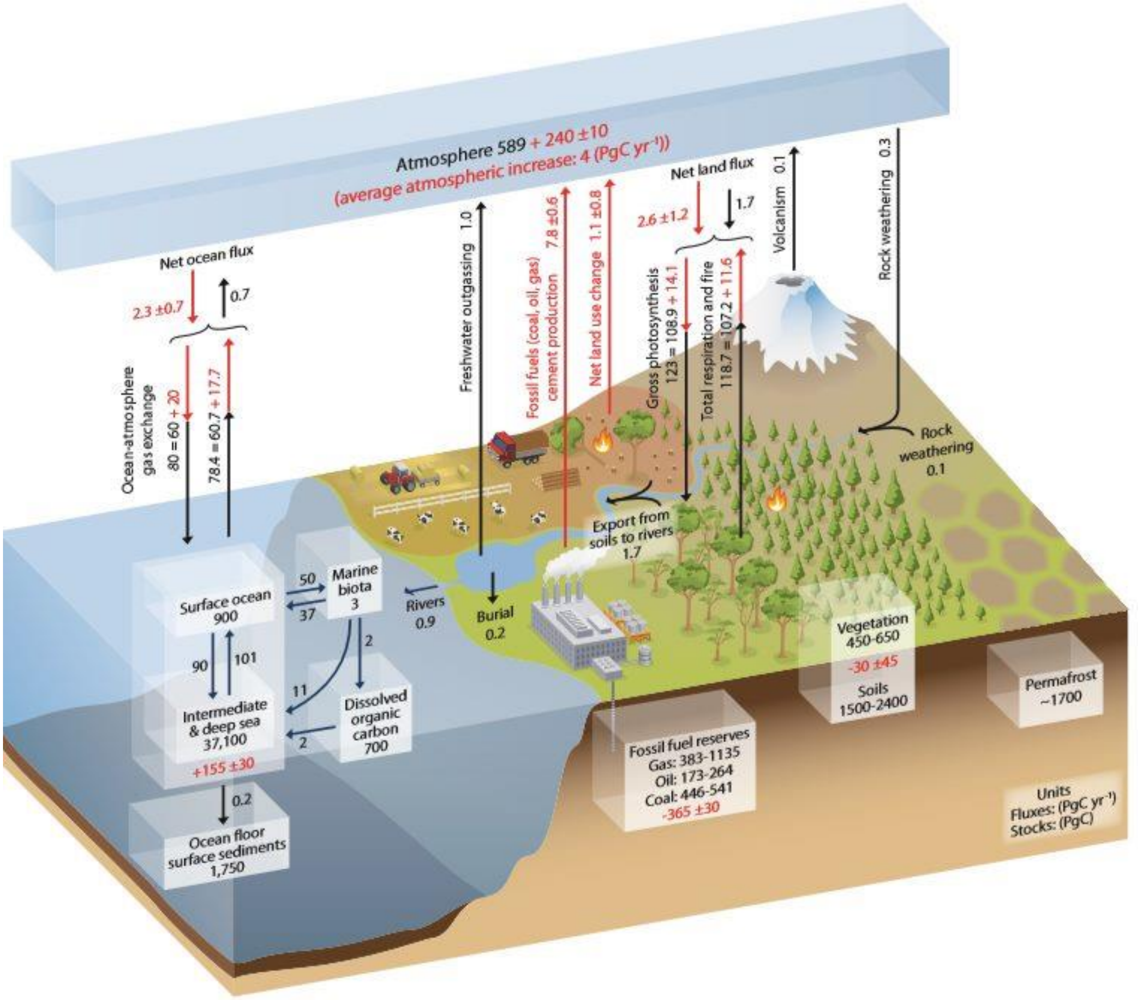


Figure 4.5.7 Mass balance of carbon (MC = MCO_2 / 3.66) in the end of year 1994 and marked with red anthropogenic changes in carbon balance in air, seas and ground (source: IPCC 2014 AR5, IPCC cumulative emission are 395 GtC=1446 $GtCO_2$. This is less than 2000 $GtCO_2$ given here in Figure 4.3.4).

Additionally, the sea currents seem to be spreading the CO_2 from the surface to the deep oceans. In the Atlantic the Atlantic Multidecadal Oscillation (AMO) is pumping the surface water to the bottom near the Nordic Circle (See chapter 6.3, Figure 6.3.4).

4.6 Forecasting CO_2 concentration using mass balance model

We can make forecasting of future concentration starting from the emissions scenarios from the year 2017 using flowing algorithm:

1) In the beginning we will evaluate CO_2 emissions (Me) for the year 2018 by each scenario.

2) We can then calculate the change of mass of CO_2 in the carbon sinks (dMCO2s) using the logarithmic formula dMs (2019) = 45.0 x ln (CCO2)-252.7 for the year 2019.

3) The change in CO_2 mass in the atmosphere, dMa(2019) = Me(2018)-dMs(2019)

4) Then the mass of CO_2 in the atmosphere, Ma(2019) = Ma(2019) + dMa(2018)

5) Finally, the concentration of CO_2 in the atmosphere will be Ma(2019)/7.8205

These calculations have been done for all scenarios until the year 2200 (Figure 4.6.1). From the figure we can find that, if the present trend from 1960 will continue, the CO_2 concentration will have a peak of 710 ppm by the year 2130.

With constant CO_2 emissions the concentration will increase until the year 2200, where it will reach 580 ppm. With 1 % annual savings the peak will be 455 ppm by the year 2060

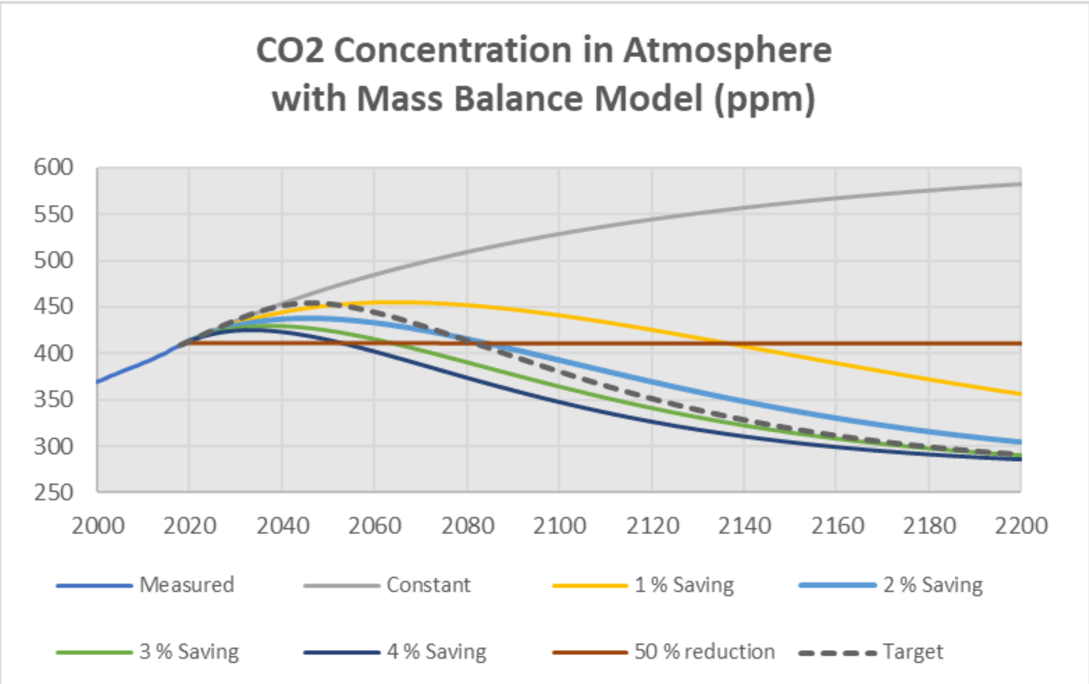


Figure 4.6.1 CO_2 concentration in the atmosphere with mass balance model.

With 2 % annual savings the peak will be 437 ppm by the year 2045 (Figure 4.6.2). With 3 % annual reductions the peak will be at 430 ppm in 2038 and finally with 4 % annual reductions the peak will be at 425 ppm at 2032. With the more realistic target scenario, the peak in concentration will be achieved in the year 2046 at 454 ppm.

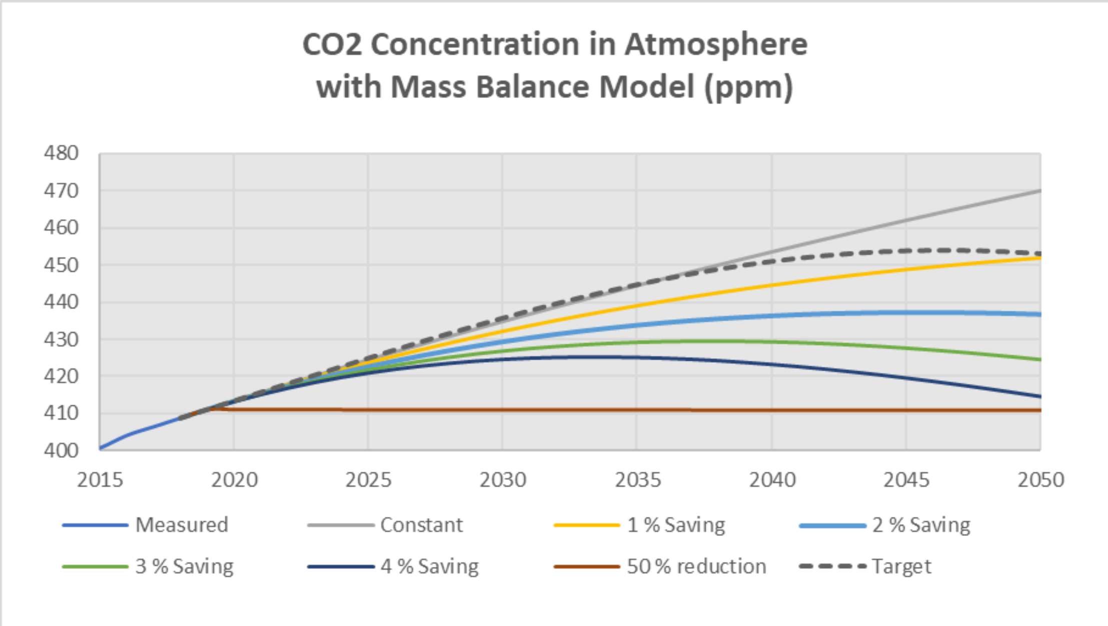


Figure 4.6.2 CO_2 concentration with mass balance model.

Concentration will stay at the present level, if the emissions will be reduced with 50 % or to level 18 Gt/a in the year 2019. This is the level, which the carbon sinks can absorb all emitted CO_2 today (Figure 4.6.3).

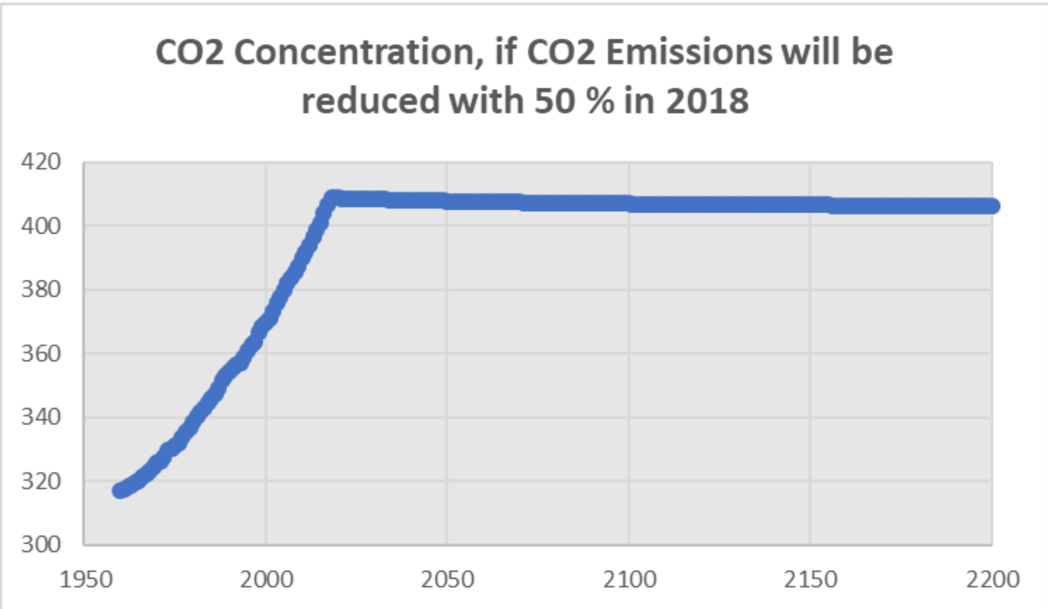


Figure 4.6.3 CO_2 concentration, if the CO_2 emissions will be reduced with 50 % in the year 2018.

With constant CO_2 emissions the difference between the linear and mass balance models will begin increasing after the year 2050 (Figure 4.6.4). Linear model predicts that concentration will be 486 ppm in 2050, but the mass balance model only 470 ppm and the linear model gives 3 % higher concentration. In the year 2100 the figures are 606 ppm and 528 ppm and the difference is already 15 %.

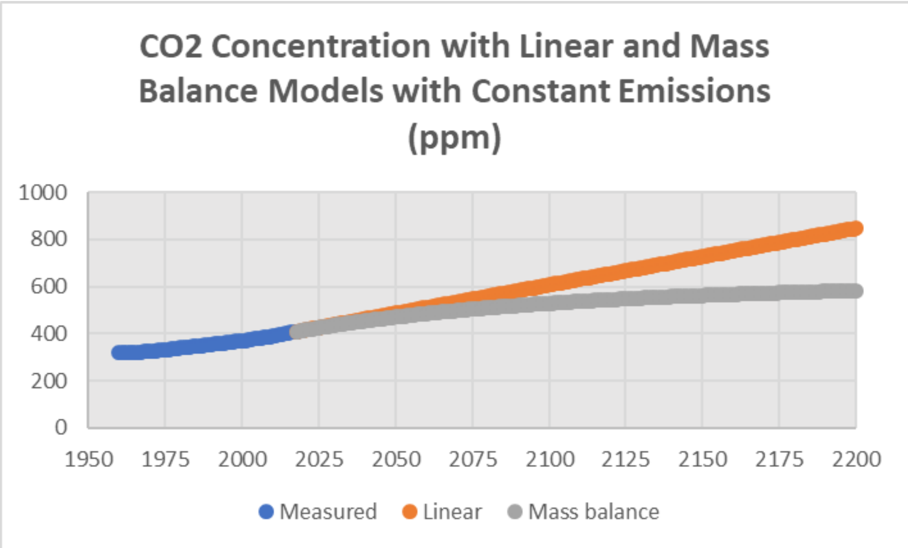


Figure 4.6.4 Difference in CO_2 concentration with linear and mass balance models, if the emissions will remain constant.

The difference with the linear and the mass balance models becomes even greater, if emissions will be saved 1 % annually (Figure 4.6.5). In the year 2100 the concentration will be 543 ppm with the linear model and 441 ppm with the mass balance model. The linear model gives 23 % higher concentration.

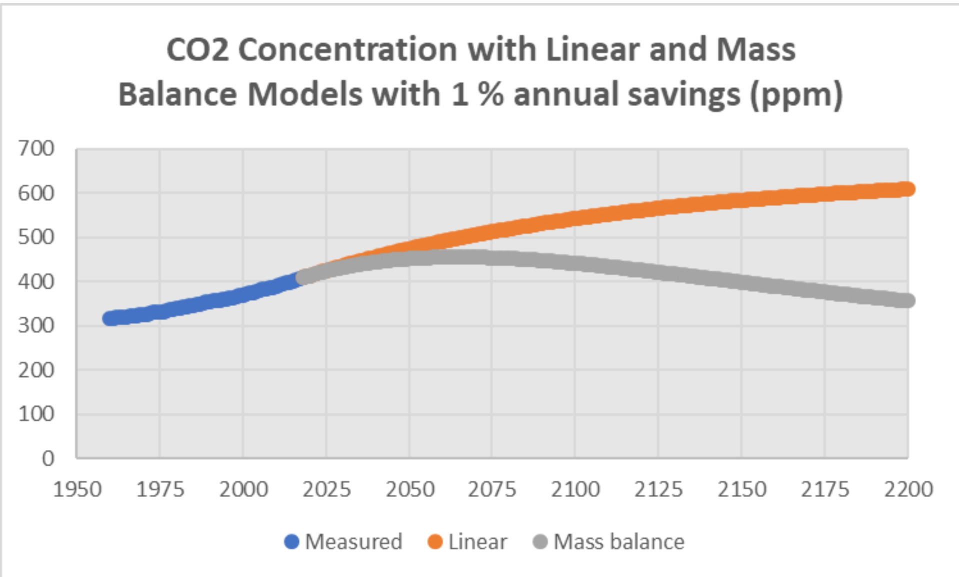


Figure 4.6.5 Difference in CO_2 concentration with linear and mass balance models, if the emissions will be saved 1 % annually.

Difference in CO_2 concentration with linear and mass balance models will become great, if the emissions follow the target scenario (Figure 4.6.6). In the year 2100 linear model gives 500 ppm and the mass balance model 400 ppm.

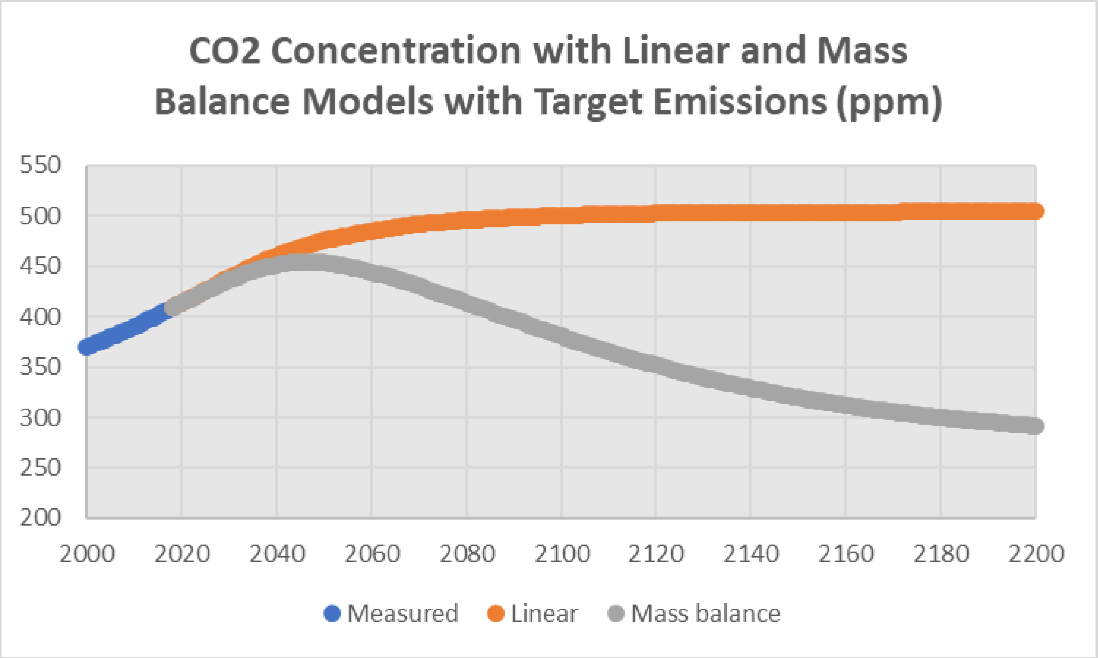


Figure 4.6.6 CO_2 concentration with linear and mass balance models, if the emissions a reduced with the target scenario.

Target reduction scenario

In my opinion it is possible to reduce CO_2 emissions only gradually with target scenario. Then the emissions will increase until 2025 and start to decrease then first with 1 % annually, then with 2 % annually, then with 3 % annually and after 2050 4 % annually. This will reduce the CO_2 emission to the same level as the carbon sinks by the year 2045 (Figure 4.6.7). The CO_2 content in the atmosphere will be started the to decrease.

The CO_2 concentration will then reach its peak value of 450 ppm at the same year 2045 (Figure 4.6.8). After 2045 the CO_2 concentration will start decreasing. CO2 concentration will be about 300 ppm in the year 2200. This is quite near the figure 290 ppm, which was in the beginning of the twentieth century.

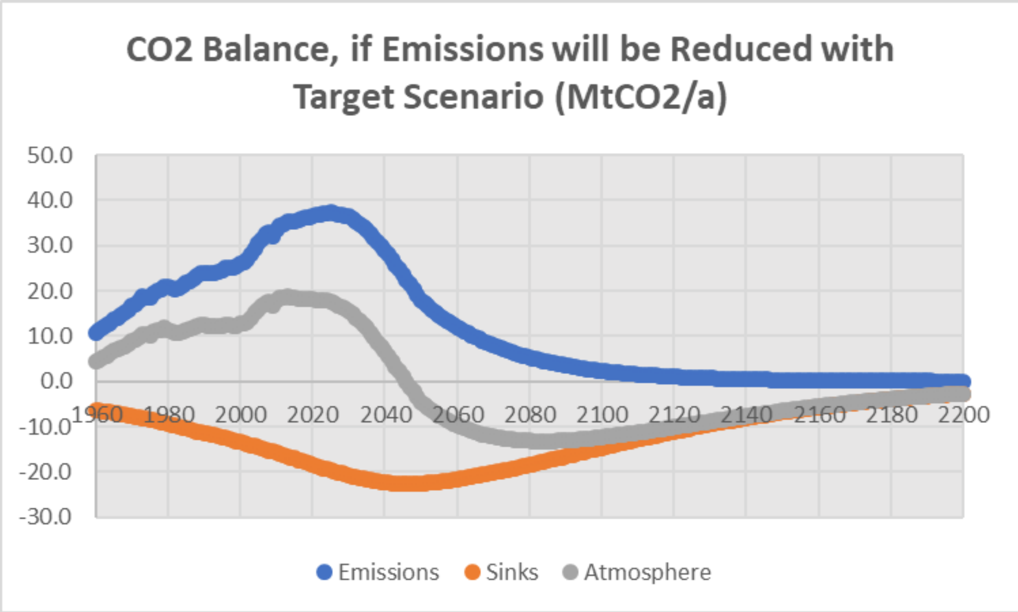


Figure 4.6.7 CO_2 balance, if emissions will decrease with the target scenario

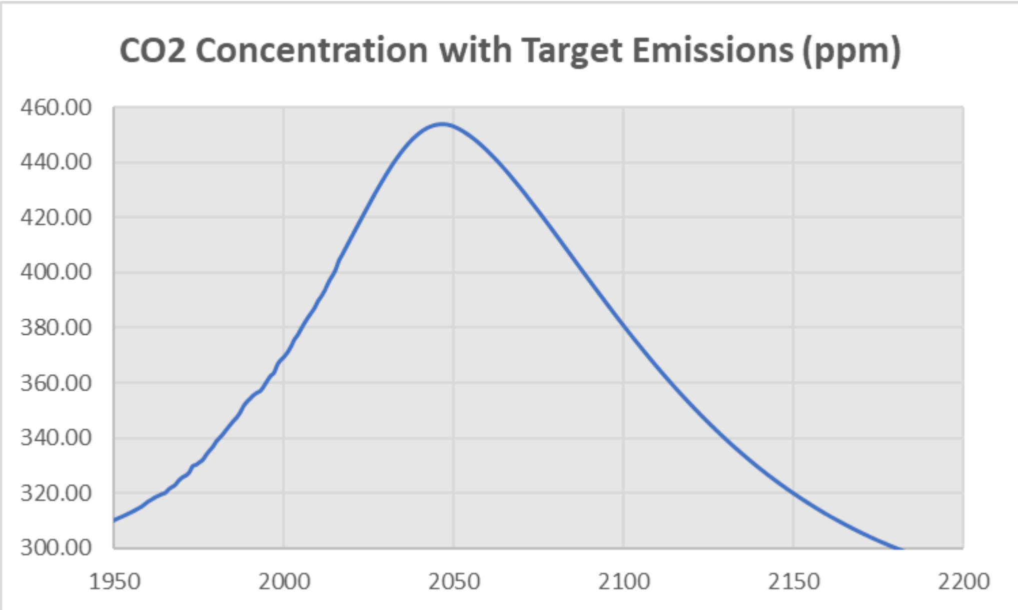


Figure 4.6.8 CO_2 concentration, if the emissions will decrease with the target scenario.

1 % annual reduction scenario

If CO_2 emissions will be reduced with 1 % annually. This will reduce the CO_2 emission to the same level as the carbon sinks by the year 2064 (Figure 4.6.9). The CO_2 content in the atmosphere will be started the to decrease.

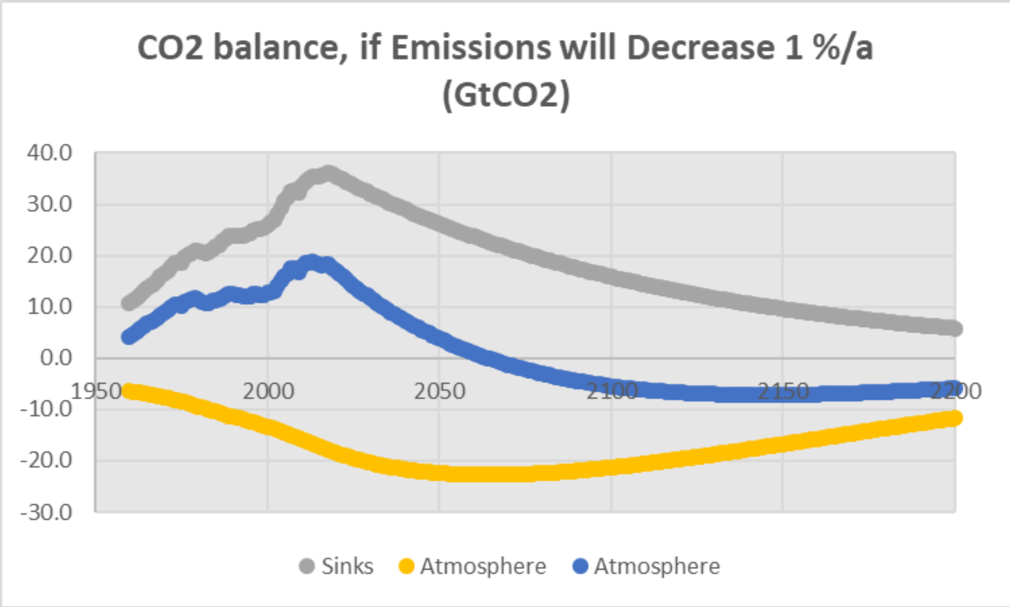


Figure 4.6.9 CO_2 balance, if emissions will decrease 2 % annually.

The CO_2 concentration will then reach its peak value of 460 ppm in the year 2064 (Figure 4.6.10).

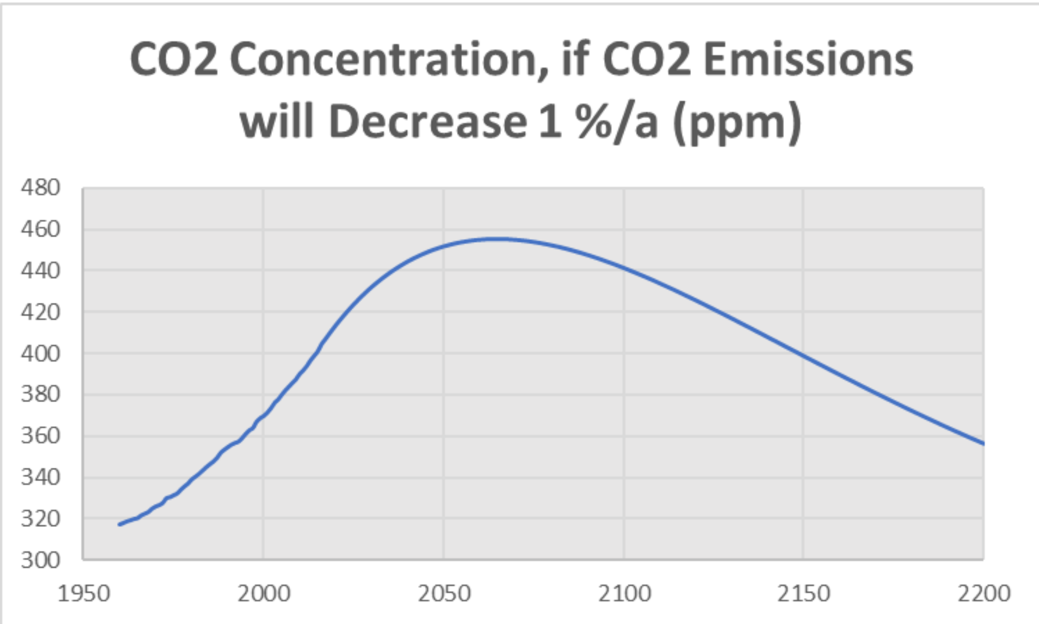


Figure 4.6.10 CO_2 concentration, if CO_2 emissions will be reduced 1 % annually.

Finally, if the emissions will stay constant at this level, the CO_2 concentration will peak at 580 ppm by the year 2200 (Figure 4.7.2). Global temperature will rise until then,

4.7 Forecasting CO_2 concentration until the year 2500

Long term emissions and absorption of CO_2 have been forecasted with the mass balance model, if the emissions will stay constant at 36.5 Gt/a until the year 2200 and then start to reduce 2 % annually because the sources of fossil fuels have been used by then (Figure 4.7.1).

The absorption by the carbon sinks (dMs) will take more that 90 % of the emissions (dMe) after the year 2170. Then after the year 2200, when the emissions start to reduce 2 % annually, the sinks (dMs) will absorb more CO_2 than will be emitted and mass of CO_2 in the air will start reducing.

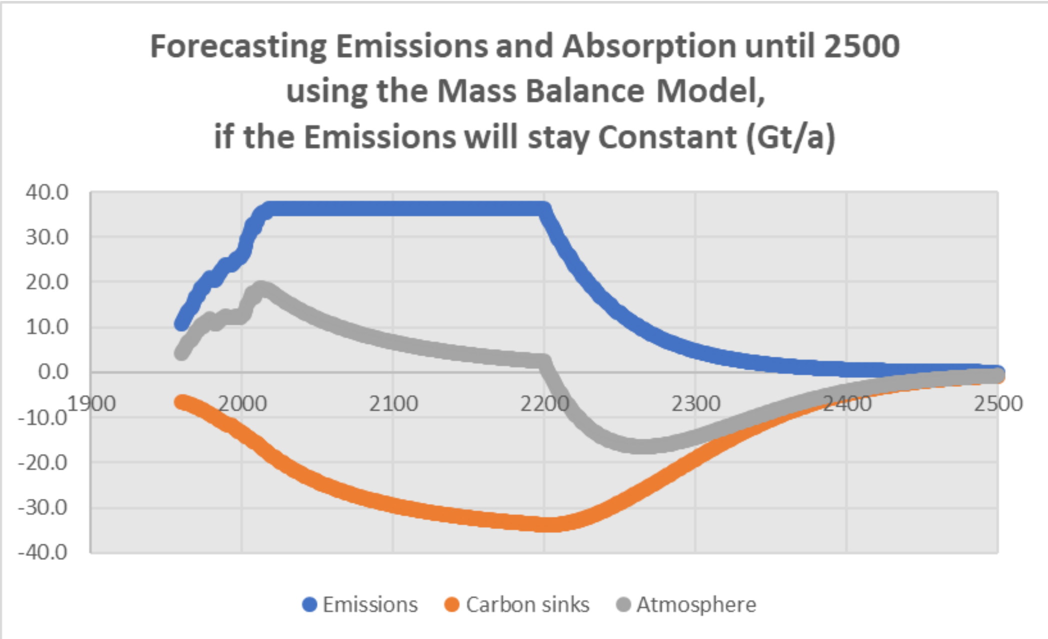


Figure 4.7.1 Emissions, absorption by the carbon sinks and carbon in the atmosphere, if the emissions stay constant until the year 2200.

Future CO_2 concentrations in air can be calculated based on the logarithmic model of CO_2 absorption by the seas assuming the emissions will continue at present level on 38 Gt/a until the year 2200 and then reduced 2 % annually after 2200 because of the fossil fuels will exhausted (Figure 4.7.2).

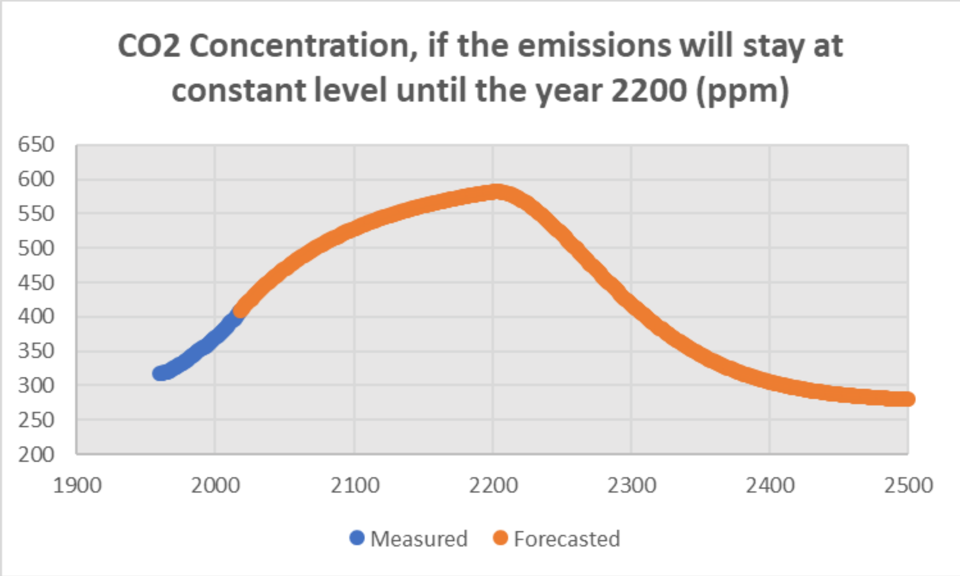


Figure 4.7.2 CO_2 concentration, if the CO_2 emissions remain stable until the year 2200 and will start to reduce after this 2 % annually.

The critical value of 450 ppm will be achieved by the year 2039. The peak value of CO_2 concentration of 580 ppm will be seen in the year 2200. After this year, the concentration starts decreasing, if the emissions decrease 2 % annually. Today's level of 409 ppm will be reached again by the year 2306.

4.8 Radiative forcing by CO_2

The greenhouse gases include water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). They all absorb IR-radiation at specific wavelengths (Figure 4.8.1).

The outgoing IR radiation is going out at about 15 µm band (Figure 4.8.2). There we can find that without CO_2 (blue curve) IR radiative flux would have a peak at 15 µm. However, at present CO_2 content (black curve) the radiative flux at 15 µm drops more than 50 % (from 0.38 to 0.15 Wm^{-2}/cm^{-1}).

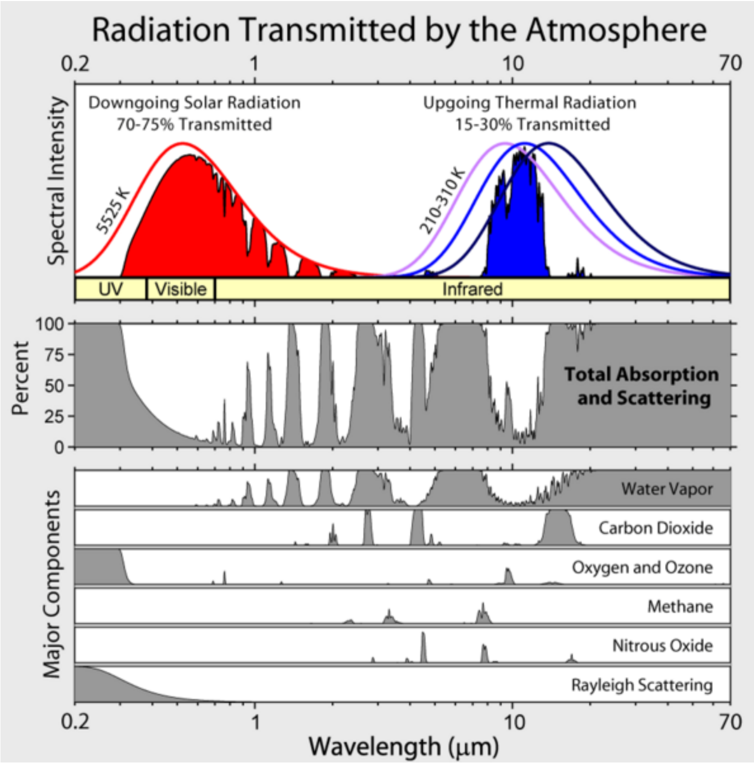


Figure 4.8.1 Absorption of IR-waves by different greenhouse gases.

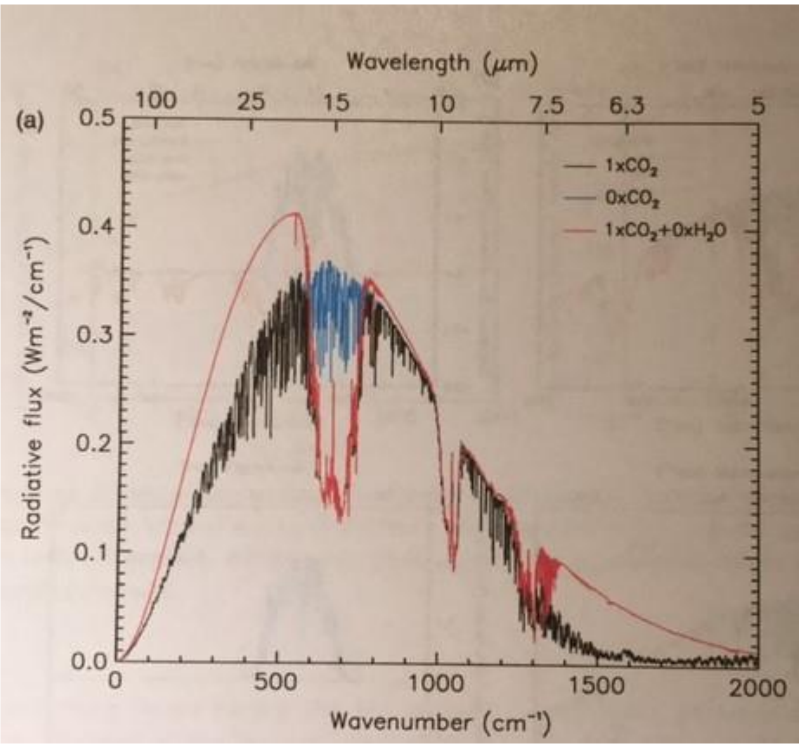


Figure 4.8.2 Outgoing radiative flux depending on the wavelength at present CO_2 level (black curve), at zero CO_2 level (blue curve) and at zero H_2O level (red curve). (Source: The greenhouse gas effect and carbon dioxide, Weney Zhong and Joanne D. Haigh, Royal Meteorological Society).

Figure 4.8.3 Svante Arrhenius (1859 – 1927).

Swedish chemist**, Svante Arrhenius,** published in *Philosophical Magazine and Journal of Science* in April 1896 a formula for radiative forcing caused by the growth of CO_2 concentration in the atmosphere:

(4.8.1) $$\mathbf{Rf = \alpha \times \ln (C/Co)}$$

Where Rf = radiative forcing (W/m^2)

α (alpha) = constant,

ln = natural logarithm

C=concentration of CO_2 in the atmosphere

He calculated that, if the concentration of CO_2 will double then the global temperature will rise with 5 – 6 deg. C. He developed this formula based on infrared tables, which were created by **Samuel Pierpoint Langley** in Rocky Mountains, USA, where he was measuring the IR-radiation of the moon.

Intergovernmental Panel Climate Change (IPCC) has used the value 5.35 for the coefficient α in the formula. Thus, the formula can be presented in form:

(4.8.2) $$\mathbf{Rf = 5.35 \times \ln (C/Co)}$$

If we give value Co = 316 ppm for the year 1959 for the concentration, the we can calculate radiative forcing for the years 1959 – 2017 (Figure 4.8.4).

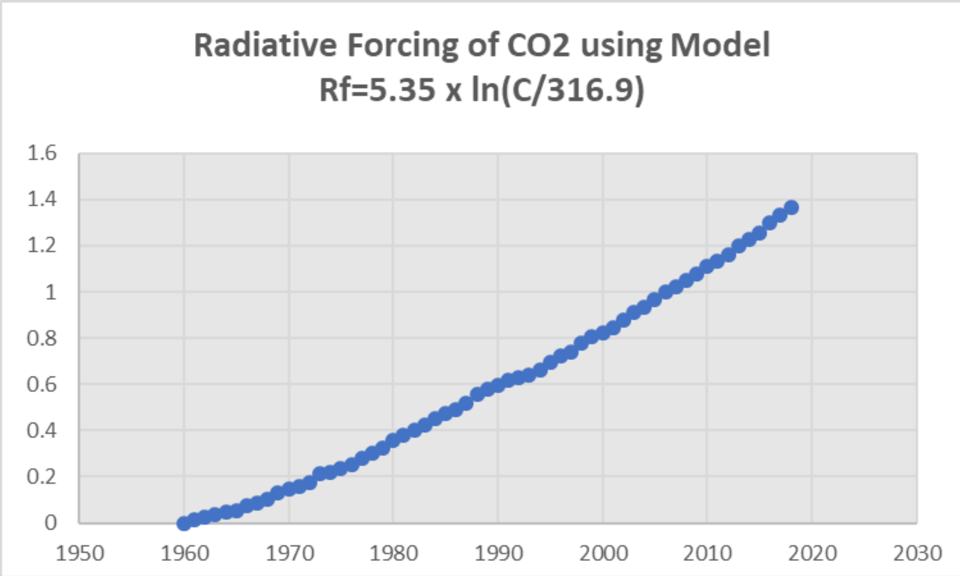


Figure 4.8.4 Radiative forcing by concentration of CO_2 using IPCC model RF=5.35 x ln(C/Co).

Temperature change in the atmosphere should be in direct relationship with radiative forcing:

(4.8.3) $$\mathbf{dT = \lambda \times Rf}$$

Where dT = change in temperature

λ = lambda = sensitivity to radiative forcing

Rf = radiative forcing.

If radiative forcing (Rf) and temperature after sun irradiance correction (T-T(TSI)) are presented in XY-diagram, the value of lambda can be found (Figure 4.8.5).

The value of lambda seems to be 0.744 (Figure 4.8.5), but there are large deviations in the calculated values from the actual values. 95 % confidence values are +/- 0.2 deg. C. Formula for global warming is then.

(4.8.4) $$dT = 0.744 \times 5.35 \times (\ln(C/Co) - 0.146$$

$$dT = 3.98 \times \ln (C/Co) - 0.146$$

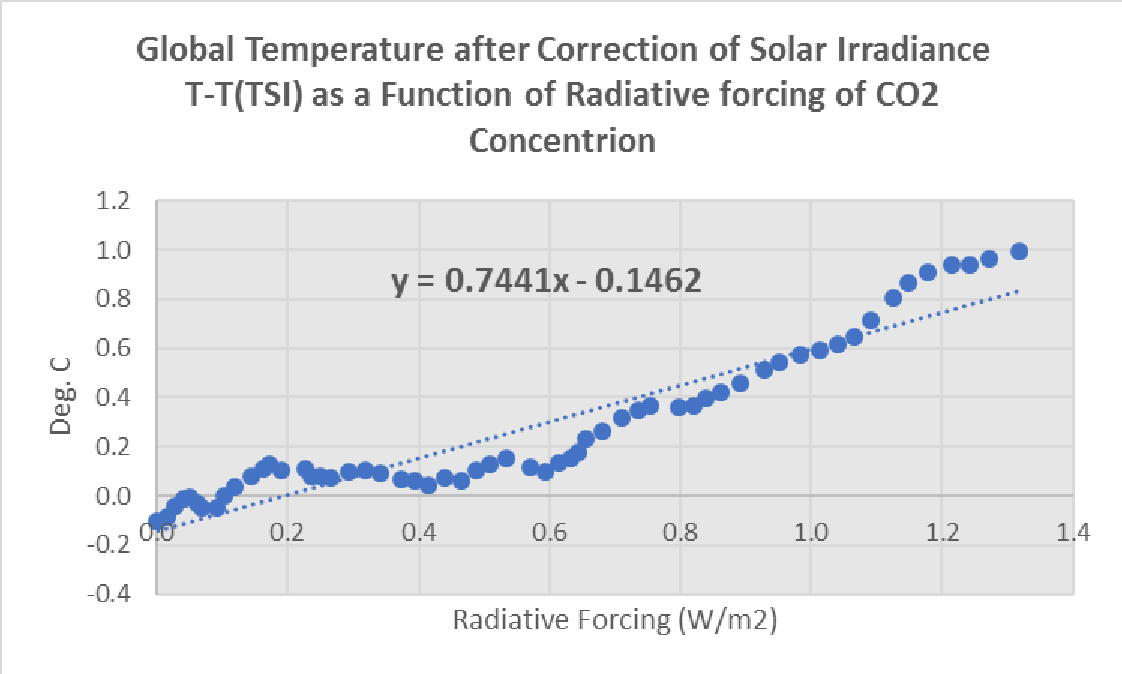


Figure 4.8.5 Change in global temperature as a function of radiative forcing by the change in CO_2 concentration, 5.35 x ln (C/Co).

With formula 4.8.4 we can then calculate the global warming, if the CO_2 concentration will be double

$$dT = 3.98 \times \ln 2 = 2.76 \text{ deg. C}$$

The range of global warming in doubling of CO_2 given by Svante Arrhenius in 1896 was 5 – 6 deg. C. Thus, the evaluated figure (2.76 deg. C.) is only a half of Arrhenius estimate.

We have already found (see formula 3.3.9) that sensitivity of solar irradiance was dT = 1.2334 x TSI. Assuming, that this is true we can develop new formula for CO_2 forcing

(4.8.5) $$Rf = 3.98/1.2334 \times \ln (C/Co)$$

$$\mathbf{Rf = 3.227 \times \ln (C/Co)}$$

The coefficient is 3.227 clearly smaller than the value 5.35 given by IPCC. Thus, starting from the year 1960, the Rf has been rising from zero to 0.8 W/m^2 (Figure 4.8.6).

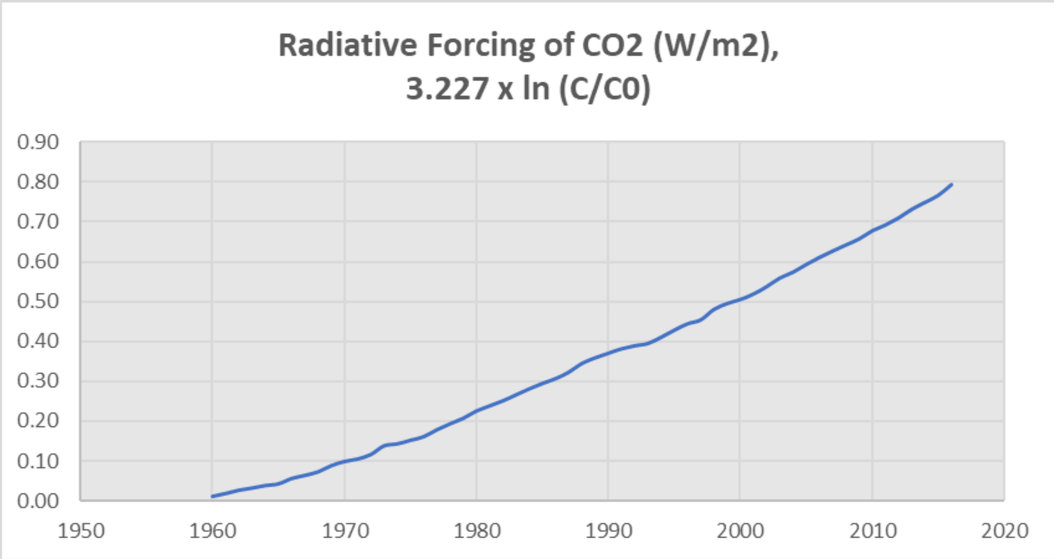


Figure 4.8.6 Radiative forcing by formula Rf = 3.227 x ln(C/Co).

Best fit with the measured global warming starting from the year 1960 can be achieved with formula 4.8.6.

(4.8.6) $dT = 1.233 \times (3.227 \times \ln(C/316) + dTSI)$

$= 3.98 \times \ln(C/316) + 1.233 \times dTSI,$

Where C = concentration of CO_2

$dTSI$ = deviation of total solar irradiance from average of years 1901-1930

This formula does not predict warming before 1960, when the CO_2 measurements were not available. The best fit from the years 1910 to 2017 can be achieved with formula 4.8.7.

(4.8.7) $\mathbf{dT = 3.98 \times \ln(C/292) + 1.233 \times dTSI}$

Within the years 1960 – 2018 the standard deviation of the model is 0.096 deg. C (Figure 4.8.7), but within years 1910 – 2010 it is only 0.18 dg. C (Figure 4.8.8). This indicates that CO_2 concentration alone cannot predict global warming alone. We will need a better model, which will be given in chapter 5.

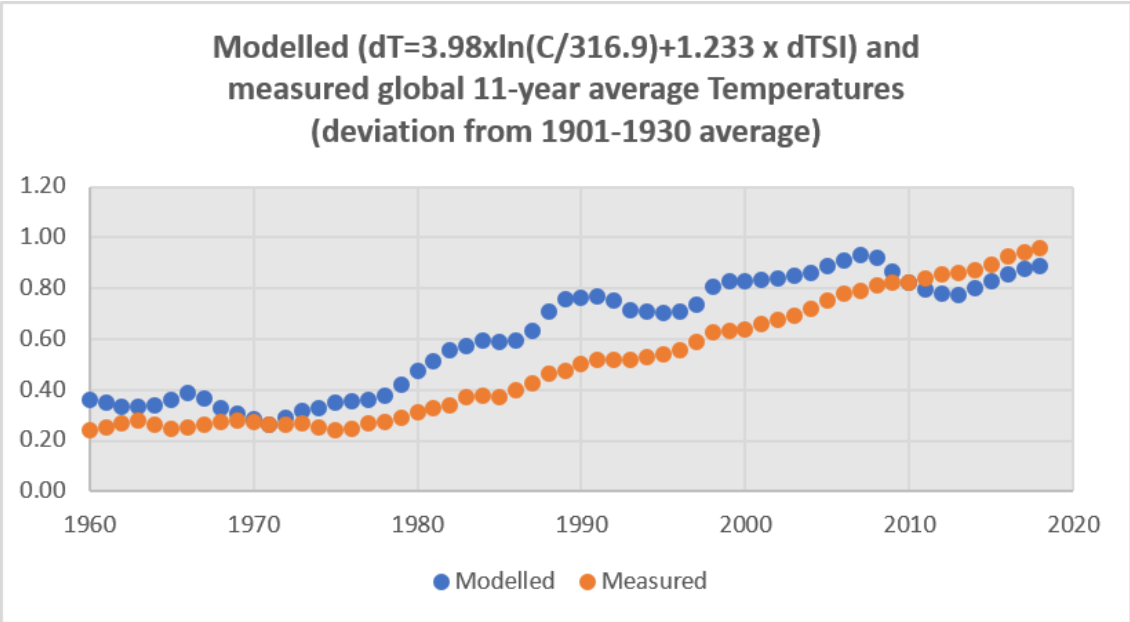


Figure 4.8.7 Modelled and measured temperatures 1960 - 2018.

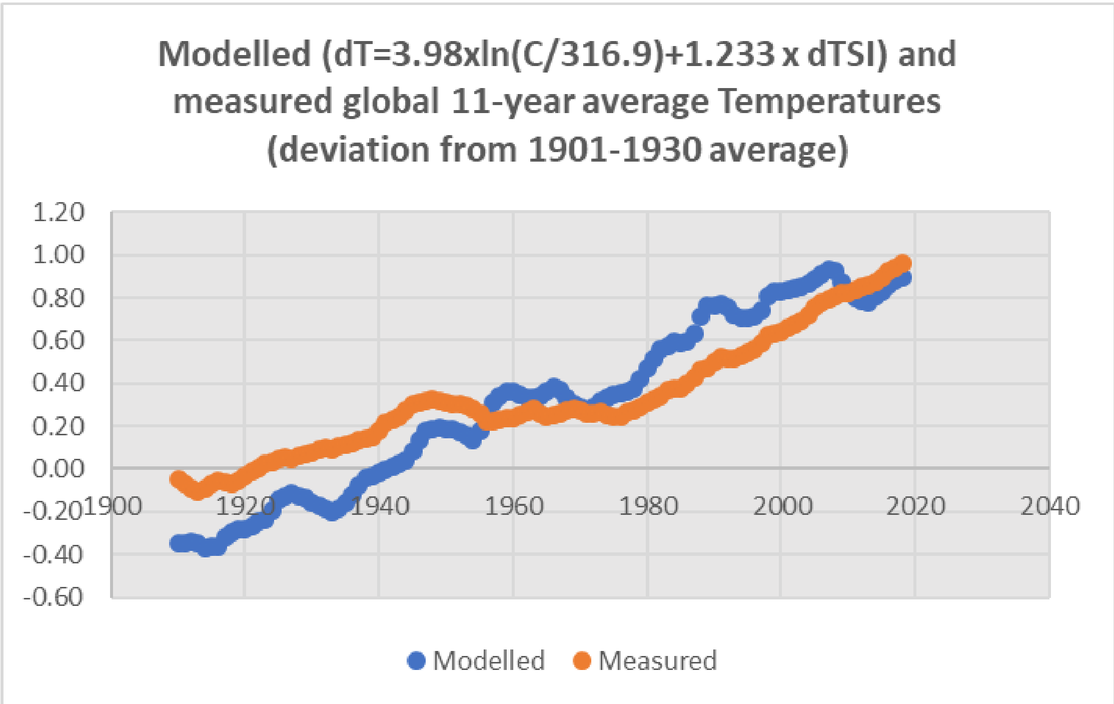


Figure 4.8.8 Modelled and measured temperatures 1910 - 2018.

4.9 Temperature rise using CO2 concentration as a variable

The future temperature changes can be forecasted using mass balance model developed in chapter 4.6. Concentration of CO_2 will be forecasted depending on the saving strategies (Figure 4.6.1). If the emissions increase with the present trend the peak concentration will be achieved at 700 ppm by the year 2100. If the concentration remains at today's level, the peak of 550 ppm will be achieved in 2180. With 1 % annual savings the peak will be 450 ppm by the year 2050. With the target emissions CO2 concentration will also have a peak at 450 ppm in the year 2045.

If these concentrations will be used, future global temperatures have been given in Figure 4.9.1 until 2200. If the emissions will continue to increase with the present trend, the temperature will be peaking at 3.3 deg, C in the year 2130. With constant emissions the peak will be at 2.5 deg. C in the year 2200.

With 1 % annual reductions the temperature peak will be at 1.35 deg. C by the year 2060 (Figure 4.9.2). If the emissions will be reduced 50 % in 2019, the global temperature will stay constant at the present level about 1.1 degrees from the years 1901 – 1930.

With the target scenario the temperature will peak at 1.5 deg. C in the year 2045. However, we should remember that this model does nota take into account variations in total solar irradiance and sulfur oxide, which both can add about 0.3 degrees to this value as we will see in the chapter 5.

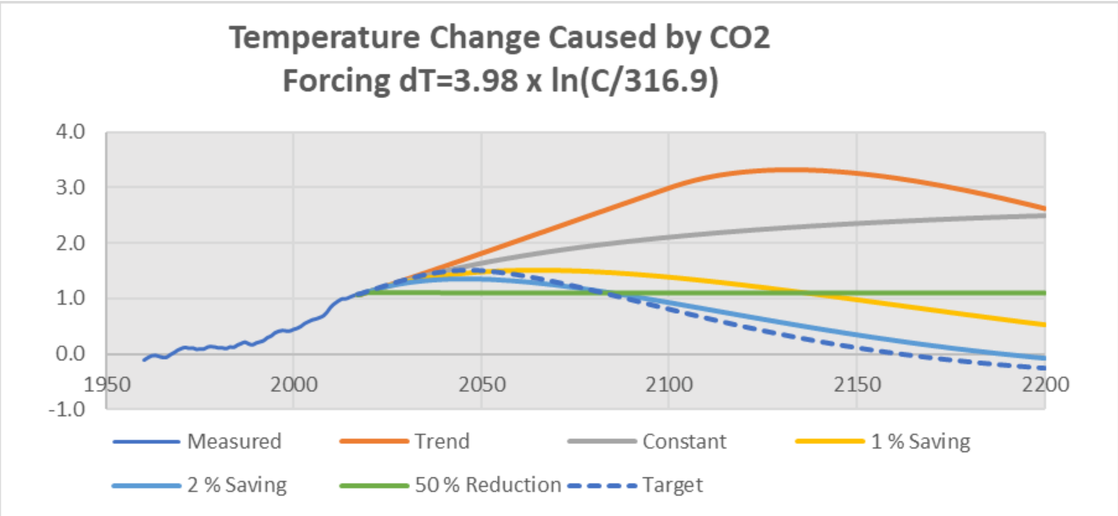


Figure 4.9.1 Forecasted temperatures using CO_2 as only variable with mass balance model (chapter 4.6).

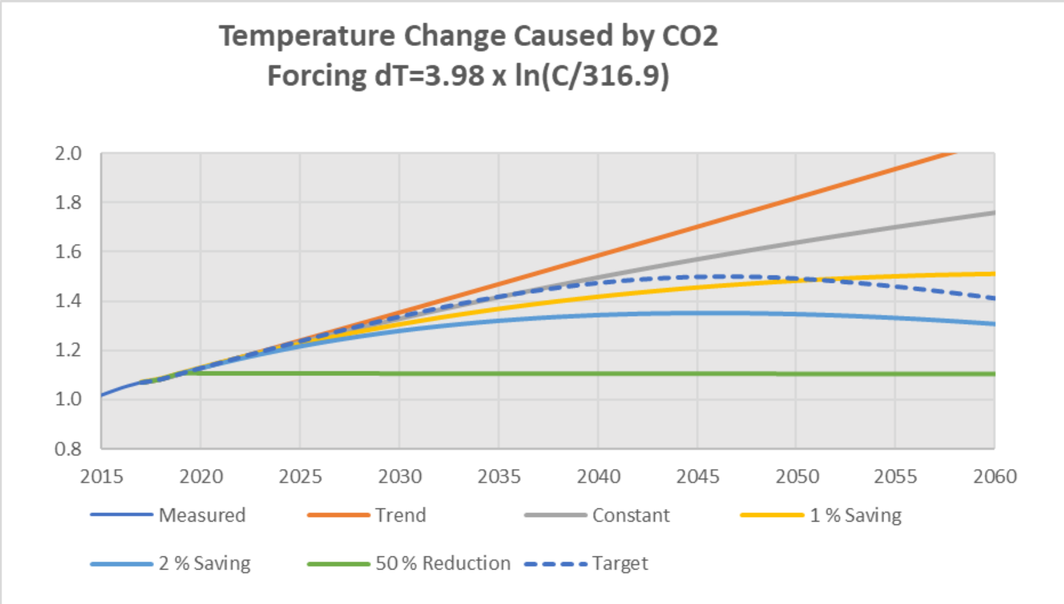


Figure 4.9.3 Global temperature changes caused using CO_2 as only variable and using mass balance models of concentration (chapter 4.6).

Summary

Mass balance model forecast with only CO_2 as variable shows that, if emissions will remain at present level, the peak temperature value of 2.3 deg. C will be achieved by the year 2200. The 2.0-deg. C limit will be achieved by the year 2100.

With 1 % annual savings, the global temperature will be peaking at 1.48 deg. C by 2060 (Figure 4.9.2). With 2 % annual savings, the global temperature will have a peak at 1.3 deg. C by 2050. With 50 % reduction in 2018 the temperature will stay constant at the present level at about +1.1 Deg. C.

Changes in global temperature after correction of solar irradiance with alternative emission scenarios using a mass balance model using CO_2 forcing (chapter 4.6) has been summarized in Table 4.9.1.

Table 4.9.1 Changes in global temperatures using mass balance models depending only on the CO_2 emissions.

Year	Trend	Constant	1 % Saving	2 % Saving	50 % Saving	Target
2018	1.08	1.08	1.08	1.08	1.08	1.08
2030	1.35	1.33	1.30	1.28	1.11	1.34
2040	1.59	1.50	1.42	1.34	1.11	1.47
2050	1.82	1.64	1.48	1.35	1.10	1.49
2100	3.00	2.10	1.39	0.92	1.10	0.80
2200	2.63	2.49	0.53	-0.08	1.10	-0.26

Results of model using only CO_2 as a variable:

If the CO_2 emissions will continue at present level, global warming will have a peak at 2.5 deg. C by the year 2200. With 1 % annual savings in emissions or with the target emissions the peak value will be at about 1.5 deg. C by the year 2050.

This model is not good enough. Better model has been developed, which into account also Sulphur oxide emissions (Chapter 5).

5 MODELLING GLOBAL WARMING USING TSI, CO_2 AND SO_2

5.1 Sulphur dioxide emissions

Fossil fuels contain Sulphur, which becomes Sulphur dioxide (SO_2) in burning process. Most of the emissions have been coming from coal combustion until the year 1950 (Figure 5.1.1). However, after 1950 oil and petroleum products have had also significant role.

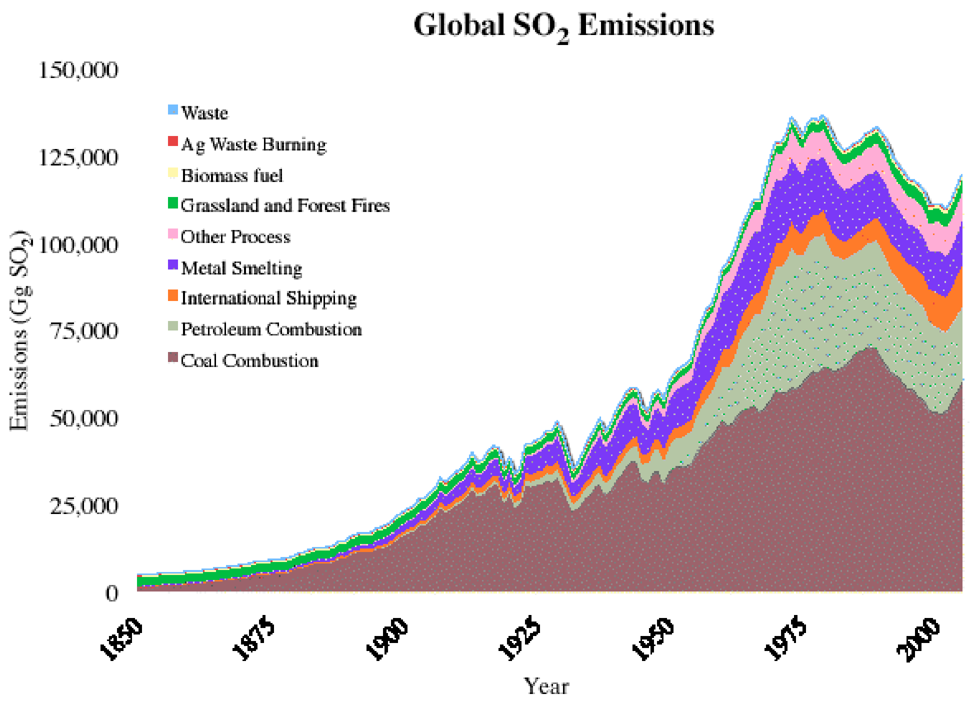


Figure 5.1.1 Global Anthropogenic Sulfur oxide emissions (Source: Anthropogenic sulfur dioxide emissions: 1850–2005. Atmos. Chem. Phys., 11, 1101–1116, 2011).

After 1975 standards for Sulphur removal from fuels and flue gases have decreased anthropogenic SO_2 emissions. But after 2000 China and India started massive construction programs of coal fired plants and have been the top emitters since then (Figure 5.1.2). There have been also volcanic eruptions which have been adding about 15-20 million tons on the top of about 100 Mt anthropogenic SO_2 emissions. These have only short-term influence on SO_2 concentration, which lasts about two years.

After 2005 the SO_2 emission have been reduced with 9.3 million tons within five years or in average 1.86 million tons (1.8 %) annually (See: The last decade of global anthropogenic sulfur dioxide: 2000–2011 emissions). It has been assumed that reductions will continue 1% annually after 2010 (Figure 5.1.3).

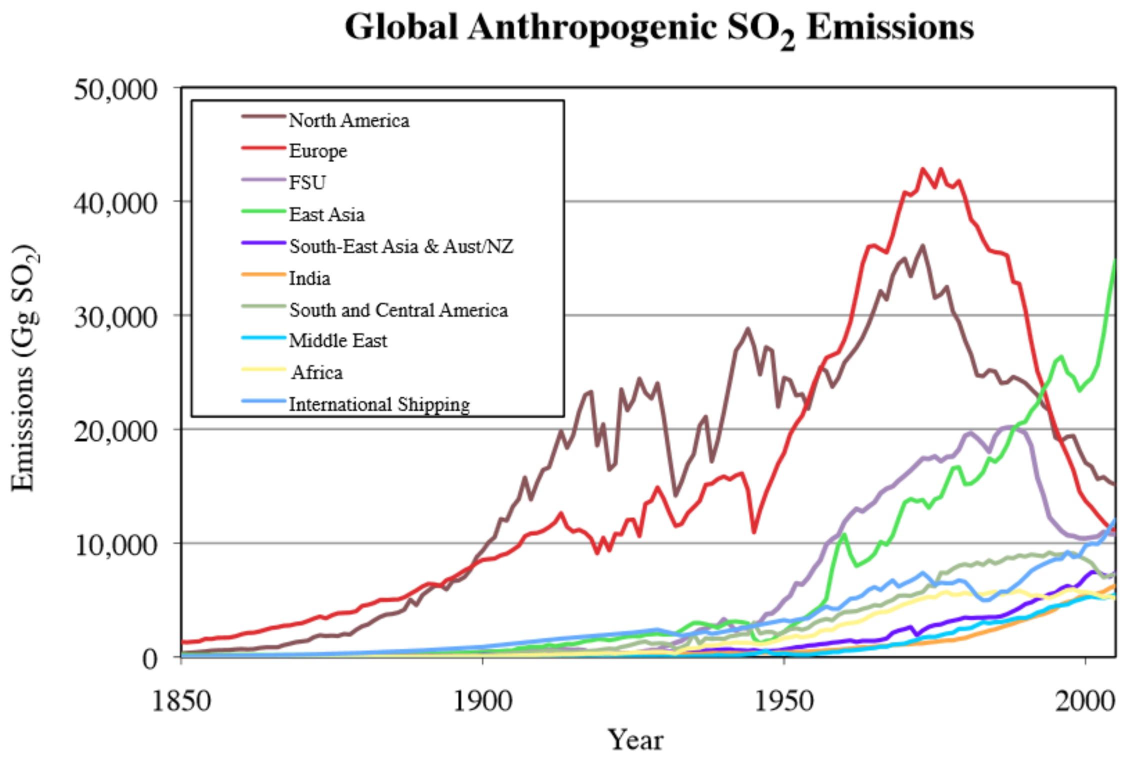
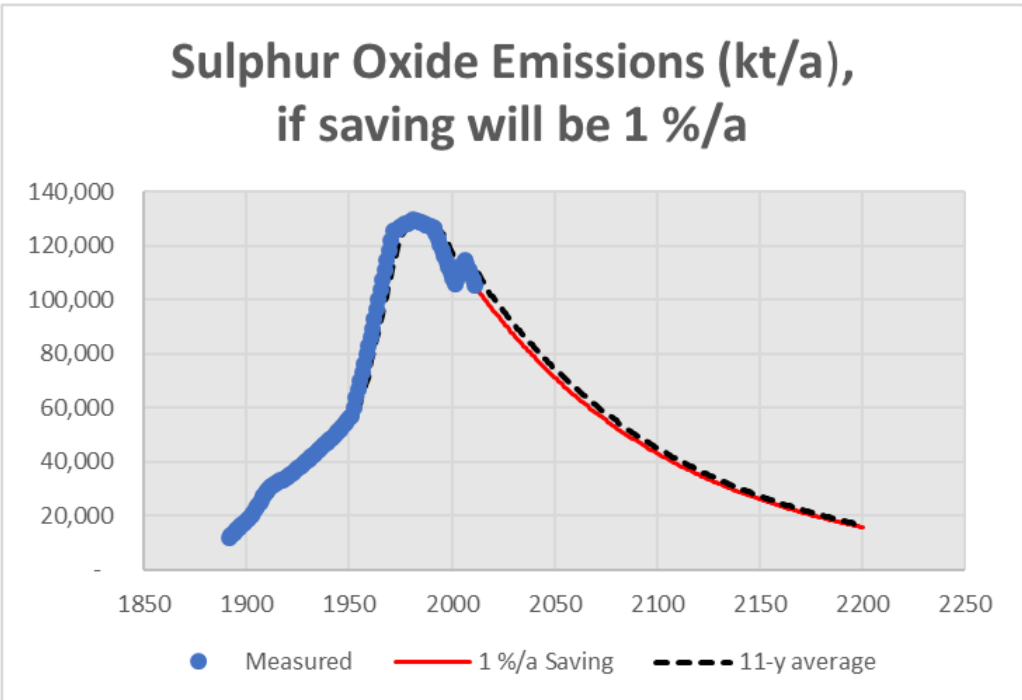


Figure 5.1.2 Anthropogenic SO_2 emissions by countries and continents (Source: Anthropogenic sulfur dioxide emissions: 1850–2005. Atmos. Chem. Phys., 11, 1101–1116, 2011).



5.1.3 Future SO_2 emissions assuming saving of emissions will be 1 %/a after 2010.

5.2 Influence of aerosols to global warming

Volcanic aerosols have influenced global weather by cooling. Latest large eruption of Pinatubo in 1991 was cooling the climate about 0.2 deg. C (Figure 5.2.1). Another large eruption was in Krakatoa in 1883 which cooled the weather mostly near Indonesia and also globally.

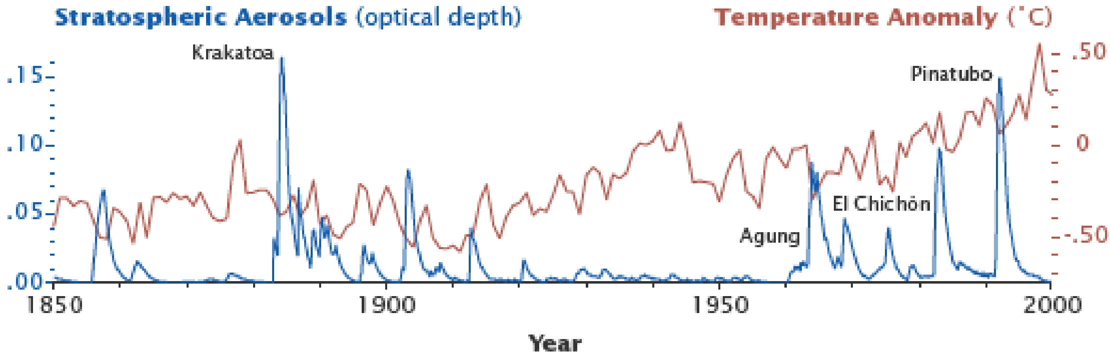


Figure 5.2.1 Aerosols have influenced to global temperature by changing the optical depth in stratosphere (Source: Nasa).

Aerosols will reflect Sun's energy back to space. They also can form clouds, which influence on climate by reflecting irradiance. Most of the influence comes from the Sulphur dioxide (SO_2), which has been emitted by the power plants, ships and industries.

By modelling global warming with three components, total solar irradiance (TSI), carbon dioxide (CO_2) and Sulphur dioxide (SO_2), we can achieve best model by formula 5.2.1.

(5.2.1) **dT = 1.23 x (dTSI + dRf (CO2) + dRf(SO2))**, where

dRf(CO2) = 3.75 x ln (C/292) = radiative forcing by CO_2

dRf(SO2) = - 0.246 x ln (E/22.57) = radiative forcing by SO_2

E = SO_2 emissions (1000 tons)

Then

(5.2.2) **dT = 1.23 x dTSI + 4.61 x ln (C/292) – 0.30 x ln (E/22.57)**

It should be noted that in this model (5.2.1) the coefficient for CO_2 radiative forcing is 3.75, which is 30 % smaller than the 5.35 x ln(C/Co) used by IPCC (chapter 4.8). However, it is clearly (16 %) greater than the coefficient 3.227 given in formula 4.8.5 in chapter 4.8, where the Sulphur dioxide was not in the model.

The modelled temperature follows very closely the measured temperature values (Figure 5.2.2). The deviation of modelled temperature from the measured global warming have been presented in Figure 5.2.3. Standard deviation between the modelled and measured temperatures is 0.071 deg. C. This is less than half of the 0.15 deg. C standard deviations found with modelling only total solar irradiance and carbon dioxide (chapter 4.8).

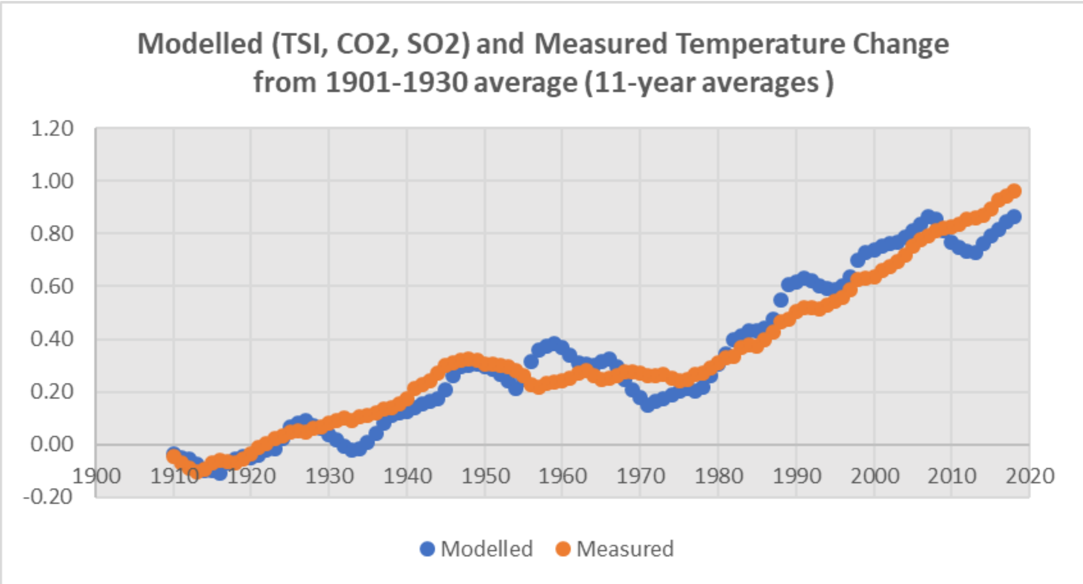


Figure 5.2.2 Modelled and measured global warming. Modelled warming has used totals solar irradiance (TSI), carbon dioxide (CO_2) and Sulphur dioxide (SO_2) as the variables.

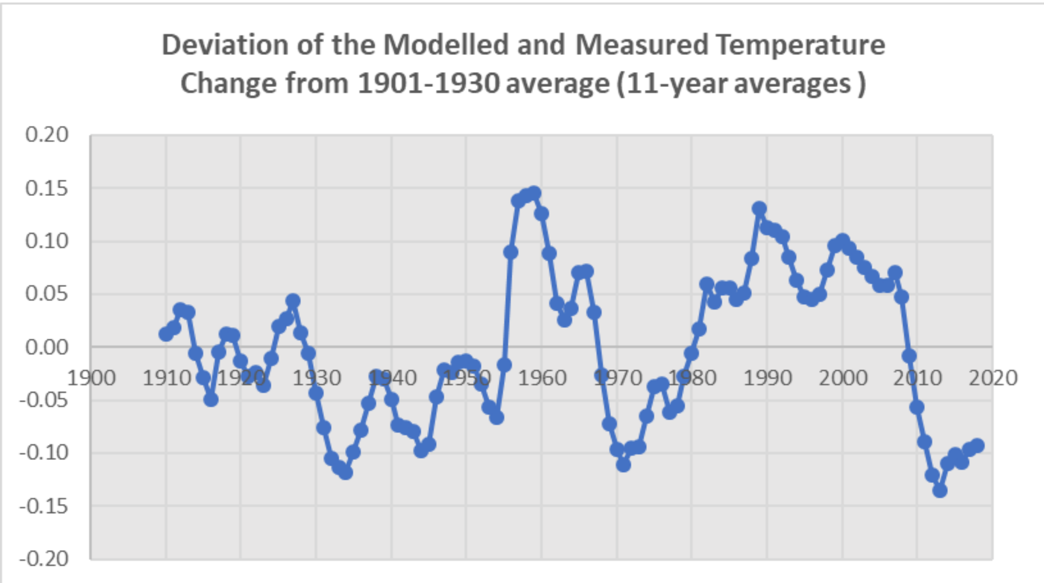


Figure 5.2.3 Deviation of modelled global warming from the measured global warming.

The main improvement by adding SO_2 to the model seems to be in years 1950 – 1980, when the rapidly increased SO_2 emissions stopped the warming for about 30 years. After 1980 SO_2 emissions started to decrease and global warming started to increase again rapidly. Since 1980 both increase in CO_2 concentration and decrease in SO_2 emissions seem to be increasing the global temperature.

Influence of the components can be found from Figure 5.2.4. By the year 2017 carbon dioxide (CO_2) has increased the global temperature with 1.4 deg. C and Sulphur dioxide (SO_2) has decreased the temperature with 0.5 deg. C. Total solar irradiance (TSI) has been decreasing global warming by 0.1 deg. C. The net global warming by the model is then about 0.8 deg. C in 11-year average temperatures from the years 1901- 1930.

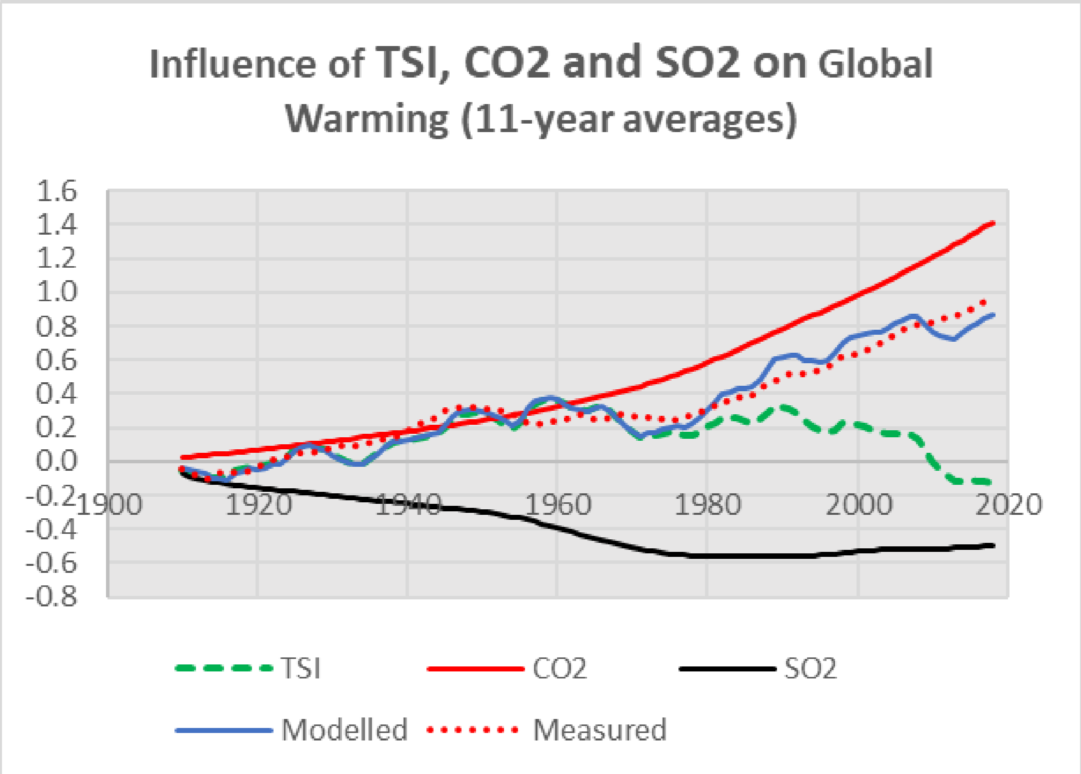


Figure 5.2.4 Influence of TSI, CO_2 and SO_2 on global warming.

5.3 Forecasting future global warming using the model

Global warming can be forecasted using total solar irradiance (TSI), carbon dioxide concentration (CO_2) and emissions of Sulphur oxide (SO_2) as parameters. Each of them could be forecasted separately and then using the model given in formula 5.2.1.

Total Solar Irradiance

Forecast for the Total Solar Irradiance (TSI) has been made assuming that the values will repeat with 99-year cycle. The past values from 1920 to 2019 etc. (Figure 5.3.1). The 11-year average TSI will rise from the present -0.2 W/m^2 to about +0.2 W/m^2 by the year 2080. Because of the coefficient dT = 1.23 x dTSI, this will cause fluctuation in global warming by +/- 0.25 deg. C.

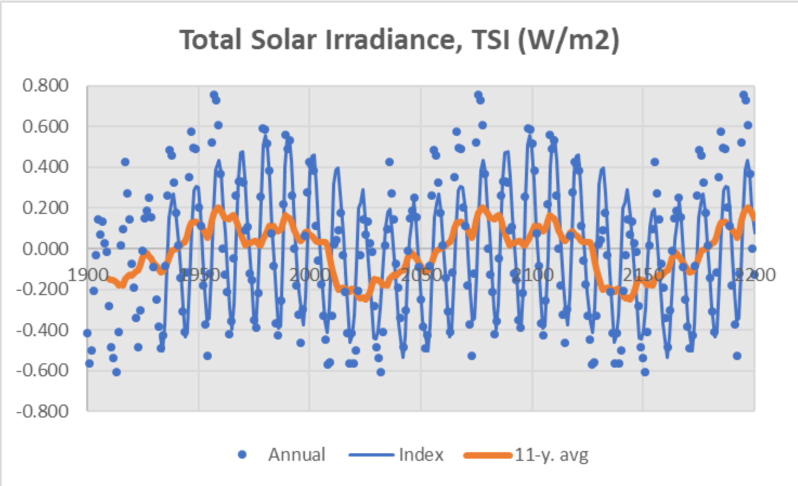


Figure 5.3.1 Forecasted deviation of TSI from average value 1360.93 W/m^2.

a) Present trend

If the CO_2 emissions will increase with the present trend from 1960 to 2017, the 2.0 deg. limit will be achieved before 2050 (Figure 5.3.2). The peak value of 4.2 deg. C warming will be achieved by the year 2120. If SO_2 emissions will stay constant the temperature will be peaking at 3.9 deg. C by the year 2110.

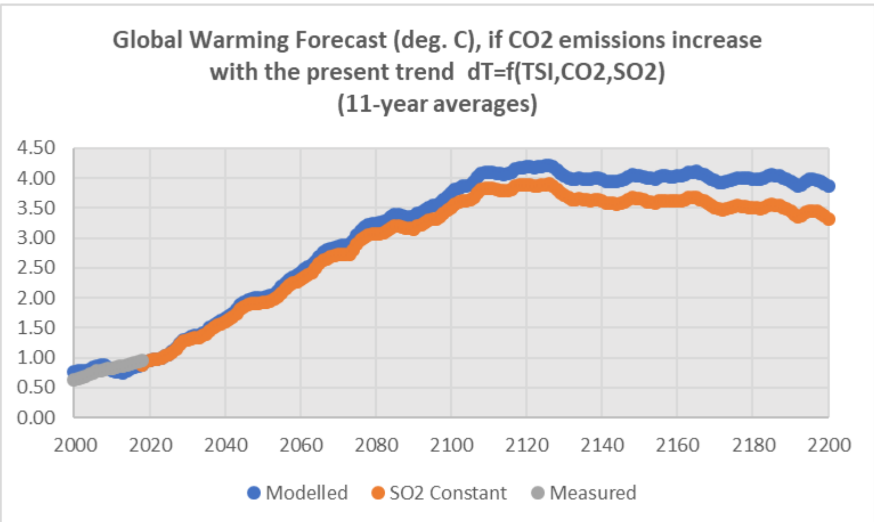


Figure 5.3.2 Global warming, if the emissions will increase with the present trend (1960-2017).

b) CO_2 emissions stay constant

If the CO_2 emissions will stay constant at the present level, the two-degree level will be achieved by the year 2057 (Figure 5.3.3). The temperature will have maximum at 3.8 deg. C in the year 2200. If the SO_2 emissions will stay constant, the global temperature will rise to 3.0 deg. C before the year 2200.

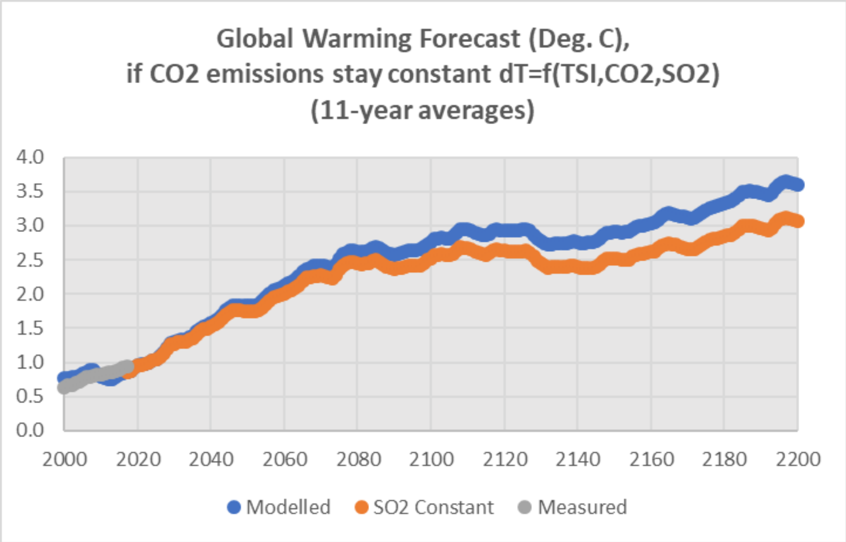


Figure 5.3.3 Forecasted global warming, if the CO_2 emissions will stay constant.

c) CO_2 emissions reduction 1 % annually

If the CO_2 emissions will be reduced 1 % annually, the 2.2 deg. C limit will be achieved by 2080 (Figure 5.3.4). Global temperature will start to decrease after 2080. If SO_2 emissions stay constant, the peak temperature will be 2.1 deg. C.

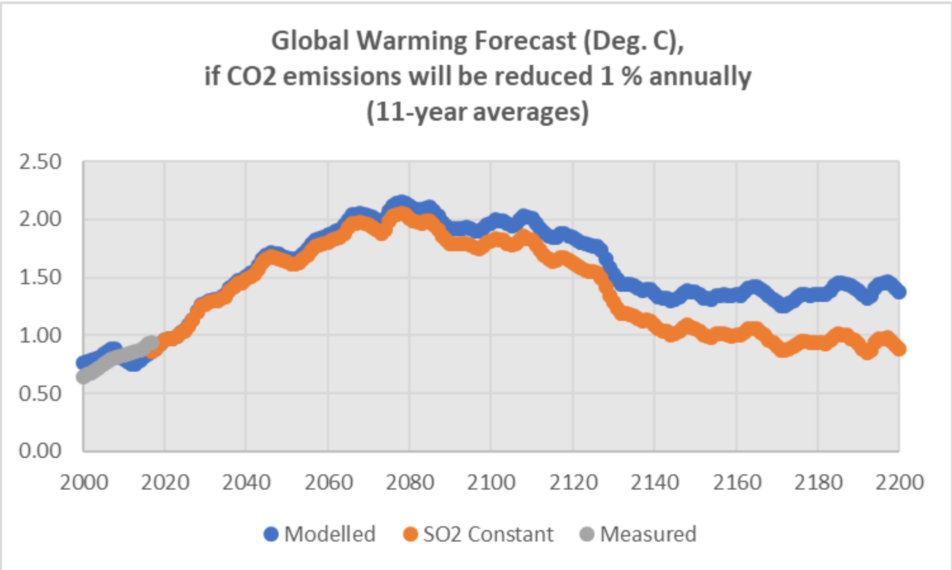


Figure *5.3.4 Forecasted global warming if the CO_2 emissions will be reduced 1 % annually.*

d) CO_2 emissions reduction 2 % annually

With 2 % annual emissions the global temperature will stay below 1.9 deg C (Figure 5.3.5). If SO_2 emissions will stay constant, the peak value will be 1.7 deg. C. Global temperature will start to decrease after 2080.

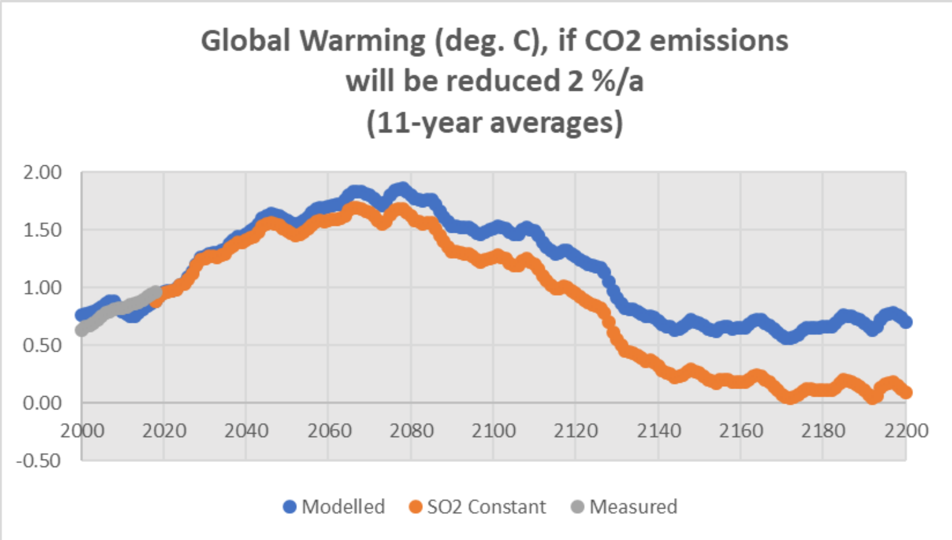


Figure *5.3.5 Forecasted global warming if the CO_2 emissions will be reduced 2 % annually.*

e) CO_2 emissions reduction 3 % annually

With 3 % annual emissions the global temperature will stay below 1.7 deg C (Figure 5.3.6). If SO2 emissions stay constant the peak value will be about 1.5 deg. C. Global temperature will start to decrease after 2080.

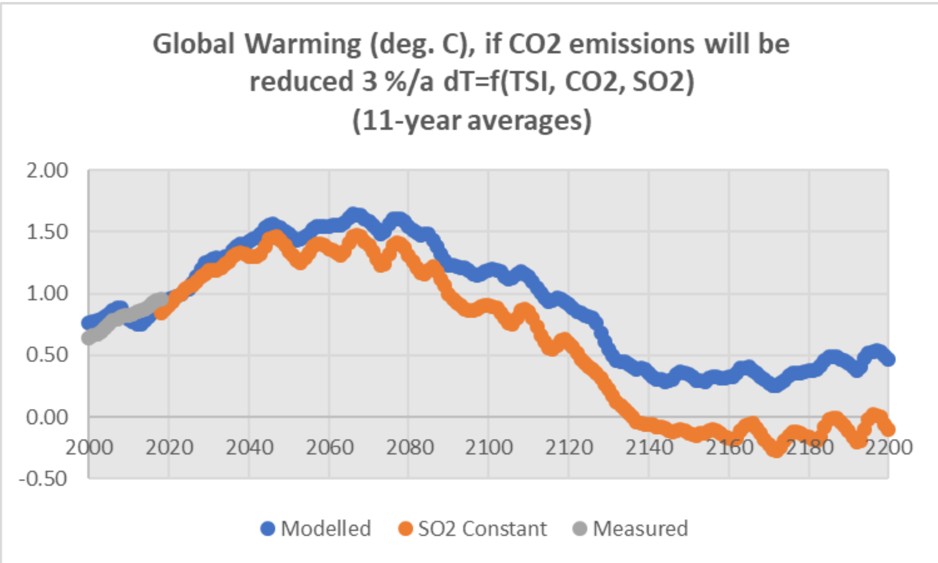


Figure *5.3.6 Forecasted global warming if the CO_2 emissions will be reduced 3 % annually.*

f) 50 % reduction 2018

If the CO_2 emissions will be reduced with 50 % in 2019 (Figure 5.3.7) the peak value of temperature will be 2.0 deg. C by the year 2150. If SO_2 emissions remain constant, the warming will peak at 1.6 deg. C by the year 2080.

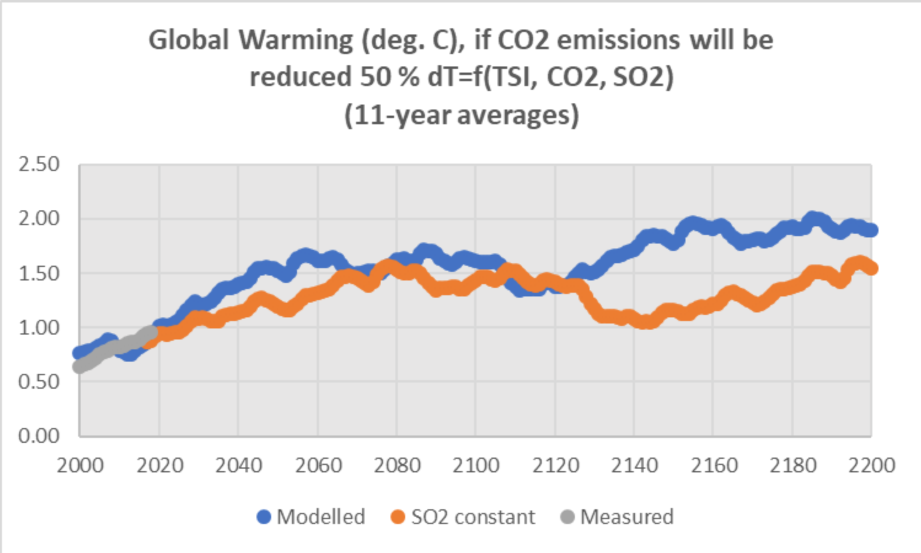


Figure 5.3.7 Forecasted global warming. if CO_2 emissions will be reduced 50 % today.

g) Target emissions

With the target emissions the global temperature will be peaking at 2.1 deg. C in the year 2057 (Figure 5.3.8). If the SO_2 emissions will stay constant, the peak temperature will be 2.0 deg. C

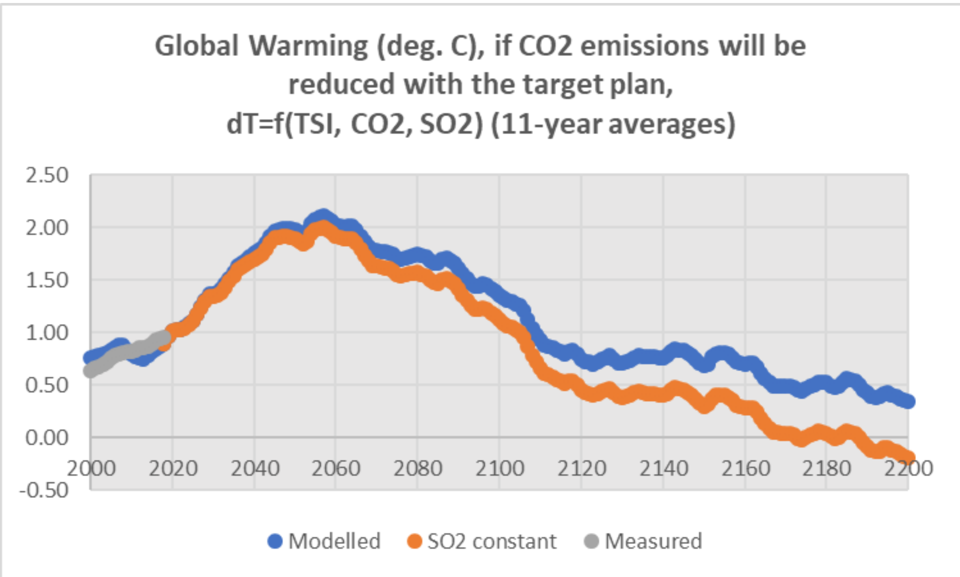


Figure 5.3.8 Global warming, if emissions will be reduced with a target plan.

Summary

The various scenarios have been summarized in Figure 5.3.9, in which the modelled global temperatures have been given until the year 2200. If the CO_2 reductions will be 2 % annually the peak temperature 1.9 deg. C. will be achieved by 2080 (Figure 5.3.9). The same influence can be achieved with 50 % reduction in the year 2019. The 1.5 deg. C limit will not be achieved, if reduction of emissions will be 4 % annually.

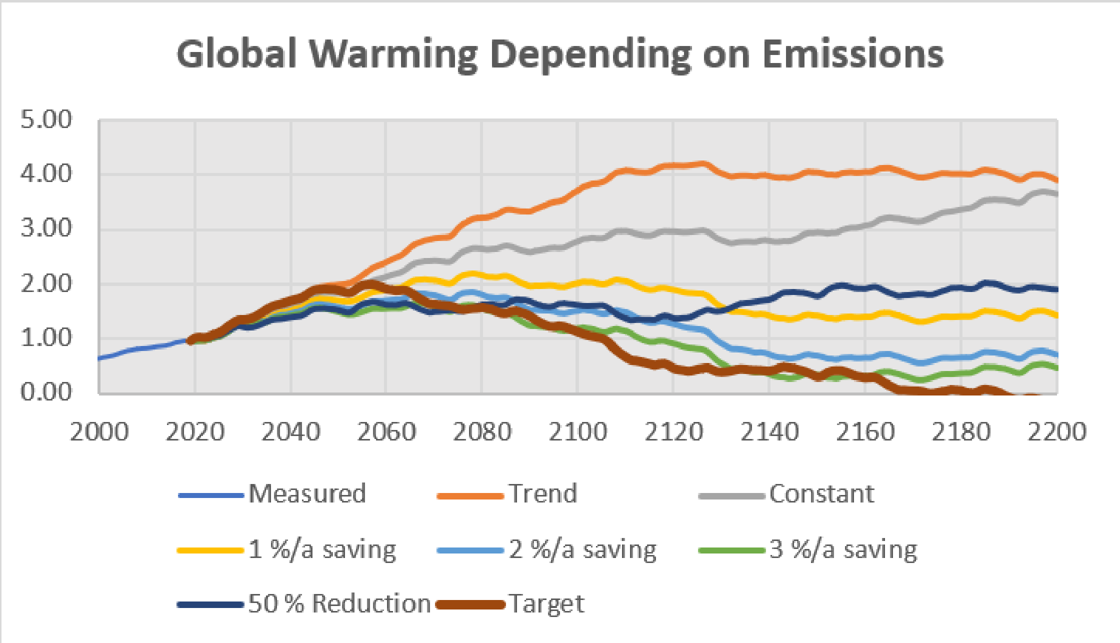


Figure 5.3.8 Global warming depending on CO_2 emissions until 2200.

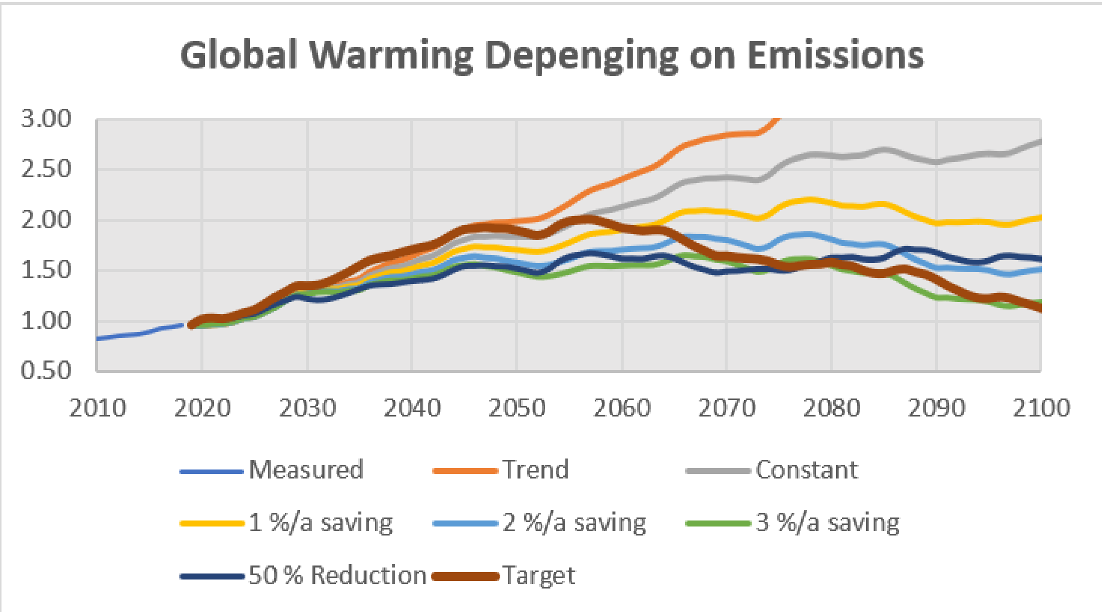


Figure 5.3.9 Global temperature change depending on CO_2 emissions until 2100.

The critical 2.0-degree limit will be achieved by 2050, if the emissions will increase with the present trend (Figure 5.3.9). With constant emissions 2.0-degree will be achieved by 2055, but temperature will continue to increase near 3.0 deg. C. If the emissions will be reduced 1 % annually, 2.0-degree limit will be exceeded by 2065. With target emissions the peak temperature will be at 2.1 deg. C in the year 2055.

The 1.5-degree limit will be achieved with present trend and with target emissions by the year 2035. With 3 % reductions in emissions the 1.5-degree limit will be achieved by the year 2045. However, it is impossible to start so large reduction so quickly.

Table 5.3.1 Global warming from years 1901-1930 with model dT = f (TSI, CO2, SO2).

	Global warming from years 1901 - 1930 (deg. C)						
Year	**Trend**	**Constant**	**1 %/a**	**2%/a**	**3 %/a**	**-50%**	**Target**
2018	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2030	1.3	1.3	1.3	1.3	1.3	1.2	1.3
2040	1.6	1.6	1.5	1.5	1.4	1.4	1.7
2050	2.0	1.8	1.7	1.6	1.5	1.5	1.9
2100	3.7	2.8	2.0	1.5	1.2	1.6	1.1
2200	3.9	3.6	1.4	0.7	0.5	1.9	-0.2
Max	4.2	3.7	2.2	1.9	1.6	2.0	2.0

Finally, we can find global warming, if SO_2 emissions stay constant at 2018 level (Figure 5.3.10). Then, the global temperature will have a peak at 2.1 deg. C (in 2078), if CO_2 emissions will be reduced 1 % annually. With 2 % savings the temperature will have peak at 1.7 deg. C in the year 2066. With target emissions the peak temperature will be achieved at 1.9 degrees in the year 2047.

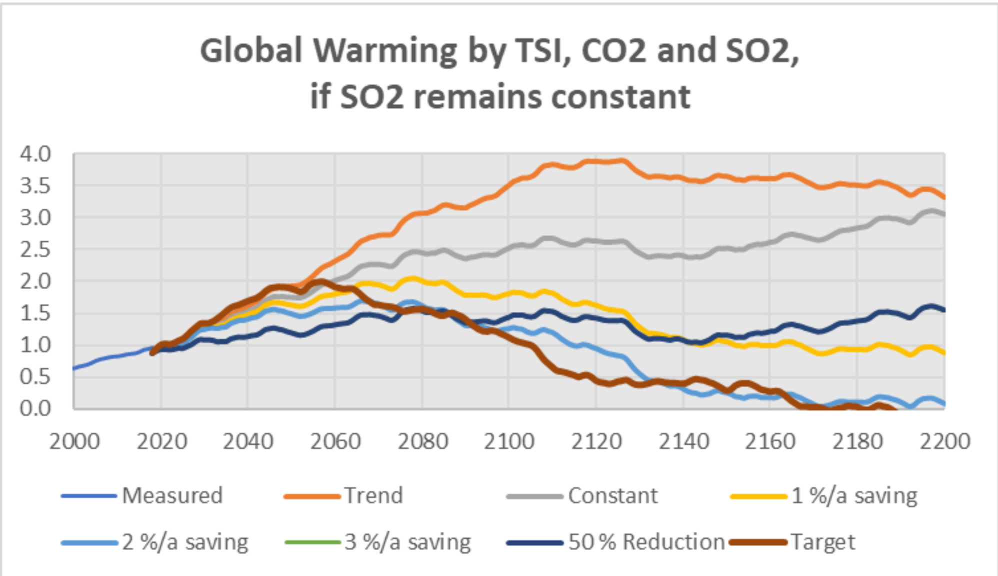


Figure 5.3.10 Global warming, if SO_2 stays constant at 2018 level.

5.4 Comparing the model with IPCC estimation

Influence of carbon dioxide

The largest influence on global warming has the concentration of CO_2, which will depend on emission savings in the future. Concentration will rise to 600 ppm by the year 2100, if the emissions will increase with the present trend.

IPCC evaluations in their latest report (Climate Change 2014, Synthesis Report). The base line scenario of IPCC assumes that emissions will stay at present level and global warming will continue in a near linear relationship with the cumulative CO_2 emissions. The warming will be 4.0 deg. C, if the CO_2 emissions will be 7000 Gt (Figure 5.4.1, total human-induced warming). The sensitivity of warming to emissions is about 0.55 deg. C/1000 Gt with IPCC model (Figure 5.4.2).

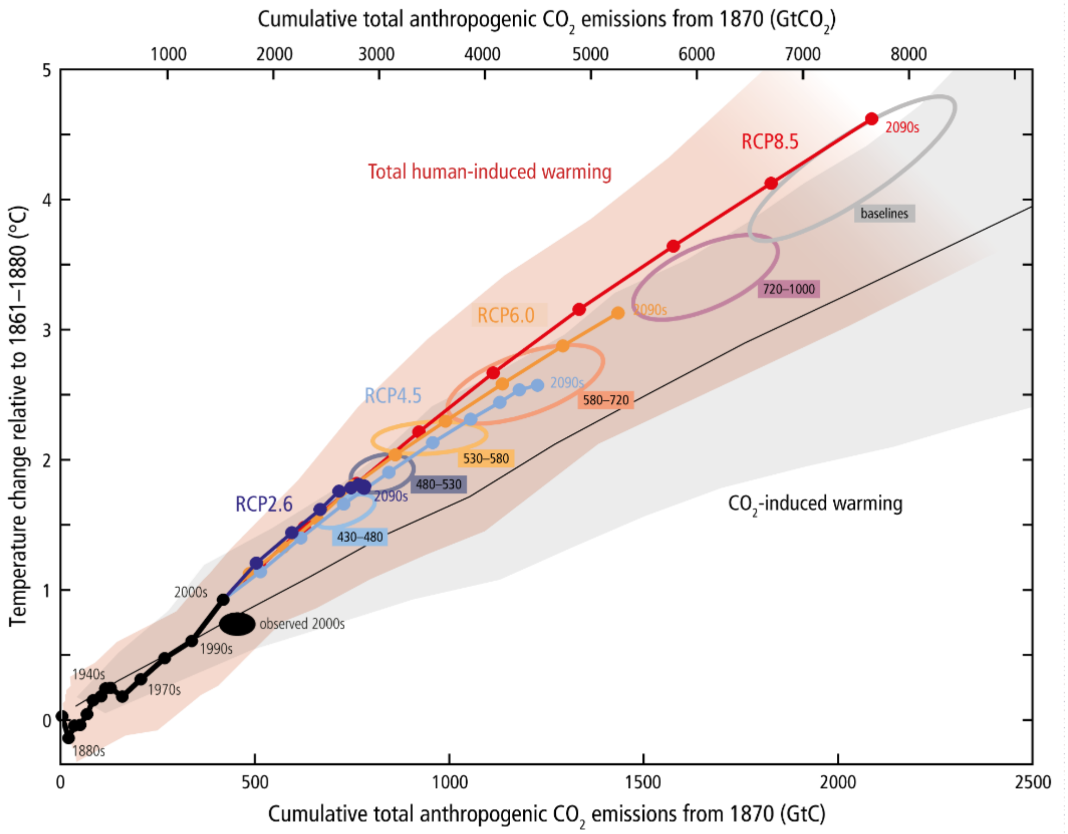


Figure 5.4.1 Temperature change as a function of cumulative carbon dioxide emissions (Source: IPCC AR4, Climate Change 2014 Synthesis Report Fifth Assessment Report).

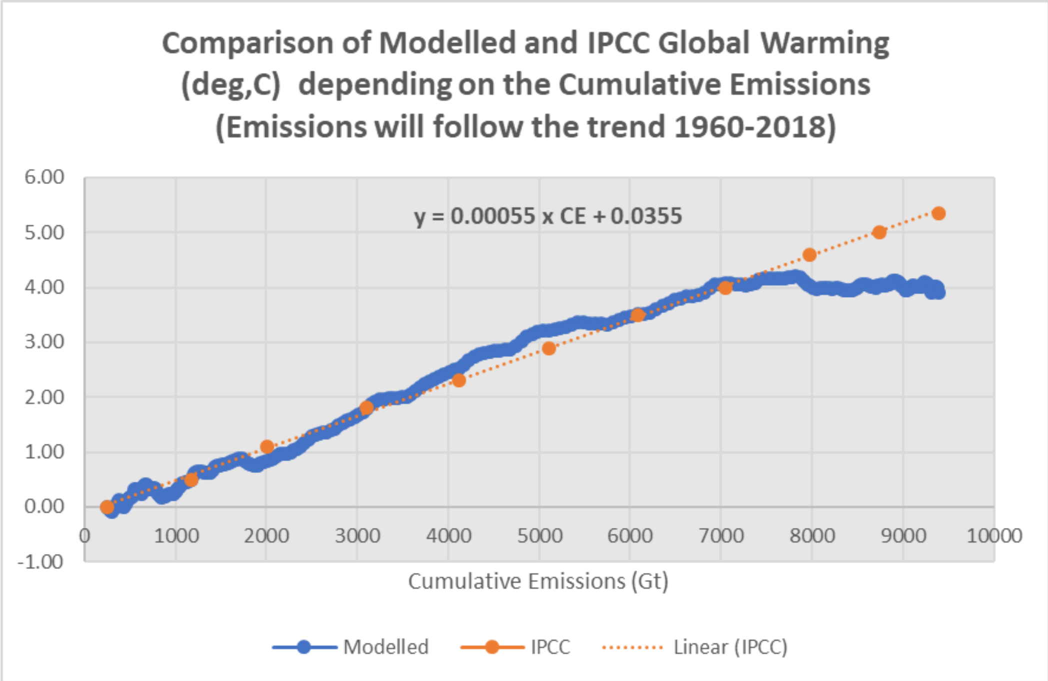


Figure 5.4.2 Comparison of modelled global warming to IPCC models as a function of cumulative CO_2 emissions assuming the annual emissions increase with the trend 1960 – 2018.

a) CO_2 emissions increase with present trend

It can be found from the Figure 5.4.2 that both the IPCC and the model of in which the CO_2 emissions increase with the present trend predict 4.0 deg C global warming until 7000 Gt CO_2 emissions. The results will be different after 7000 Gt our mass balance model starts to degrease CO_2 concentration in the atmosphere because the emissions from fossil fuels will start to decrease because of the ultimate reserves will be xhausted.

b) Constant CO_2 emissions

If the CO_2 emissions will remain at the present level, difference in our model and IPCC model are very small until 5500 Gt emission, where the global warming will be about 3.0 deg. C (Figure 5.4.3). After 6000 Gt the difference becomes large, because our model predicts that the CO_2 emissions and absorption will reach its balance with at about 550 ppm concentration and 3.0 deg. C warming.

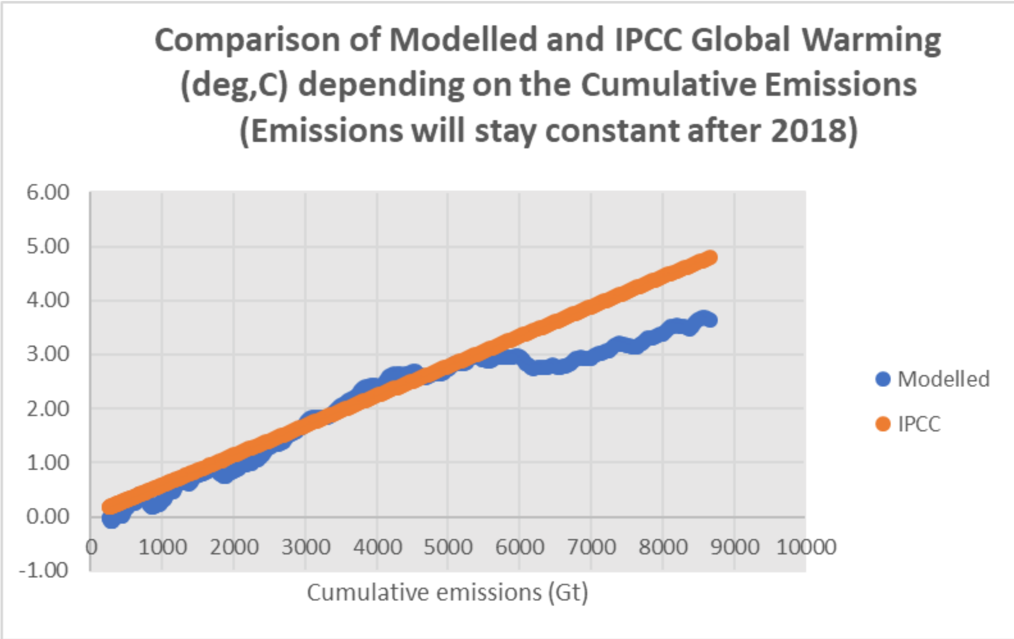


Figure 5.4.3 Global warming depending on cumulative emissions assuming the annual emissions will stay constant.

c) Emissions decrease 1 % or 2 % annually

If the CO_2 emissions will decrease 1 % annually, the IPCC model and our model can predict 2.0 deg. C global warming until 3700 Gt emissions (Figure 5.4.4). After it our model starts global cooling, but IPCC model will continue global warming.

With 2 %/a reduction in emissions our model and IPCC model give same results until 3200 Gt emissions (Figure 5.4.5).

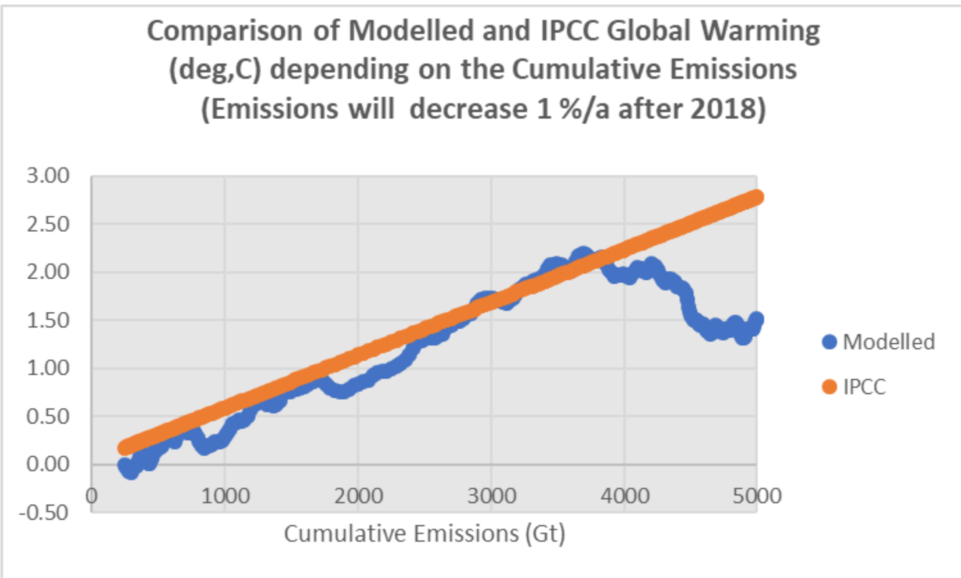


Figure 5.4.4 Global warming depending on cumulative emissions assuming the annual emissions will decrease 1 % annually.

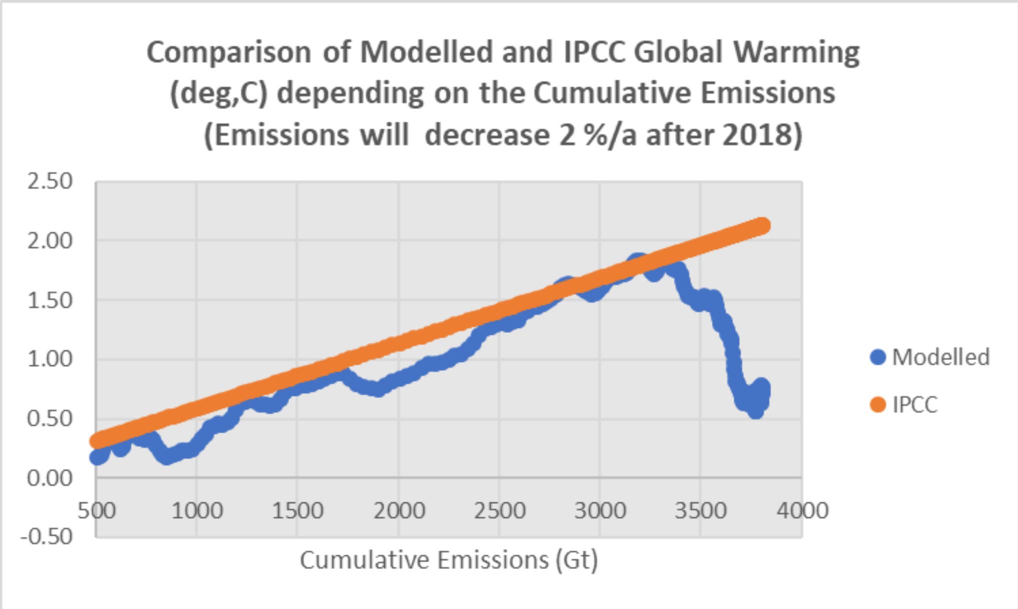


Figure 5.4.5 Global warming depending on cumulative emissions assuming the annual emissions will decrease 2 % annually.

c) Emissions will be decreasing 3 % annually

Finally, if the emissions can be reduced by 3 % annually, the global warming will achieve 1.5 deg. C, when the cumulative emissions will be 2800 Gt (Figure 5.4.8).

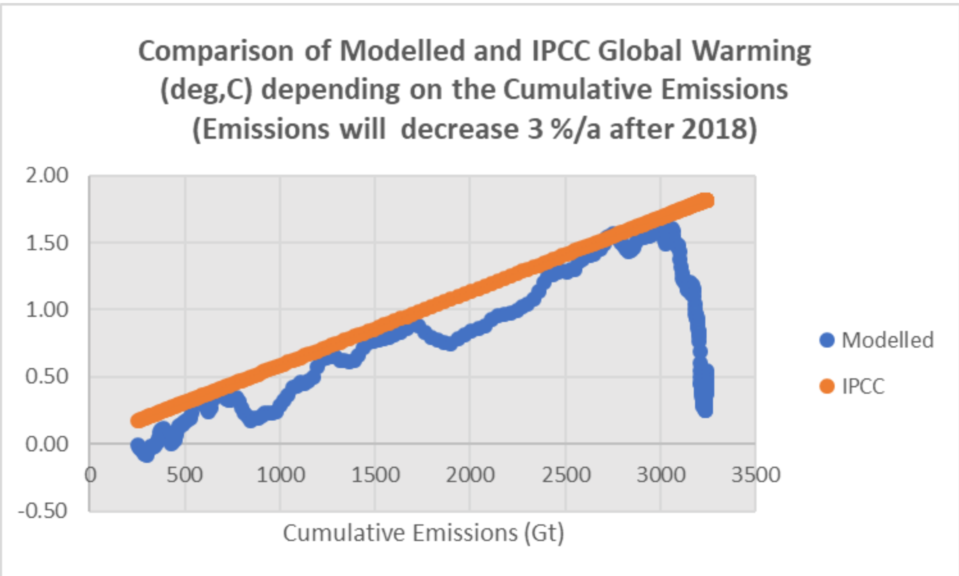


Figure 5.4.6 Global warming depending on cumulative emissions assuming the annual emissions will decrease 3 % annually.

d) Target emissions

Finally, if the emissions will be reduced with the target plan, the IPPC model and our model give the same 2.0 deg. C global warming until 3400 Gt, when the cumulative emissions will be about 3300 Gt. But after 3500 the emissions will not be increasing and

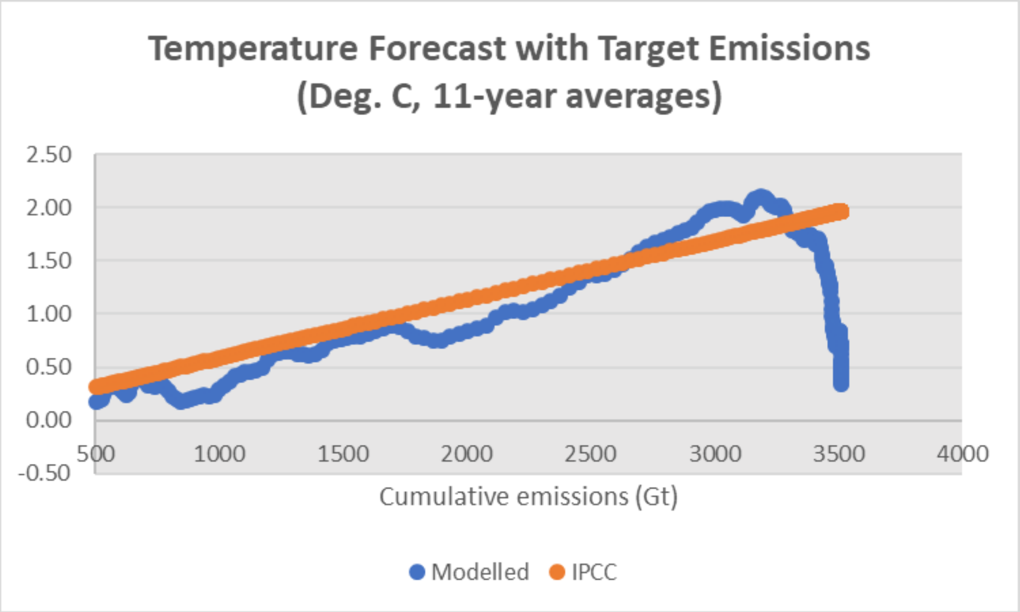


Figure 5.4.7 Global warming with our model and IPCC estimates, if the emissions will follow the target plan.

Summary

Both our model and IPCC models predict the 2 deg. C warming until 3300 Gt cumulative emissions similarly, if the emissions will be reduced 1 % annually after the year 2018 or with the target plan. The 1.5 deg. C warming will be reached at about 2700 Gt cumulative CO_2 emission.

6 CHANGES IN SEA WATER

6.1 Temperature rise in seawater

East Anglian University has collected HadSTT3 data set starting from the year 1850. Their data of sea water temperature has been increasing from average of 1901 – 1930 about 0.8 degrees (Figure 6.1.1). The seawater temperature has been rising at about the same rate as the global temperature of the atmosphere (Figure 6.1.2).

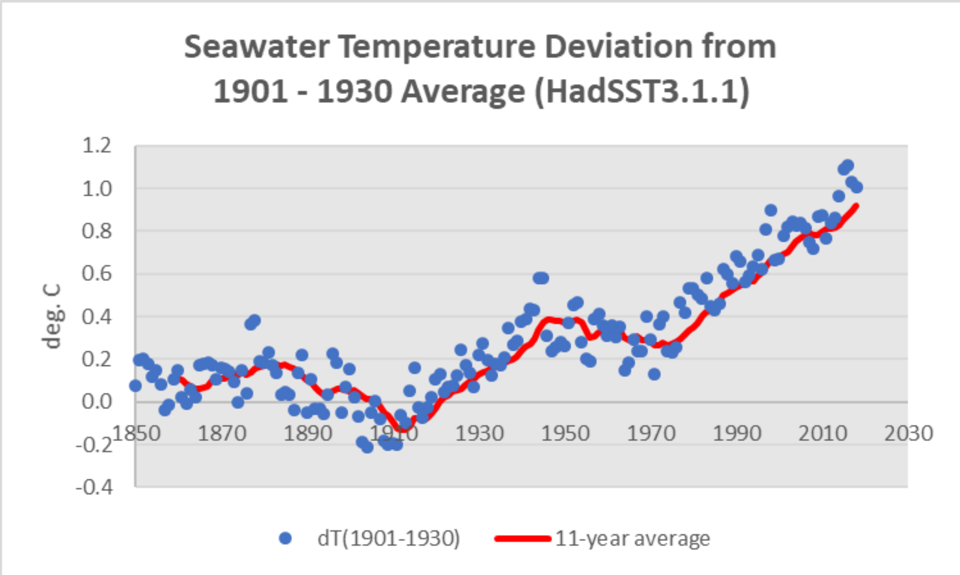


Figure 6.1.1 Seawater temperature deviation from 1901 – 1930 average.

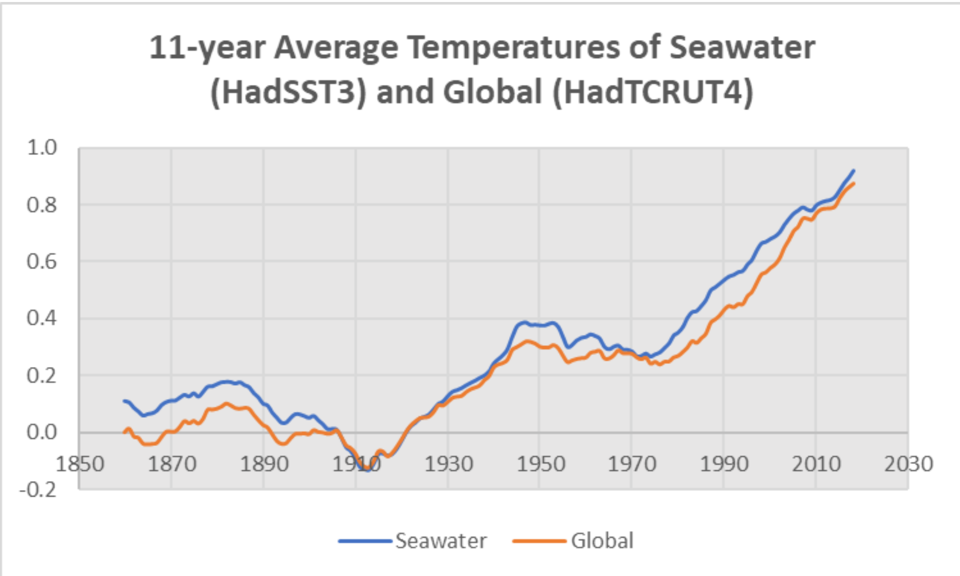


Figure 6.1.2 11-year average temperatures of seawater and global.

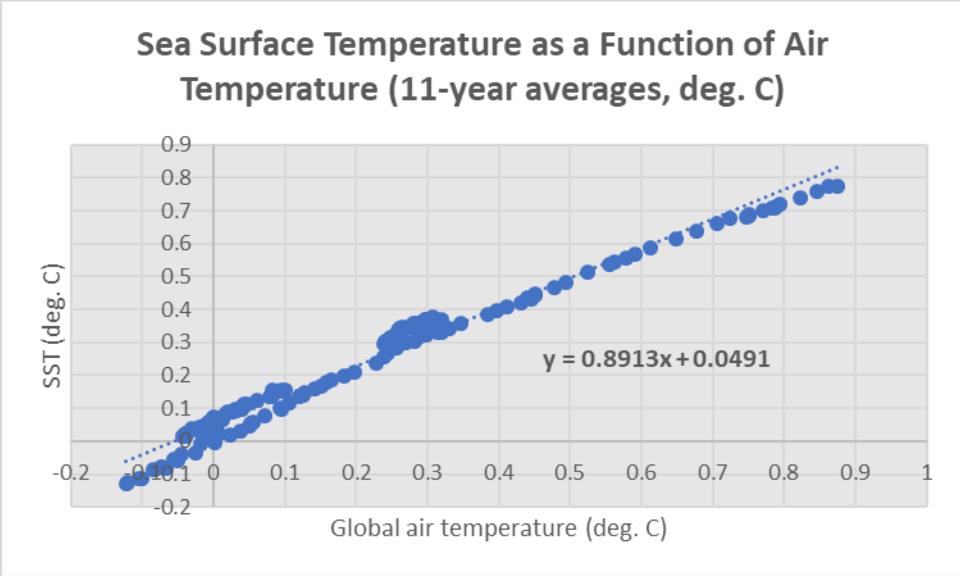


Figure 6.1.3 Seawater temperature changes 89.5 % of air temperatures

Seawater temperature has been warming 86 % of the air temperature (Figure 6.1.3). However, the warming has not been quite linear, but it has been decreasing. This may have caused by the evaporation of water, which will increase at higher temperatures.

Seawater temperature changes also with solar irradiance, if 11-year average values of seawater temperatures and irradiance for years 1890 – 1950 are presented in XY-diagram (Figure 6.1.4). If irradiance changes with 0.1 W/m^2 the seawater temperature would change with 0.14 deg. C.

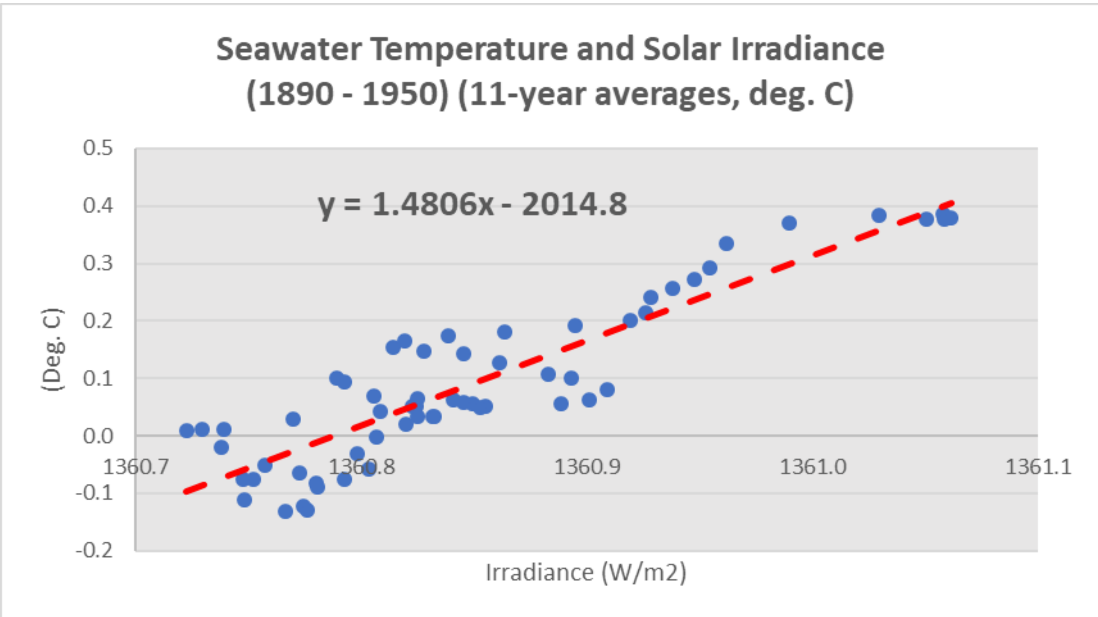


Figure 6.1.4 11-year average figures of seawater temperature and total solar irradiance from years 1890 – 1950.

We can then separate seawater warming in two parts by the formula (6.1.1)

(6.1.1) $$\mathbf{T(TSI) = 1.4252 \times TSI - 1939.5}$$

The first part, T(TSI), has been caused by total solar irradiance (TSI) and the second, which is caused by other reasons, T-T(TSI). We can then find that seawater temperature changes have been mainly caused by sun irradiance until the year 1990. After 1990 other than sun has caused the quite rapid warming after 1990 (Figure 6.1.5).

The trend after 1990 of seawater temperature after sun irradiance has been rising from about 0.1 deg. C to 0.95 deg. C in 27 years. The trend in now 0.32 deg. C / decade (Figure 6.1.6). This is slightly smaller than temperature increase in global air, which has been 0.34 deg. C / decade (see Figure 3.4.7). Seawater temperature has been measured about 25 cm from the surface, which means that the surface water has been mixed with colder water from deep sea.

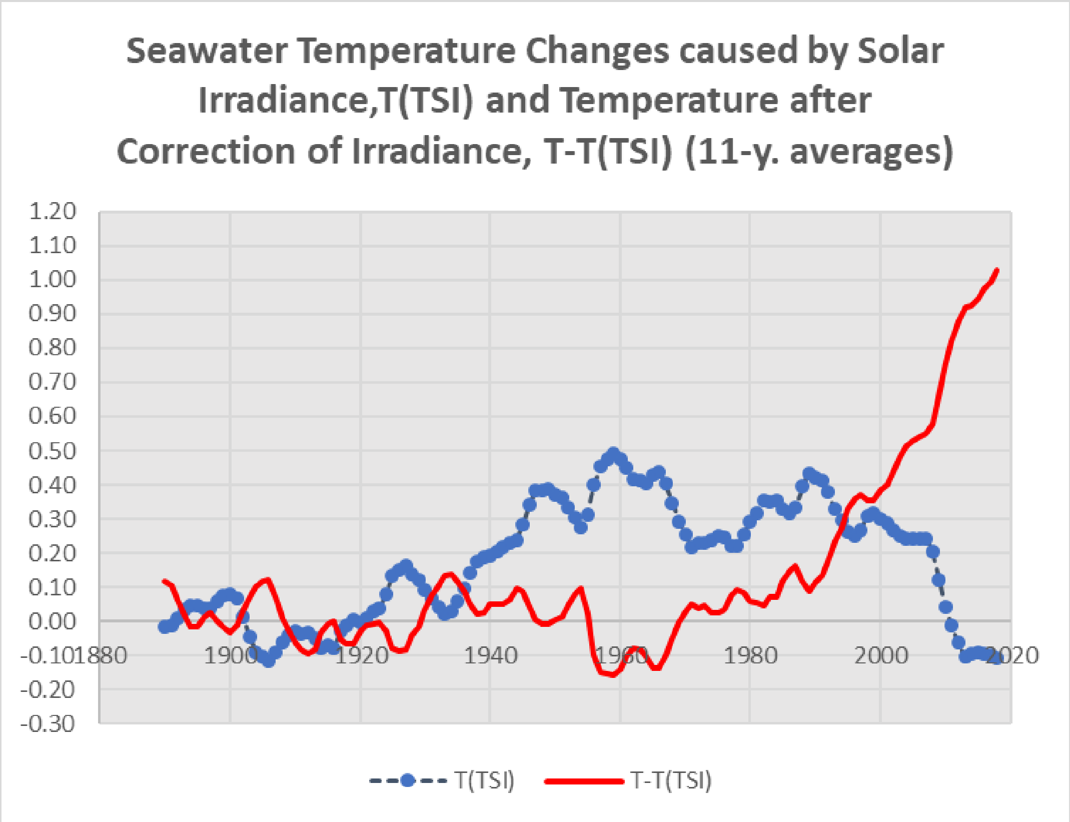


Figure 6.1.5 Temperature change caused by solar irradiance T(TSI) and the other factors T-T(TSI).

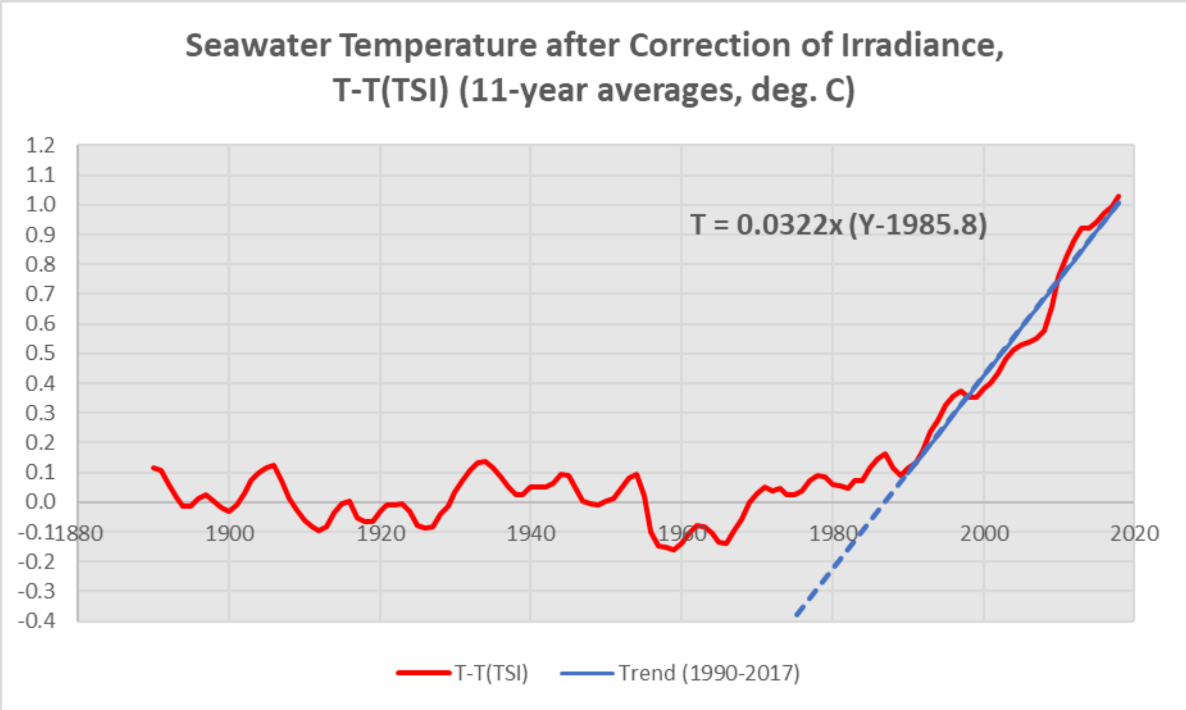


Figure 6.1.6 Seawater temperature after correction of sun irradiance.

Solar irradiance has caused about 0.4 degree warming of seawater during years 1950 – 1990 and about 0.2 deg. C cooling after 2013 - 2018 (Figure 6.1.7)

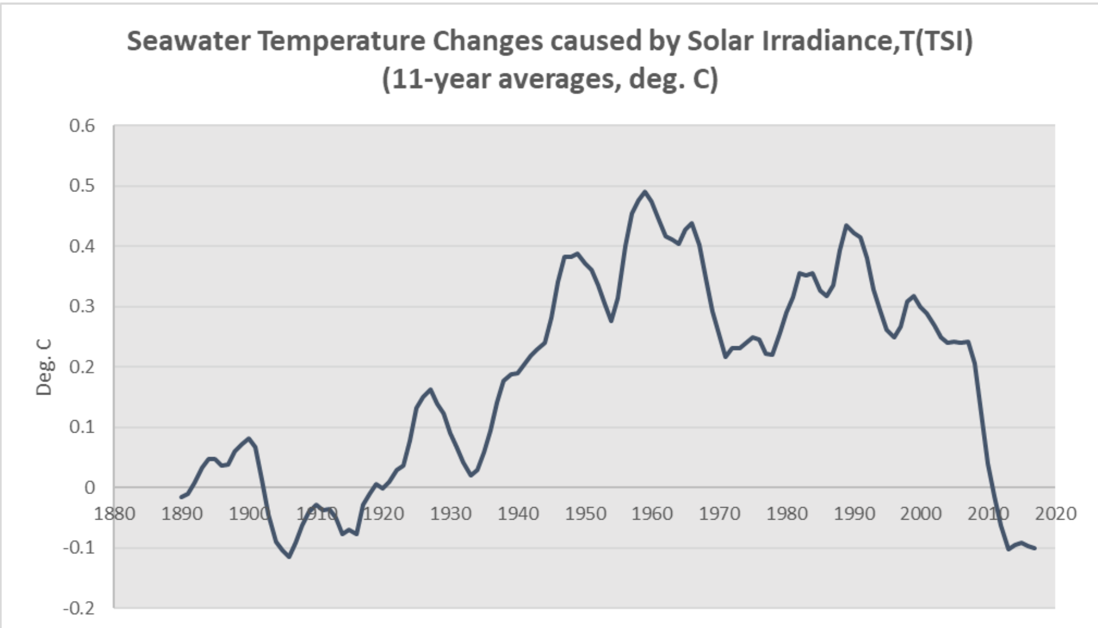


Figure 6.1.7 Seawater temperature changes caused by solar irradiance.

6.2 Atlantic Multidecadal Oscillation (AMO)

Sea surface temperature (SST) varies locally because of temperature oscillations in seas. In the Atlantic Ocean, this is called as Atlantic Multidecadal Oscillation (AMO). AMO Index is measuring difference between North Atlantic SST (between 0°N to +60°N) and global SST (between 60°S to 60°N).

AMO cycle has about 60 – 80-year duration and the AMO Index were last time higher than average during years 1930 – 1970 (Figure 6.2.1). Low AMO Index period was followed during years 1970 – 2000 and today we are experiencing the higher than normal period, which may last from 2000 to years 2030-2040.

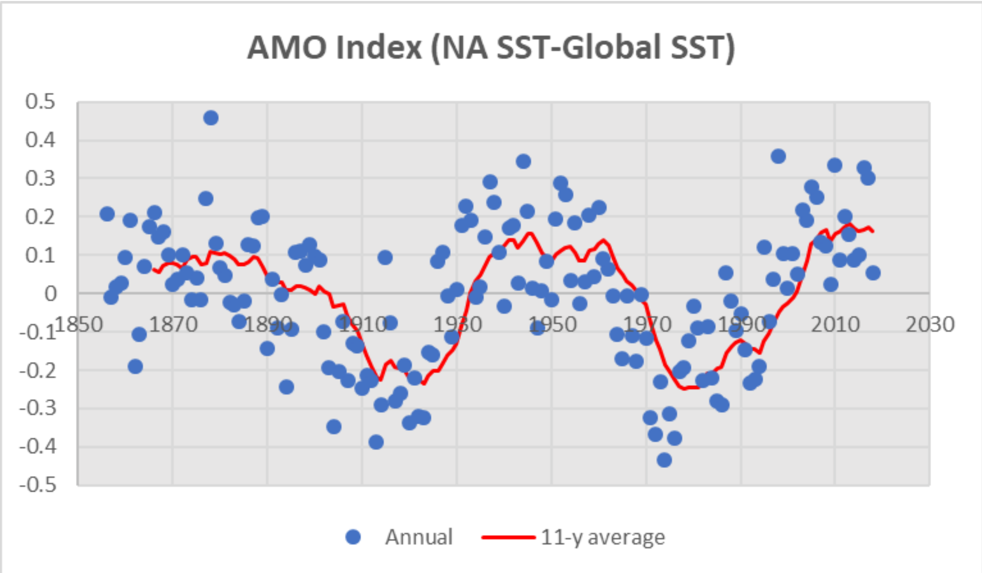


Figure 6.2.1 AMO index or deviation of SST in North Atlantic (from 0°N to 60°N) from global SST (60°S – 60°N) starting from average of years 1901 – 1930 (Source NOAA, Kaplan SST V2 data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/).

AMO index seems to be following global seawater surface temperature (SST, Figure 6.2.2). However, the AMO index was declining from years 1960 to 1980, but global SST stayed almost constant.

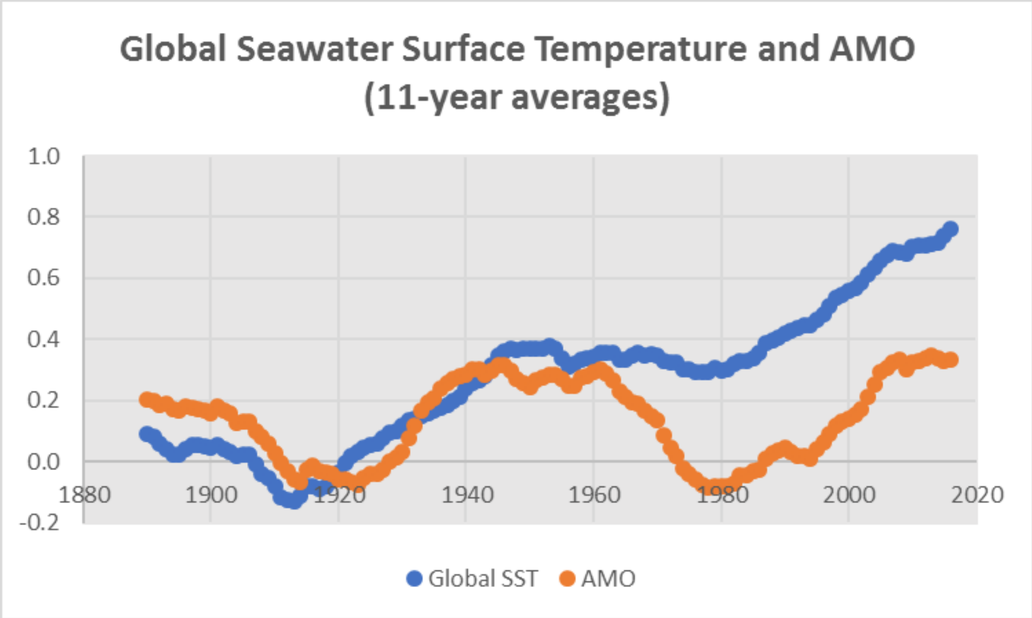


Figure 6.2.2 Global seawater surface temperature and AMO index.

If we add AMO to global SST, we will get North Atlantic temperature (Figure 6.2.3). We can notice that North Atlantic SST has been fluctuating much more than the Global SST. The temperature is today 1.1 deg. C higher than during years 1901 – 1930.

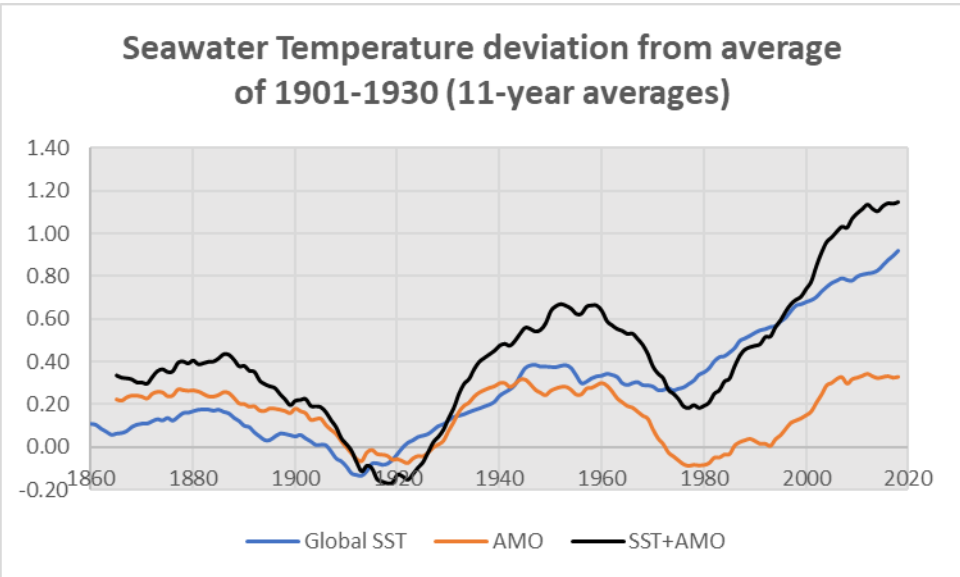


Figure 6.2.3 Seawater temperature and AMO change from the years 1901 – 1930.

The 70-year AMO cycle has lasted from 1930 to 2000 from average to average. Today we are living the warm phase which may last from 2000 to 2035.

6.3 North Atlantic Oscillation (NAO)

North Atlantic Oscillation (NAO) is measured by air pressure difference between Gibraltar and Iceland. It is changing cyclically with peak is 1990 and 1015 (Figure 6.3.1).

North Atlantic seawater temperature changes are closely connected to North Atlantic Oscillation (NAO) (Figure 6.3.2).

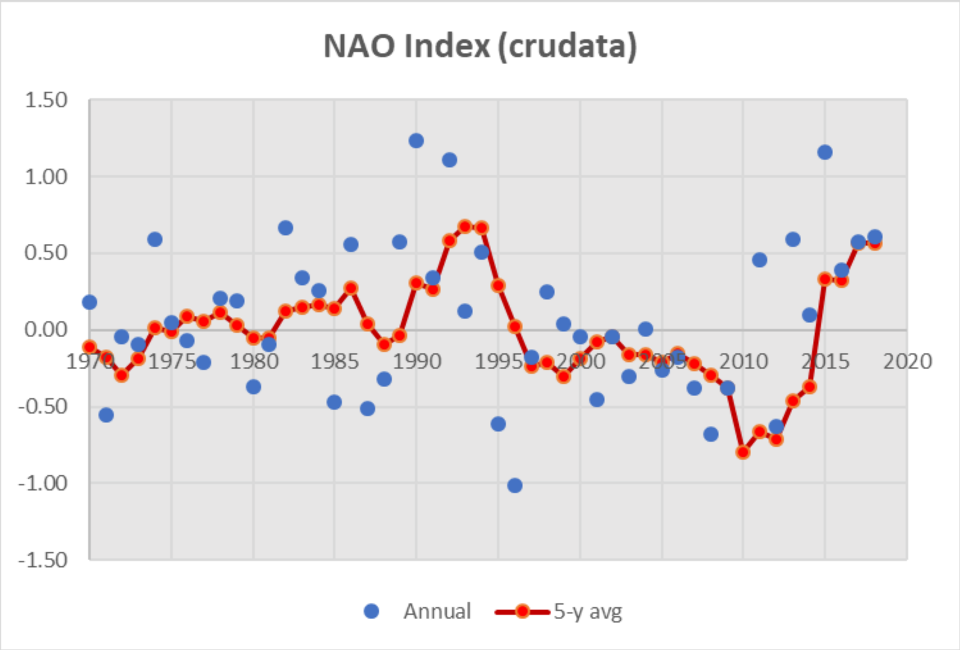


Figure 6.3.1 North Atlantic Oscillation.

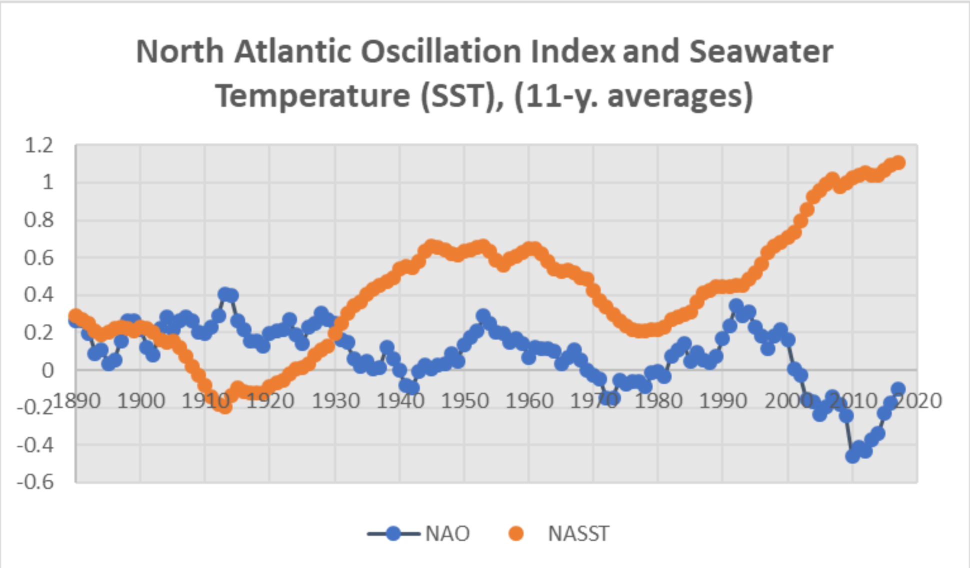


Figure 6.3.2 North Atlantic Oscillation and seawater temperature (11-y. averages).

This pressure difference (= NAO Index) is increasing, if the low pressure stays near Iceland, which means that the westwards winds will be become stronger and will travel across northwester Europe. With higher NAO index during the summer North West Europe will be warmer and South Europe colder than normal (Figure 6.3.3). Also, precipitation will be decreasing in the North and decreasing in South Europe. NAO index is now approaching positive phase (Figure 6.3.4).

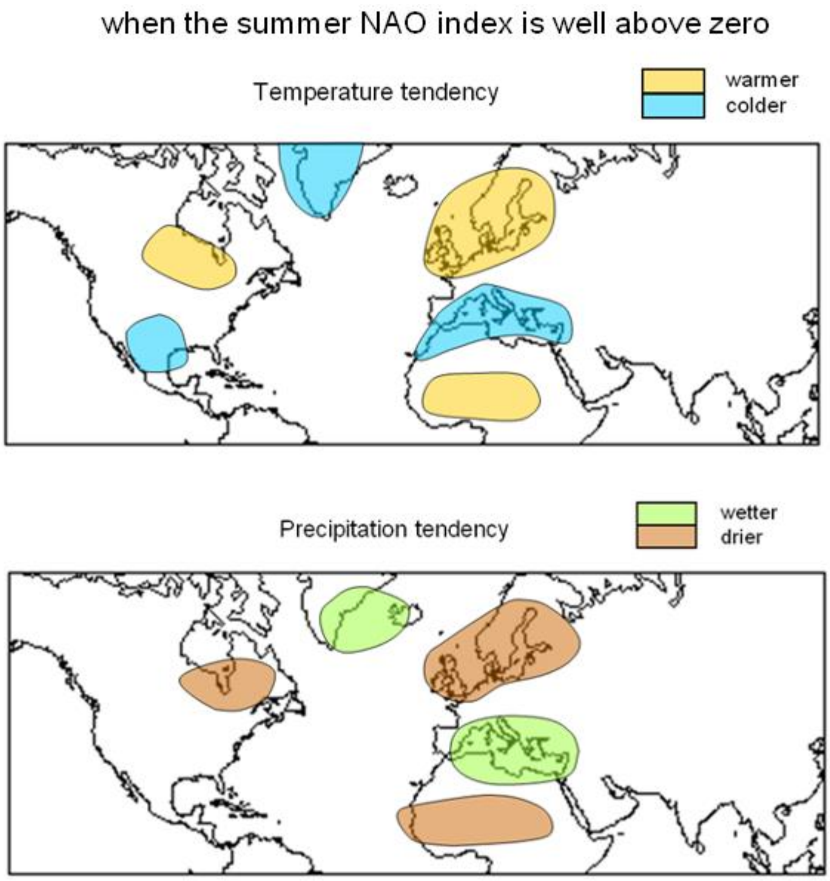


Figure 6.3.3 Influence of high NAO Index to weather in summer (Met office, Osborne).

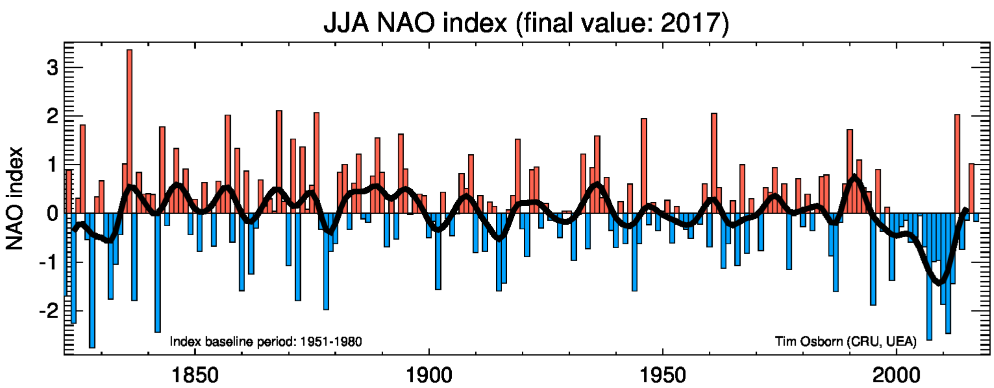


Figure 6.3.4 NAO Index has been higher than normal in the summers after 2014 (Source: Tim Osborne CRU).

With lower than zero during summer the weather will be colder in North West Europe and warmer in South Europe (Figure 6.3.5).

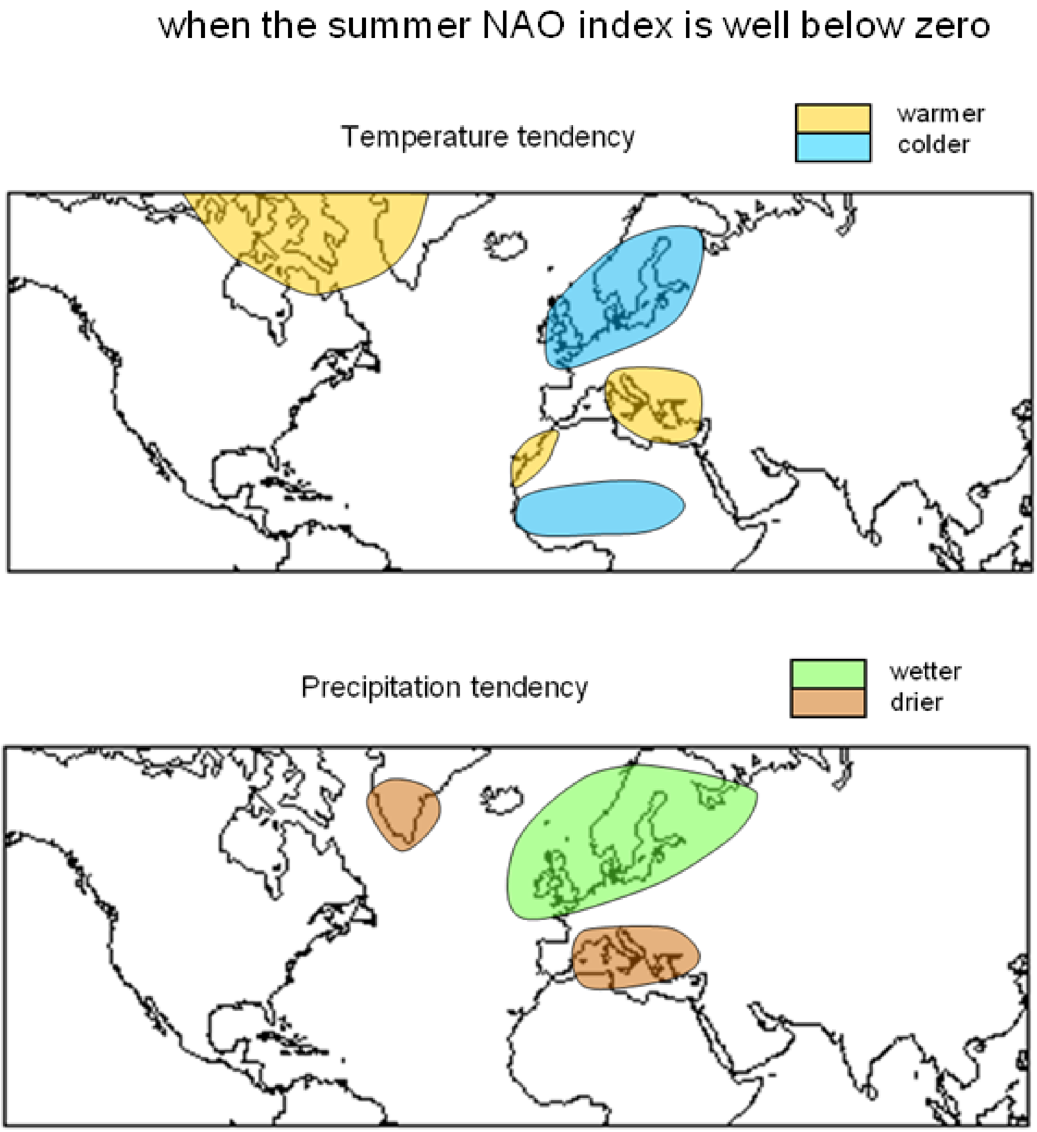


Figure 6.3.5 If NAO is below zero North-West Europe will be cooler (Met Office, Osborne).

When the winter NAO is above zero, the weather in North-East Europe becomes warmer (Figure 6.3.6). Winter NAO Index has been above zero during last five years (Figure 6.3.7)

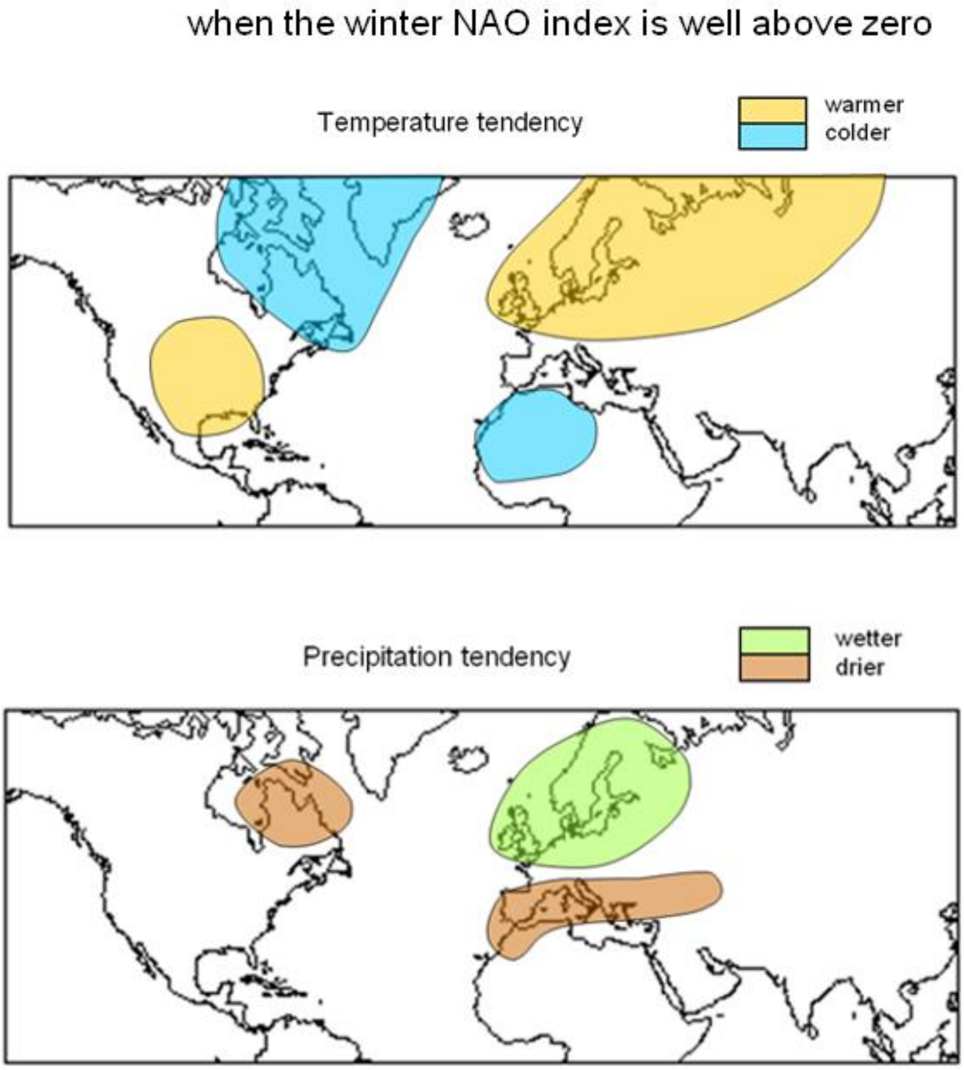


Figure 6.3.6 If NAO is above zero during winter, weather will be colder in North-Wets Europe (Met Office, Osborne).

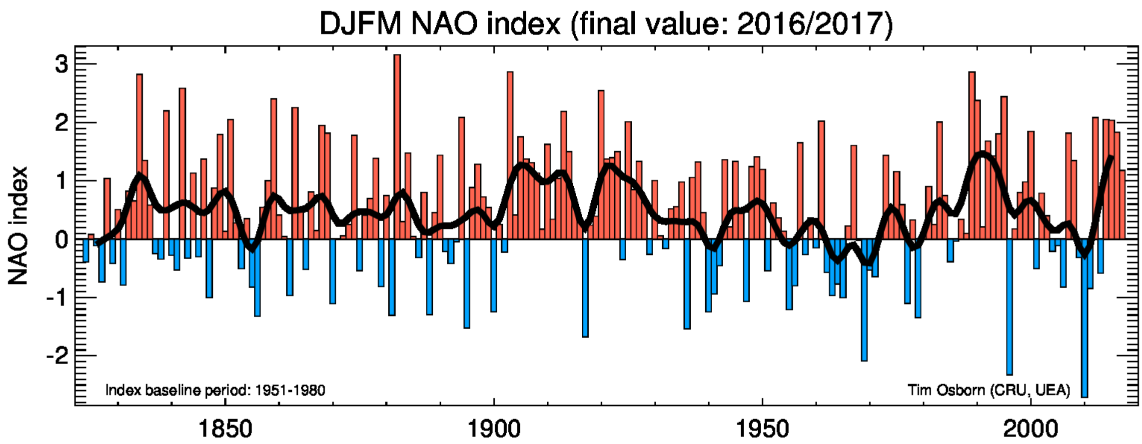


Figure 6.3.7 NAO Index during winter (Source: Tim Osborne CRU).

With low NAO Index during winter there will be colder in North-West Europe and warmer in North-Africa and colder weather in USA (Figure 6.3.8)

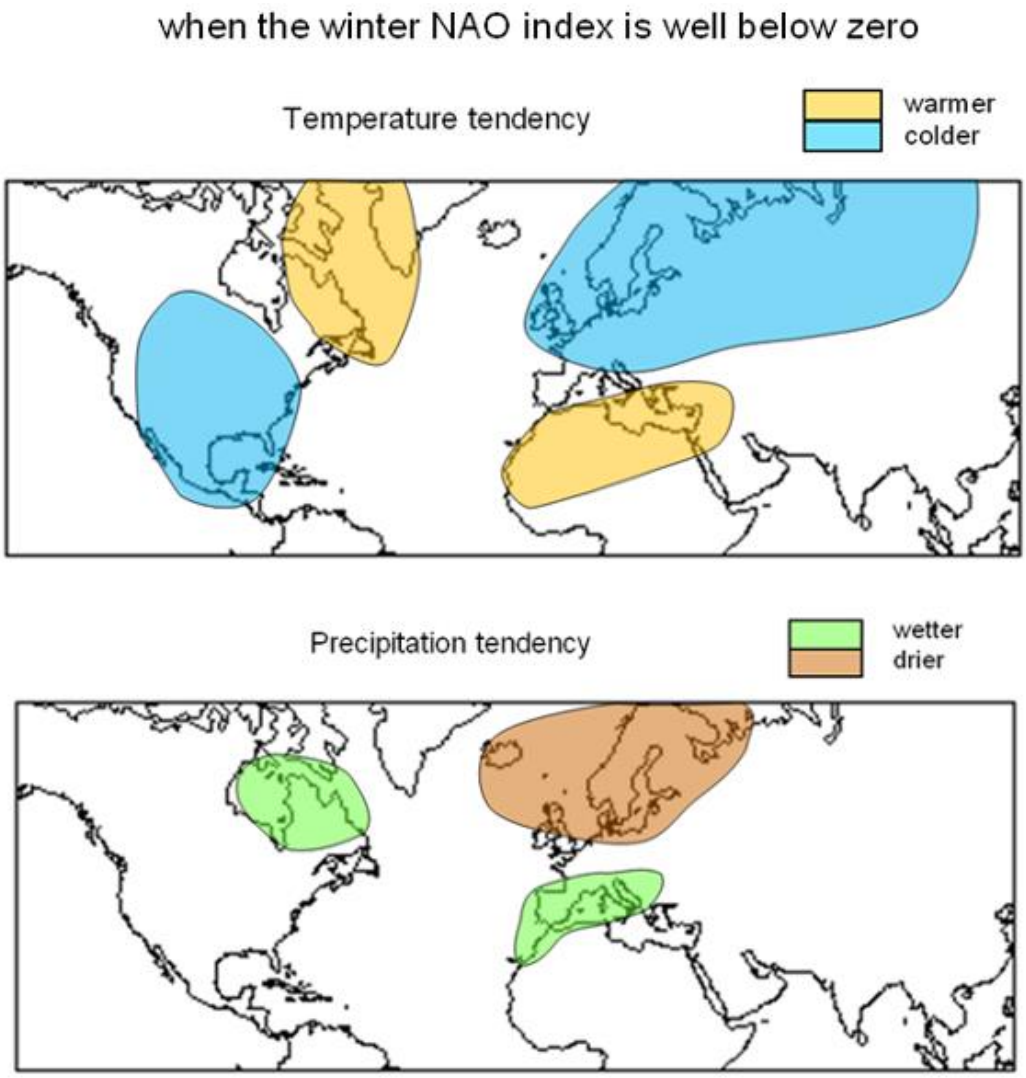


Figure 6.3.8 If NAO in below zero during winter, weather will be colder in North-Wets Europe (Met Office, Osborne)

NAO Index seems to be depending on the seawater temperature in North Atlantic (NASST). With higher NASST in North Atlantic the NAO Index becomes lower (Figure 6.3.9).

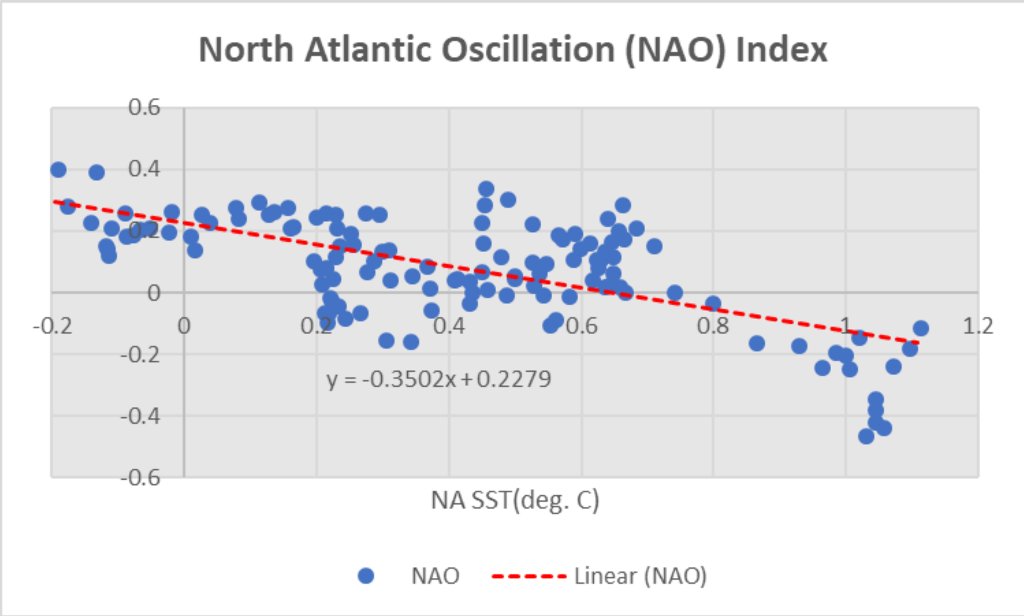


Figure 6.3.9 NAO Index seems to be depending on the seawater temperature (SST).

Atlantic hurricanes

Atlantic category 5 hurricanes have been monitored during the last hundred years and found that they have been increasing their strength as measures by pressure (Figure 6.3.10). There have been 16 category 5 hurricanes in years 2000-2019, but there were only 9 during 1920 – 1960. Their average pressure has declined from 924 mbar in 1929 to 912 mbar in 2019 or 11 mbar in a century.

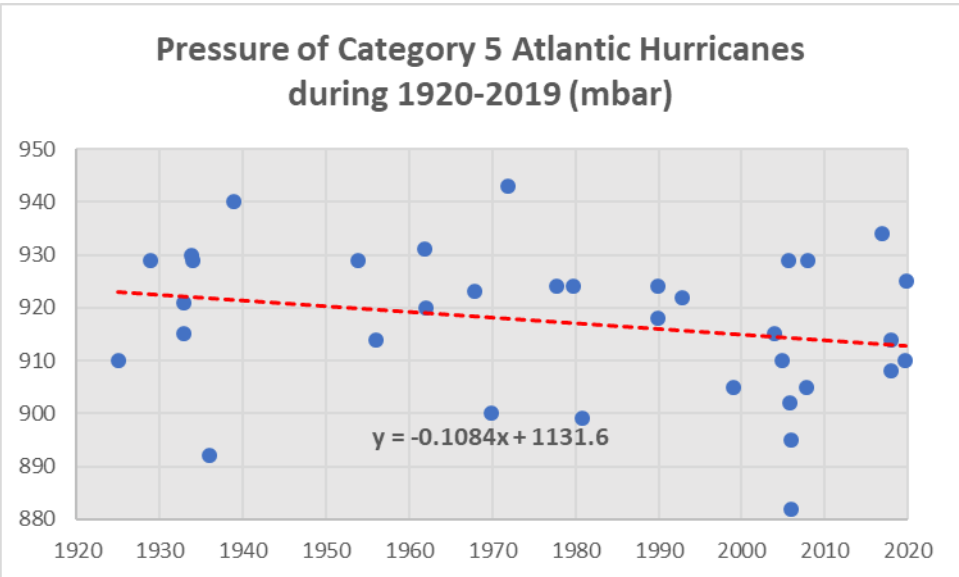


Figure 6.3.10 Trend of Atlantic hurricanes has been decreasing their pressure and increasing the strength at the same time.

6.4 Pacific Decadal Oscillation (PDO)

Pacific decadal oscillation (PDO) is the same kind of multidecadal oscillation in the Pacific Ocean as already described in North Atlantic oscillation. It has been measured as difference of seawater surface temperature in North Pacific (above 20ºN) against global SST. PDO has had peak temperatures in 1900, 1940 and 1990 or about 40-50-year intervals (Figure 6.4.1 and 6.4.2).

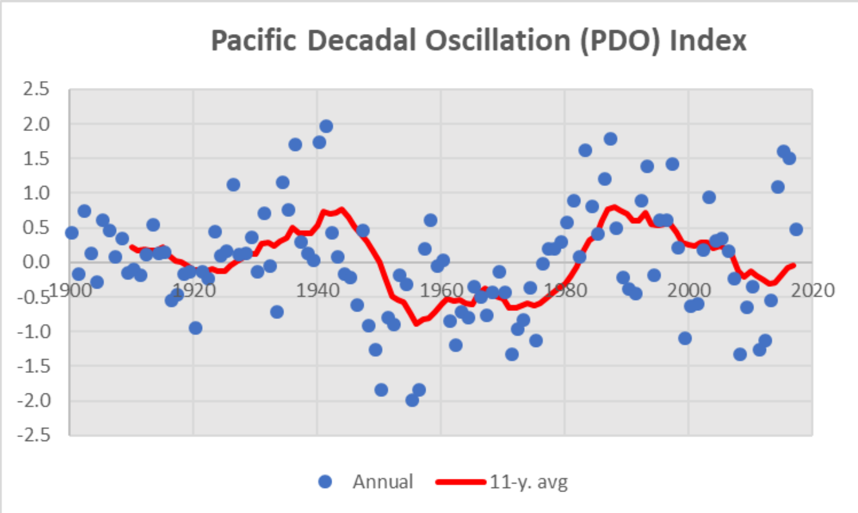


Figure 6.4.1 Pacific Multidecadal Oscillation (PDO).

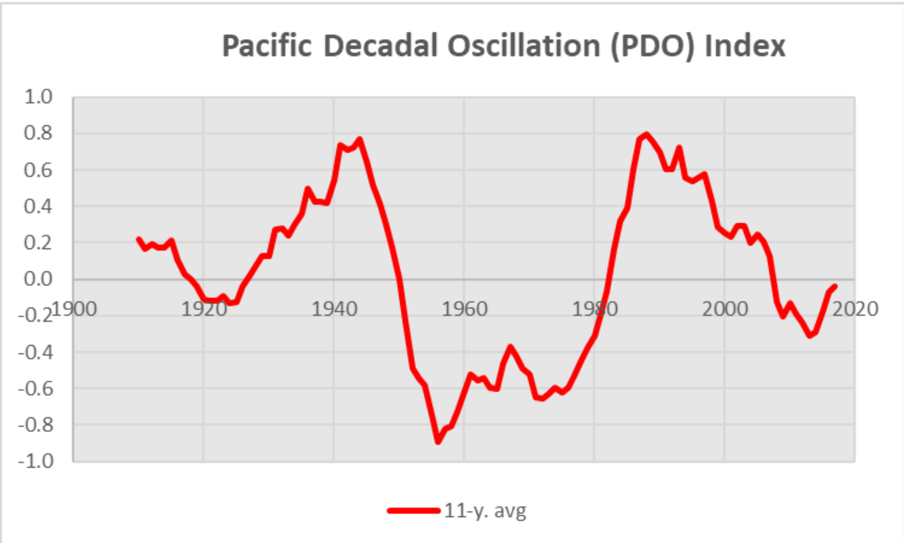


Figure 6.4.2 Pacific Multidecadal Oscillation (PDO) 11-year averages.

PDO seems to have much large variation than AMO (Figure 6.4.3). The temperature changes in PDO are from -0.9 to +0.8 deg. Celsius. AMO and PDO seem to be in opposite phases today. AMO is at its positive maximum and PDO is at its negative minimum. The average of these two fluctuates only -0.4 to 0.4 deg. Celsius.

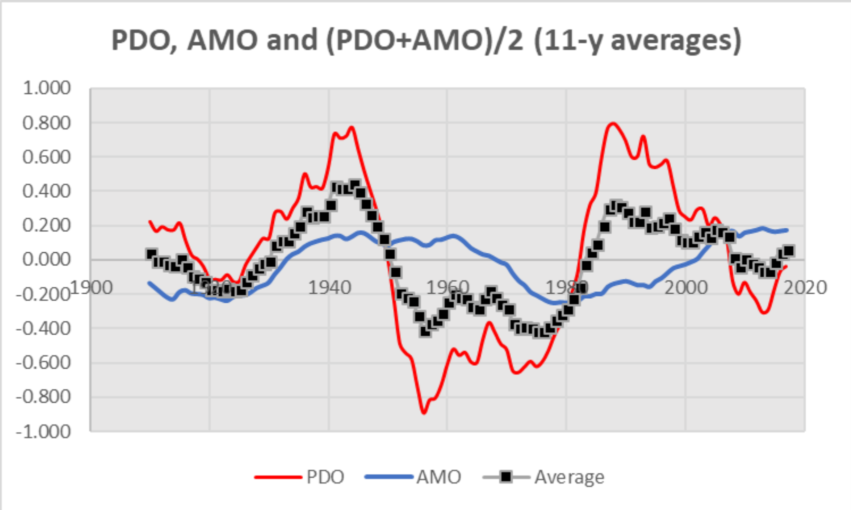


Figure 6.4.3 PDO and AMO seem to be in opposite phases.

Thermohaline circulation

Some scientists assume that North Atlantic temperature fluctuations are connected to thermohaline circulation the seas (Figure 6.4.4). Golf stream is causing warm water flow from South to North Atlantic. The same stream will transfer water trough the Pacific and Indian Ocean. The streams are rotating in the latitude 40°S (roaring forties), where the cold Gulf Stream will rotate round the world to Indian Ocean and Pacific.

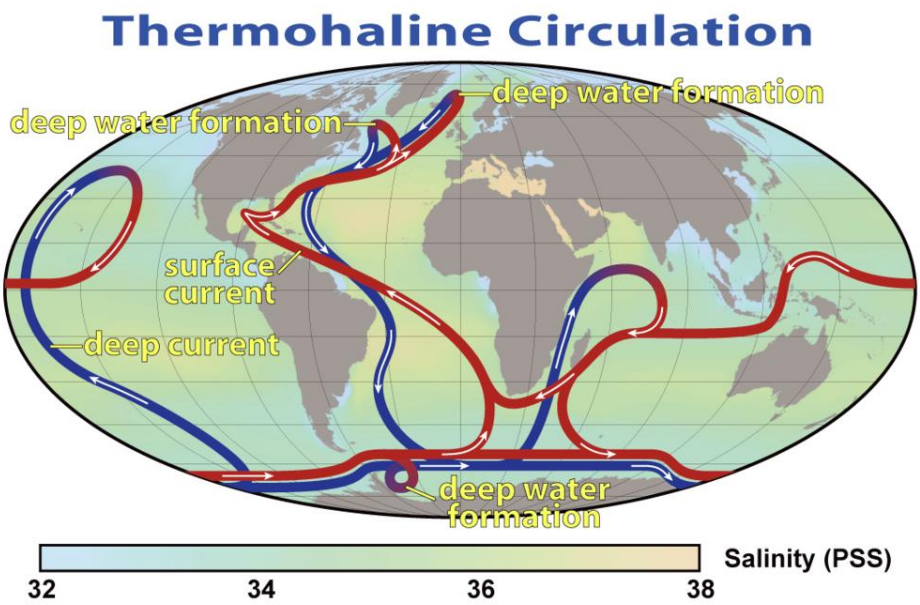


Figure 6.4.4 Thermohaline circulation.

6.5 El Nino South Oscillation (ENSO)

El Nino South Oscillation (ENSO) is temperature variation in the Center Pacific Ocean near equator. It is caused by the winds and sea currents. When, the trade winds are blowing normally from east to west, the weather will be warmer in Western Pacific and colder in Eastern Pacific. The trade winds are blowing according to the Walker Circulation (Figure 6.5.1).

When the low-pressure area is near Indonesia and high-pressure area near South America, trade winds are blowing from East to West. But when the low-pressure area is near South America and high-pressure area near Indonesia, the trade winds will blow from West to East.

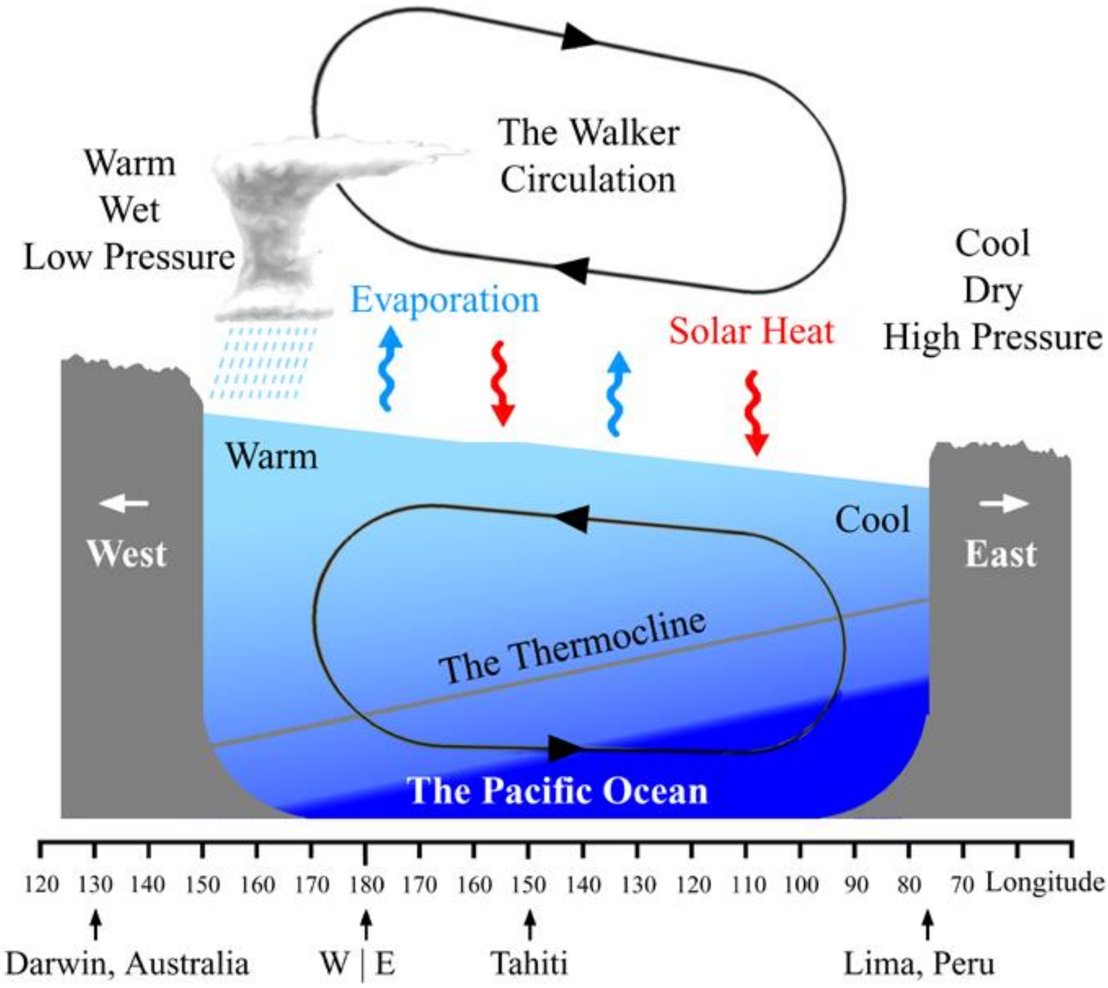


Figure 6.5.1 The Walker Circulation determines winds in the Pacific (Source: http://en.wikipedia.org/wiki/File:LaNina.png).

La Nina-phase

During La Nina-phase seawater temperature will be cooler in the middle of Pacific (Figure 6.5.2). This will be caused by the higher than normal trade winds, which will cause the surface water flow from east to western Pacific. The waters in the east Pacific will be cooler, because the colder water will be coming from the bottom of the Ocean.

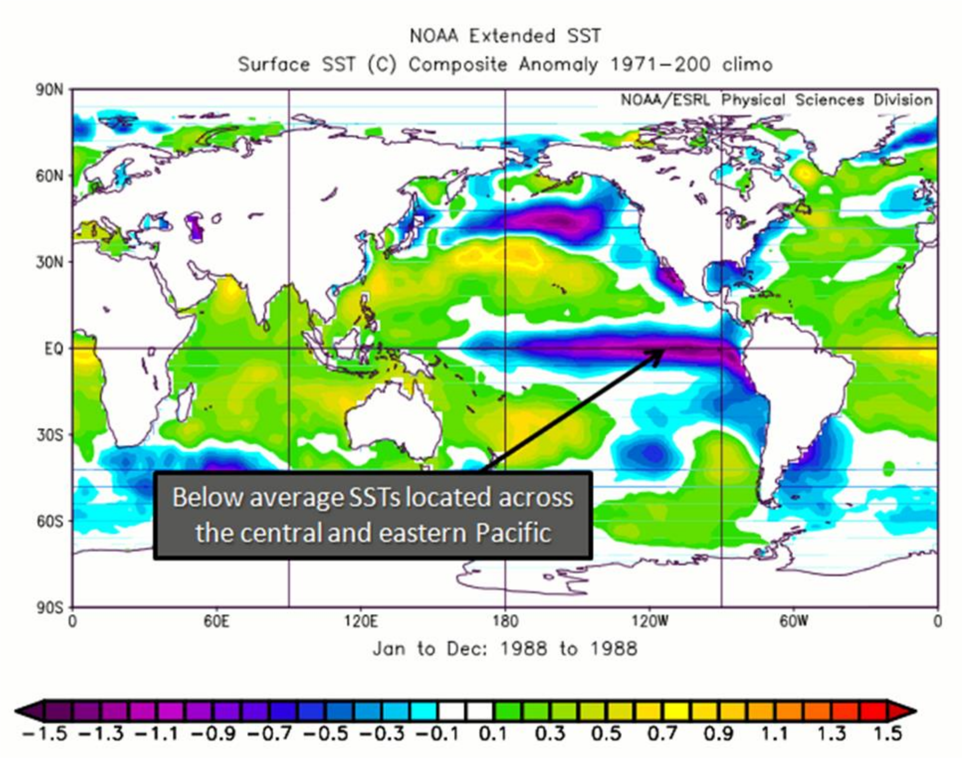


Figure 6.5.2 During La Nina phase seawater temperature will be cooler in middle of Pacific (NOAA).

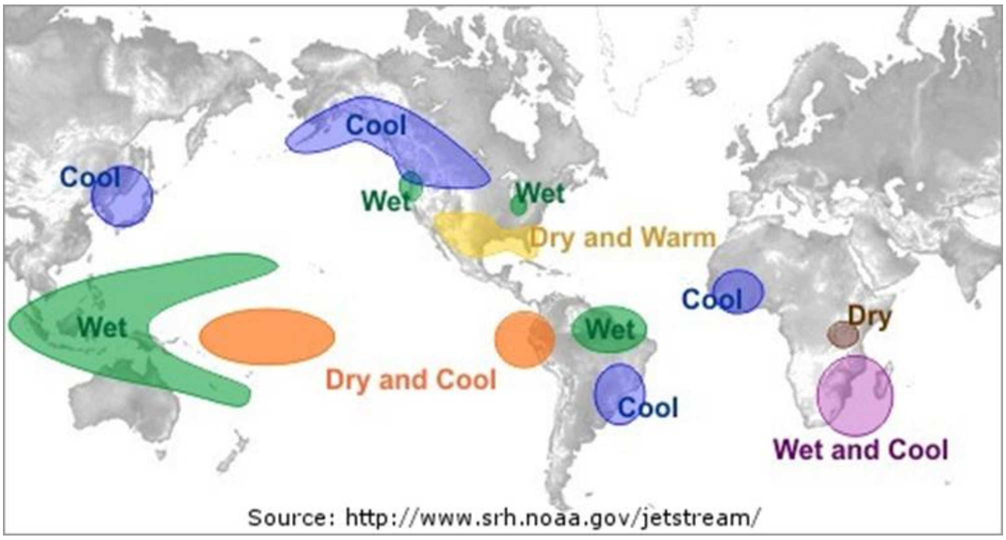


Figure 6.5.3 During La Nina phase in winter (DJF) the weather will be dry and cool in West coast of South America (NOAA).

During La Nina phase in winter (DJF) the weather will be dry and cool in West coast of South America (Figure 6.5.3). During La Nina phase in summer (JJA) the weather will be wet and cool in Central America, in East Asia and in India (Figure 6.5.4).

Recent winters are in La Nina phase (Figure 6.5.5), but in summer to in El Nino phase (Figure 6.5.6).

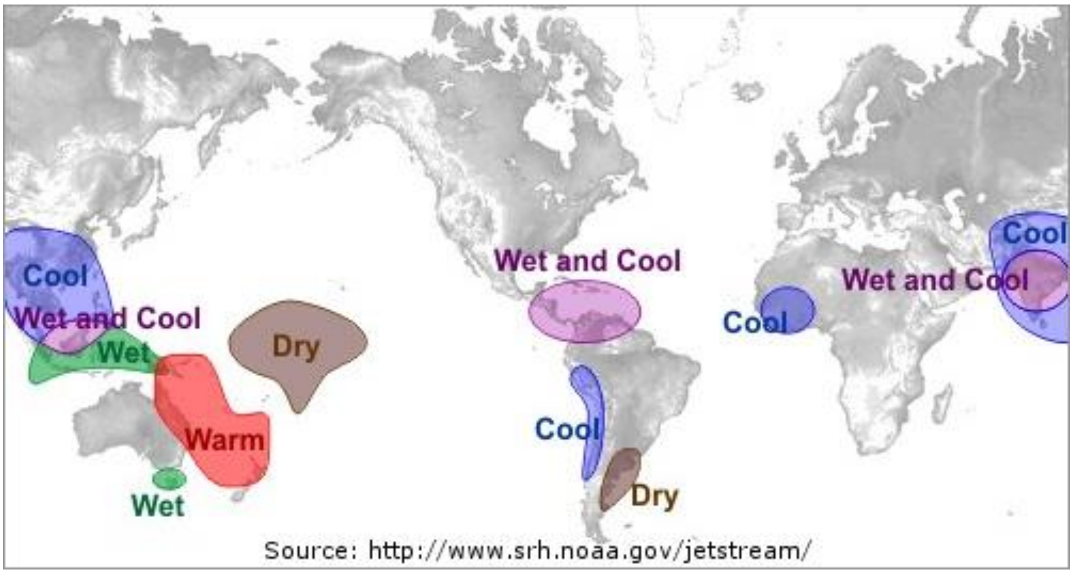


Figure 6.5.4 During La Nina phase in summer (JJA) the weather will be wet and cool in Central America, in East Asia and in India (NOAA).

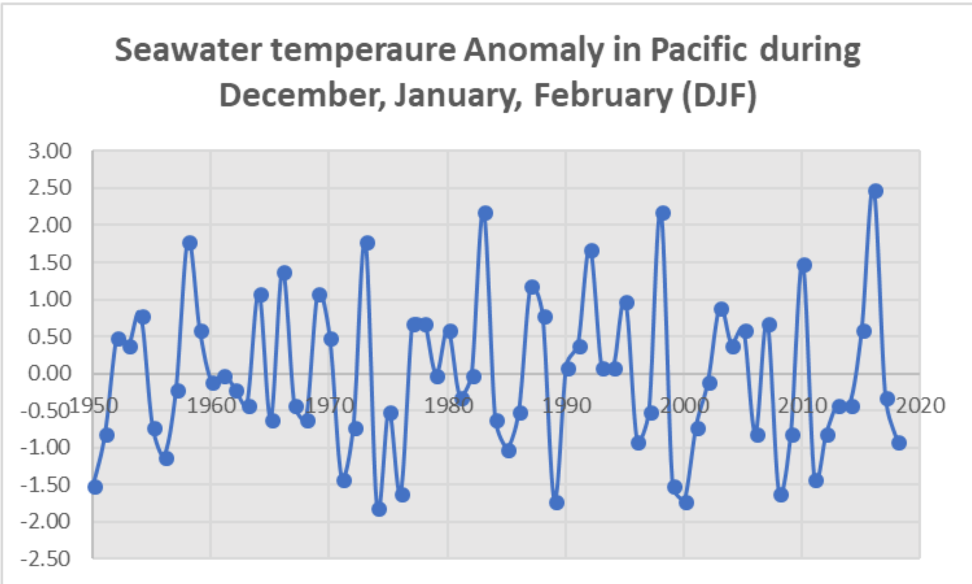


Figure 6.5.5 During winter (DJF) the temperature has been higher than normal during years 2015-2017 (NOAA).

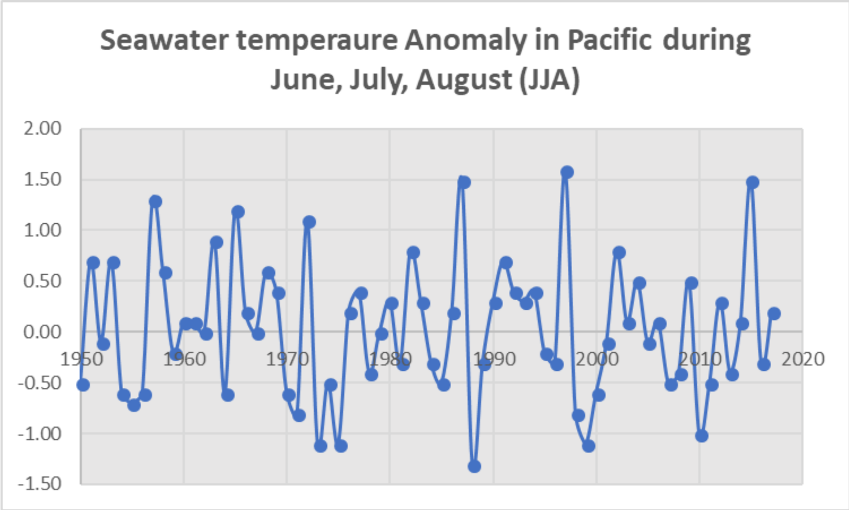


Figure 6.5.6 During summer (JJA) the temperature has been higher than normal during years 2015-2017 (NOAA).

El Nino-phase

During El Nino phase the seawater temperature is higher than normal in East Pacific near equator (Figure 6.5.7). This will be caused by the low pressure near South America and high pressure in Indonesia, which will cause winds blowing from the West to East in the Pacific.

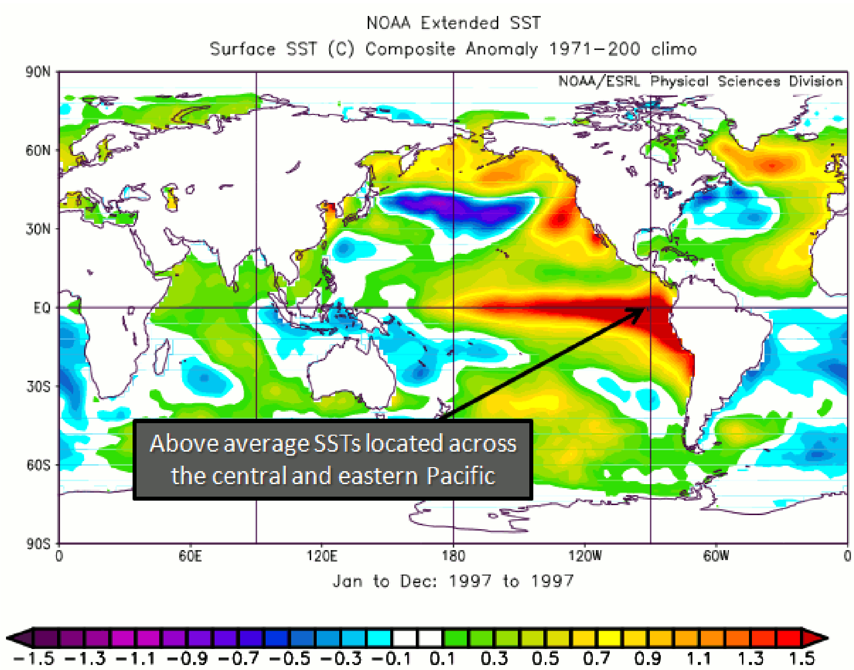


Figure 6.5.7 During El Nino phase the temperature is higher than normal in East Pacific (NOAA).

During El Nino phase in winter (DJF) the weather will be wet and warm in the west coast South America and dry in Philippines (Figure 6.5.8). Additionally, the weather in India will be warm and in East Africa dry. This may cause famine in Africa. The El Nino Phase in winter has ended in 2017, when the temperature anomaly during winter dropped below zero (Figure 6.5.5).

During El Nino phase in summer (JJA) the weather will be dry in Philippines and India and dry and cool in Australia (Figure 6.5.9). The weather will be wet in Western USA. The summer weather has been coming into El Nino phase in 2018 (Figure 6.5.6).

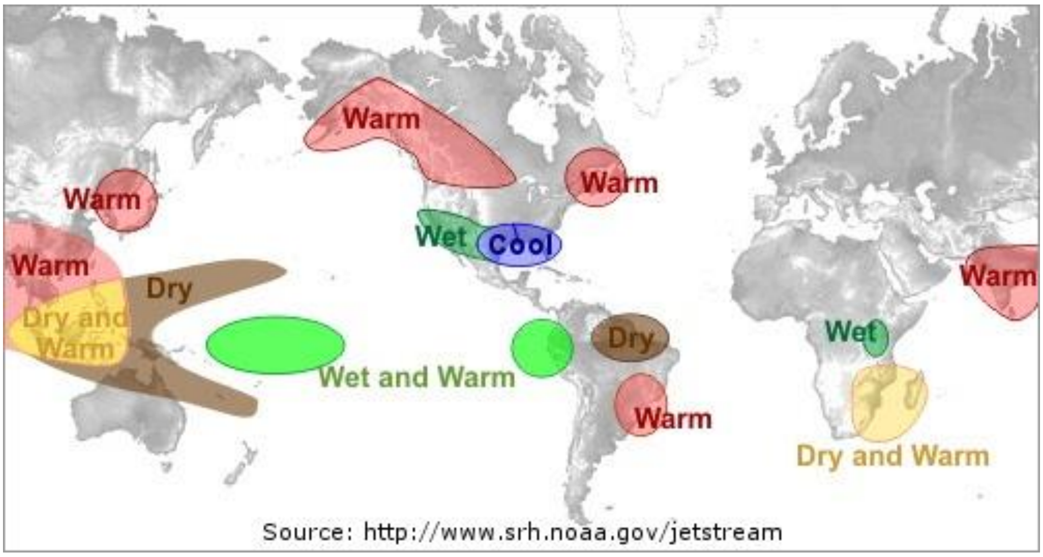


Figure 6.5.8 During El Nino phase in winter (DJF) the temperature is higher than normal in East Pacific (NOAA).

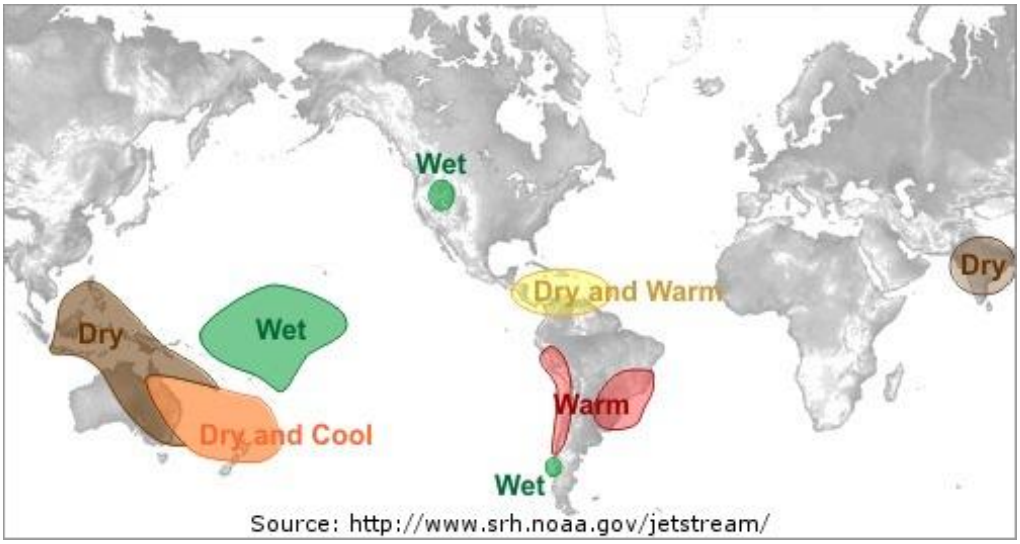


Figure 6.5.9 During El Nino phase in summer (JJA) the temperature is higher than normal in East Pacific (NOAA).

7 CHANGES IN ICE CONDITIONS AND SEAWATER RISE

7.1 Declining of ice cover

Warming of seawater has caused declining of arctic ice cover. The ice cover in September has declined from 5 million square kilometers in 1990 to about 3 million in 2019 (Figure 7.1.1) or about 2 million square kilometers in 29 years or 76 000 km^2 annually (2 %/a). If this trend will continue the ice cover will disappear by 2057. However, declining of ice cover do not rise the sea level.

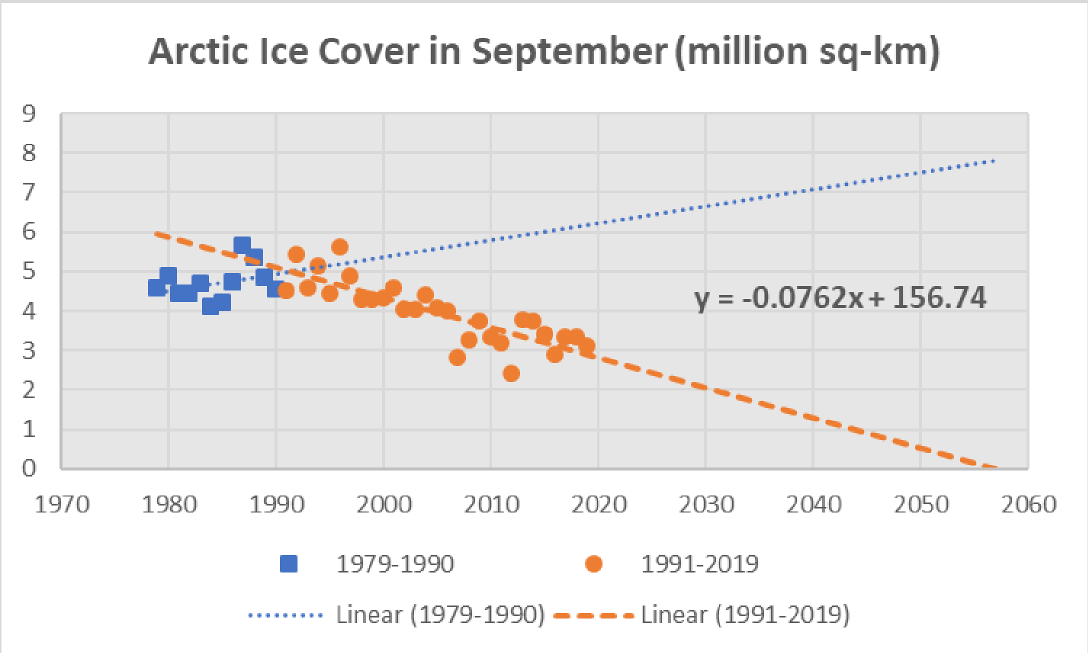


Figure 7.1.1 Declining of Arctic ice cover in September (Source data from: https://climate.nasa.gov/vital-signs/arctic-sea-ice/).

7.2 Seawater rise

Ice cover in Antarctica, Greenland and glaziers is above ground and thus smelting of ice will rise the sea level. The total mass of ice is 27.4 Gt and if this ice will smelt, sea level will rise about 75 meters (Table 7.2.1).

Table 7.2.1 Mass of ice on land

		Antarctica	Greenland	Glaziers	Total
Including ice shelves					
Volume of ice	Mcub.km	26.92	2.85	0.16	29.93
Area of ice	Msq.km	13.92	1.71	0.726	16.36
Mean thickness	km	1.93	1.67	0.22	1.83
Density	Gt/cub.km	0.9167	0.9167	0.9167	0.9167
Mass of ice	MGt	24.68	2.61	0.15	27.44
Excluding ice shelves					
Volume of ice	Mcub.km	26.54			
Area of ice	Msq.km	12.295			
Mean thickness	km	2.16			
Density	Gt/cub.km	0.9167			
Mass of ice	MGt	24.33			
Sealevel equivalent					
Volume of water	M cub.km	24.33	2.61	0.15	27.44
Area of seas	M sq.km	361.8	361.8	361.8	361.8
Equivalent sea rise	m	67.2	7.2	0.4	75.8
Change in ice mass					
Loss of ice mass	Gt/year	118	281	259	658
Years 2002-2016	cub.km, Gt	1652	3934	3626	9212
Area of seas	M sq.km	361.8	361.8	361.8	361.8
Equivalent sea rise	mm	4.6	10.9	10.0	25.5
	mm/decade	3.3	7.8	7.2	18.2
Time to melt down	thousand years	206	9.3	0.57	42

According Nasa Grace satellite (Figures 7.2.1 and 7.2.2) Antarctica and Greenland ice loss has been since 2002 about 118 and 281 Gt/year respectively (400 Gt/year totally). This corresponds to sea level rise of 11.1 mm/decade.

If we add the smelting of glaziers (259 Gt/a) to ice loss of Antarctica and Greenland (400 Gt/y), the total sea level rise has been 25.5 mm in 14 years or 18.2 mm/decade. The glaziers are smelting at higher speed and in about 570 years the ice will be disappeared, if this speed continues. However, the speed will decline because highest places will remain covered with ice.

Smelting of Antarctica will take 206 000 years and Greenland 9300 years at the present pace. Thus, the next ice age might be ahead before this.

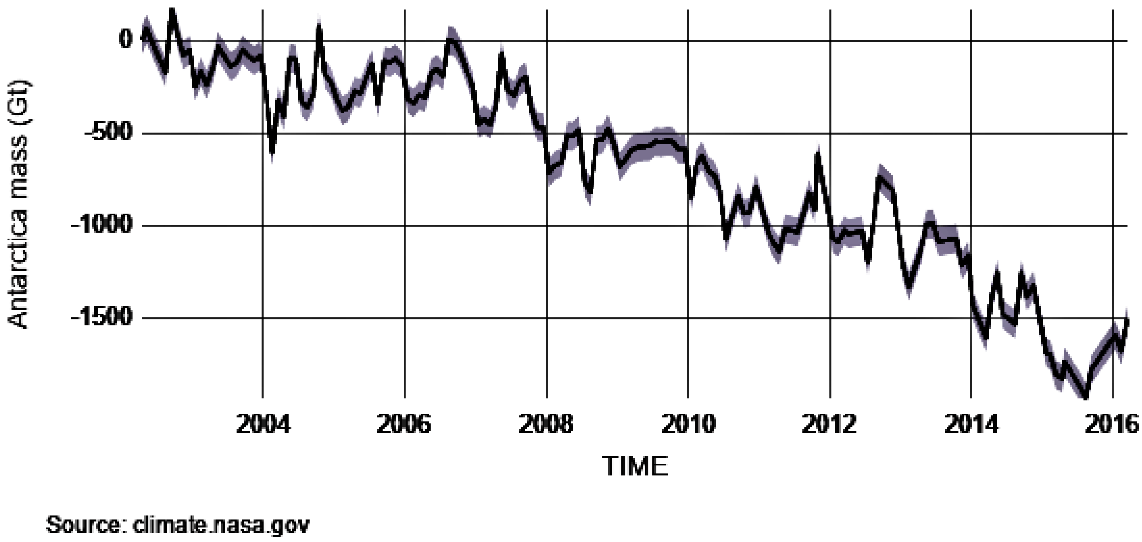


Figure 7.2.1 Change in mass of ice in Antarctica (Source: Nasa Grace-satellite).

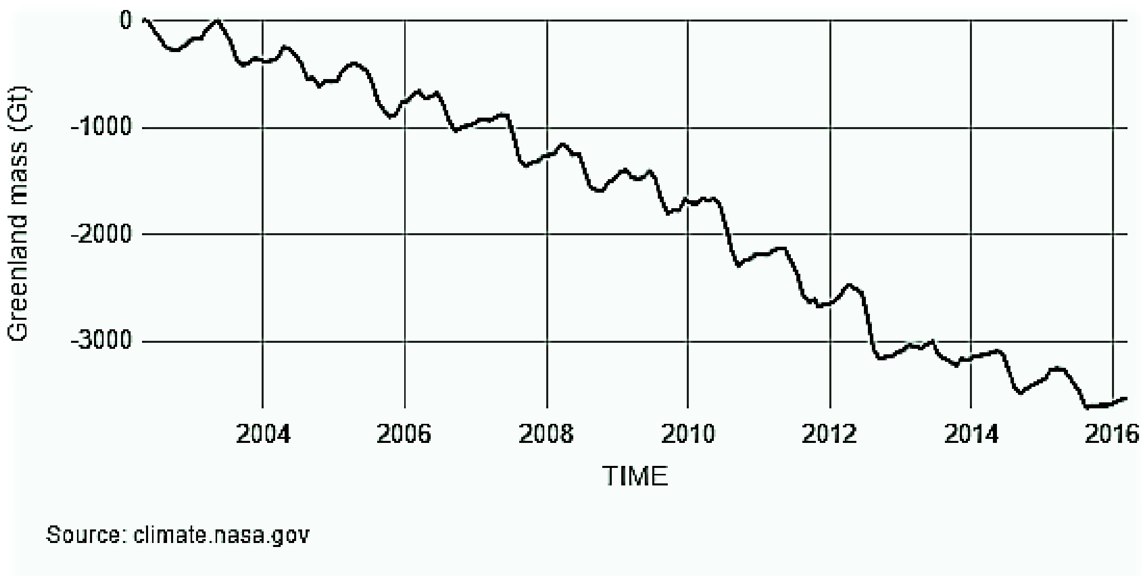


Figure 7.2.2 Change of ice mass in Greenland (Source: Nasa Grace satellite).

Total sea level rise after the year 1900 has been about 20 cm (Figure 7.2.3), which corresponds the smelting of ice data (18 mm/decade) in Table 7.2.1.

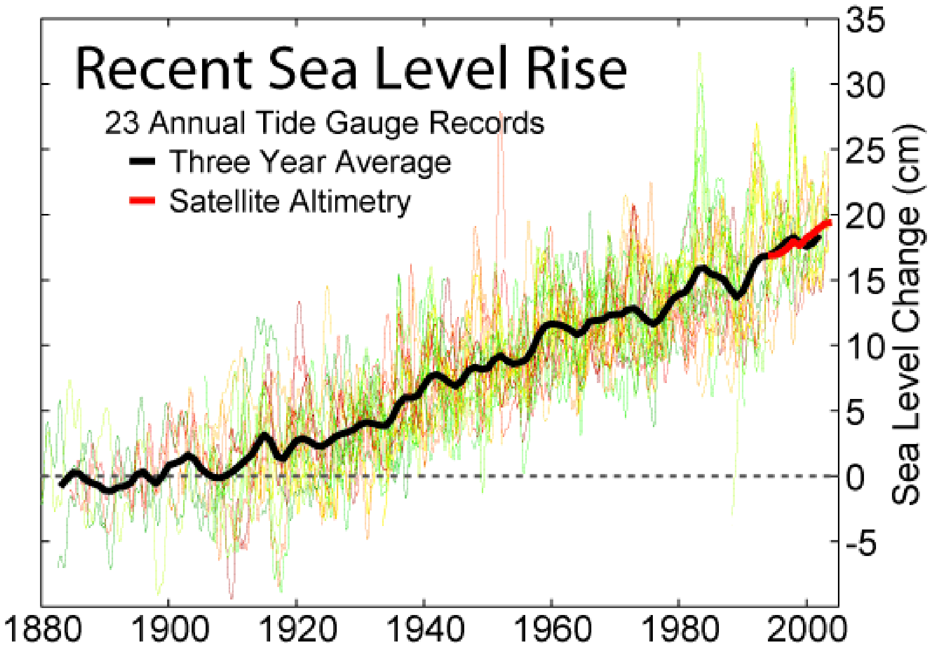


Figure 7.2.3 Sea level rise (Credit: Bruce C. Douglas (1997). "Global Sea Rise: A Redetermination". Surveys in Geophysics 18: 279–292.)

7.3 Temperature and sea level in the past

There are long term cycles which are causing ice ages. The weather was becoming warmer at about 21,000 years ago, when the last ice age reached its maximum (Figure 7.3.1).

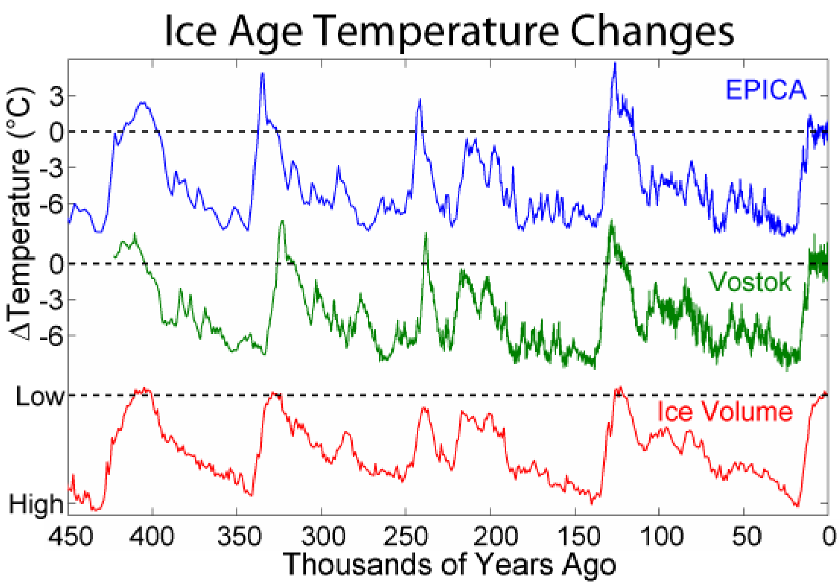


Figure 7.3.1 Ice ages in the past and changes in the volume of ice.

The ice ages seem to follow in about 100,000-year cycles (Figure 7.3.1) as found by the studies about the ice in Antarctica. We are living at warm phase of the cycle and cold phase may follow during the next 100,000 years, if the cycle will be repeating itself. This is opposite what is happening just now, when the climate is warming mainly because of the man's actions.

At the moment, we are living a warm period between ice ages, which is called as Holocene (Figure 7.3.2). This has lasted about 10.000 years BP, when the global temperature has been above the long-term average.

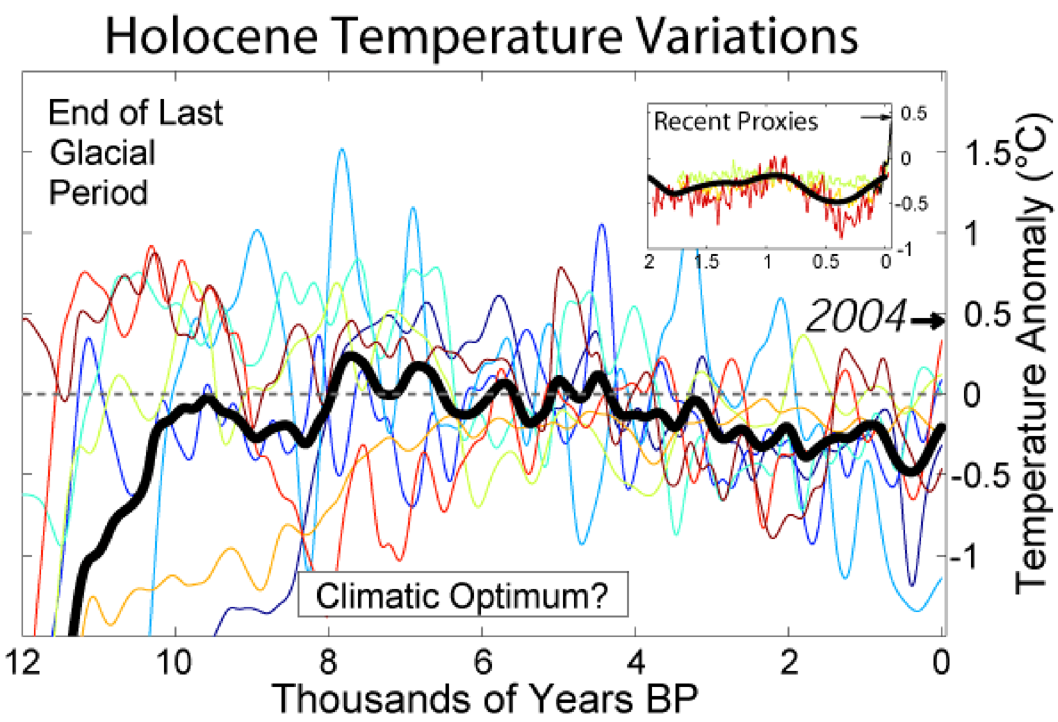


Figure 7.3.2 Temperature of the earth during Holocene period (11 500 BCE to present). Median value of five different estimates (Source Wikipedia).

Holocene period has caused about 100 m (125 mm/decade) rise during years 15000 to 7000 BP (Figure 7.3.3). During the last 7000 years the seawater level has been rising only about seven meters or about 10 mm/decade. Thus, the recent rising speed of the seas has been about two times of the past speed.

The ice ages have been explained Milankovitch cycles, which will be explained in the next chapter. The temperature variations are caused mainly by the changes in earth's orbit (eccentricity) and axial tilt (obliquity).

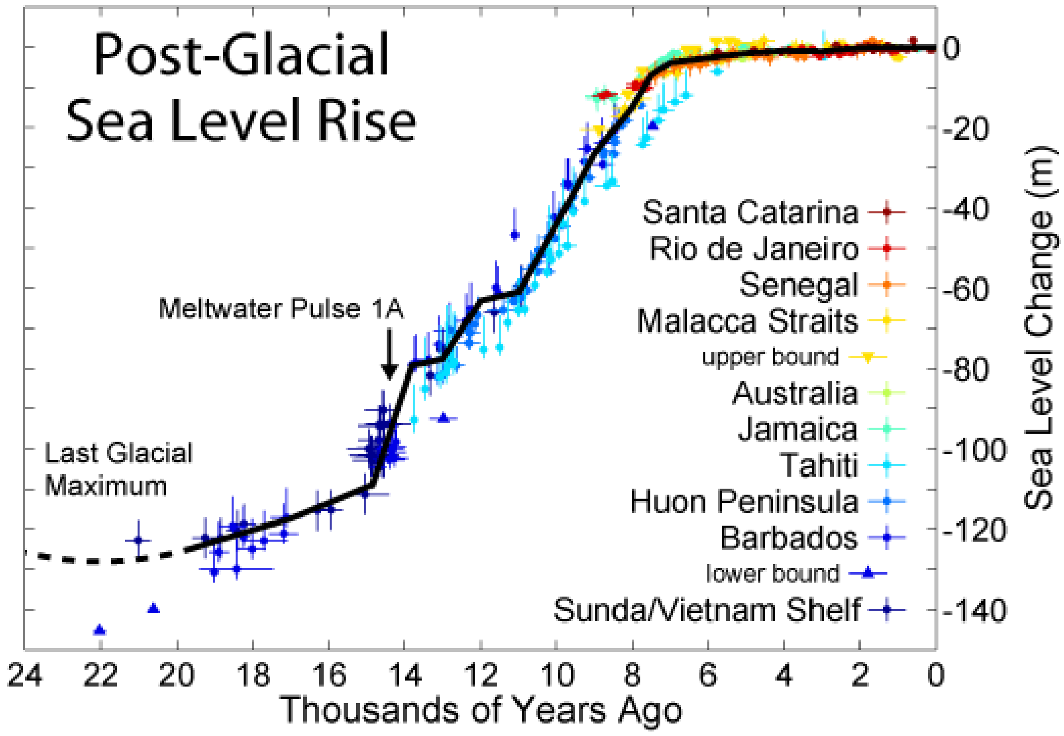


Figure 7.3.3 Sea level rise during last 24,000 years.

7.4 Future seawater rise

Future seawater rise will be depending how much the atmosphere and seas will be warming. European Environmental Agency is projecting 70 cm rise, if the temperature cannot be limited to 2 degrees and 42 cm rise with 2-degree limit (Figure 7.4.1):

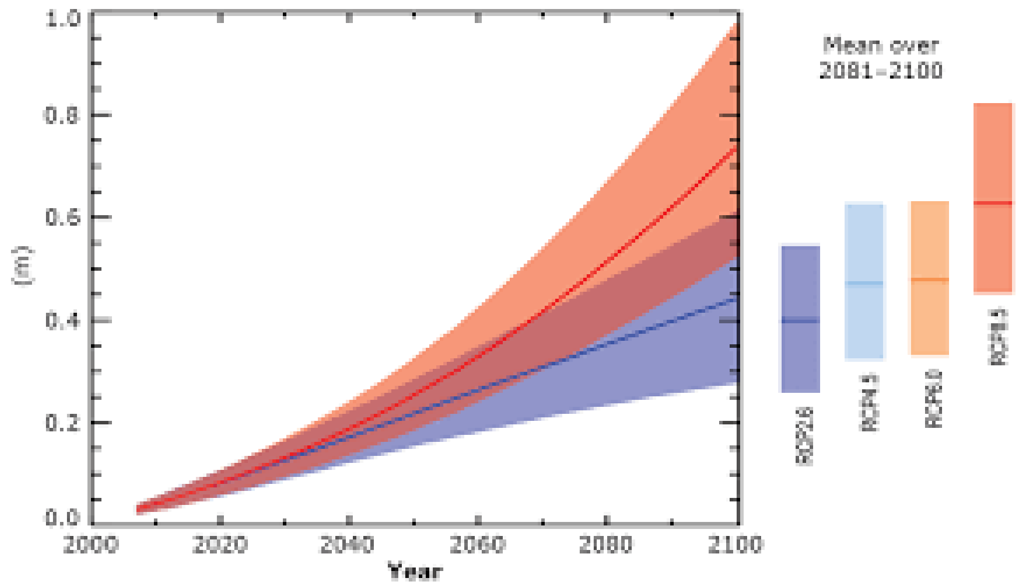


Figure 7.4.1 Future sea level rise by European Environmental Agency.

8 MILANKOVITCH CYCLES

8.1 Introduction

Serbian astronomer **Milutin Milankovitch** (1879 – 1958) found that earth trajectory and position is changing in with the time and is changing temperature in cycles, which were called after his name as Milankovitch cycles.

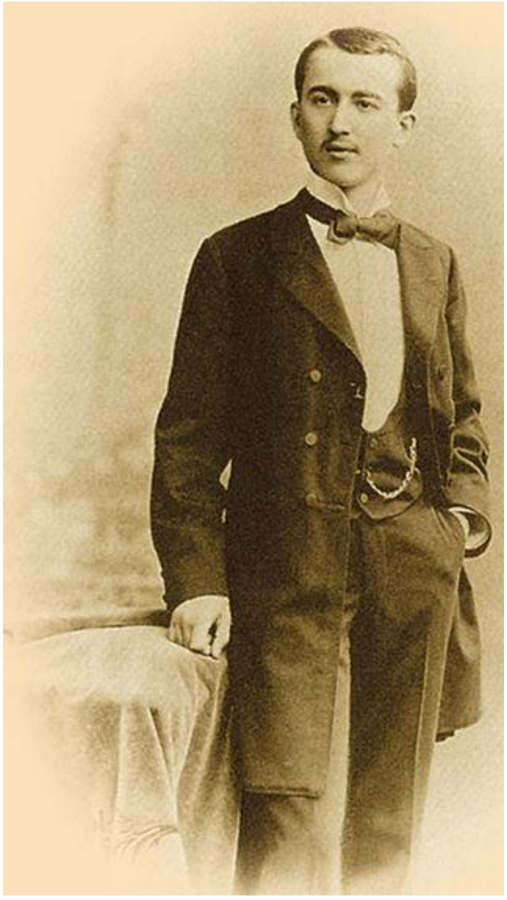


Figure 8.1.1 Milutin Milankovitch was a Serbian civil engineer, mathematician and professor.

He found that eccentricity of the orbit of the earth is changing in a 100,000-year cycle. Eccentricity is difference of earth's orbit between the shape of ellipse and circle (Figure 8.1.2).

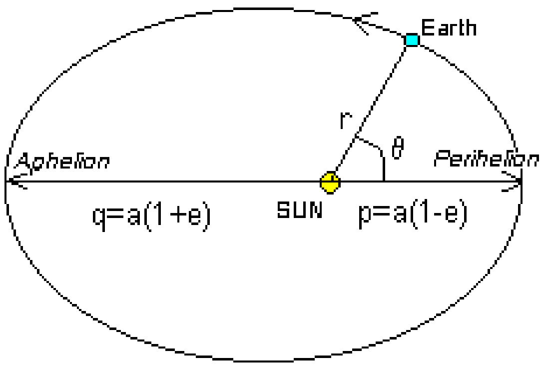


Figure 8.1.2 Eccentricity (e) of earth's orbit means that sun distance at perihelion becomes shorter p = a(1-e).

Eccentricity has been calculated by J. Laskar et. al (*La2010: a new orbital solution for the long-term motion of the Earth*) in Astronomy Astrophysics 2011 and the results can be found in NOAA pages (ftp://ftp.ncdc.noaa.gov/pub/data/paleo/insolation/). The data indicates that the eccentricity is changing in 100,000-year and 400,000-year cycles (Figure 8.1.3).

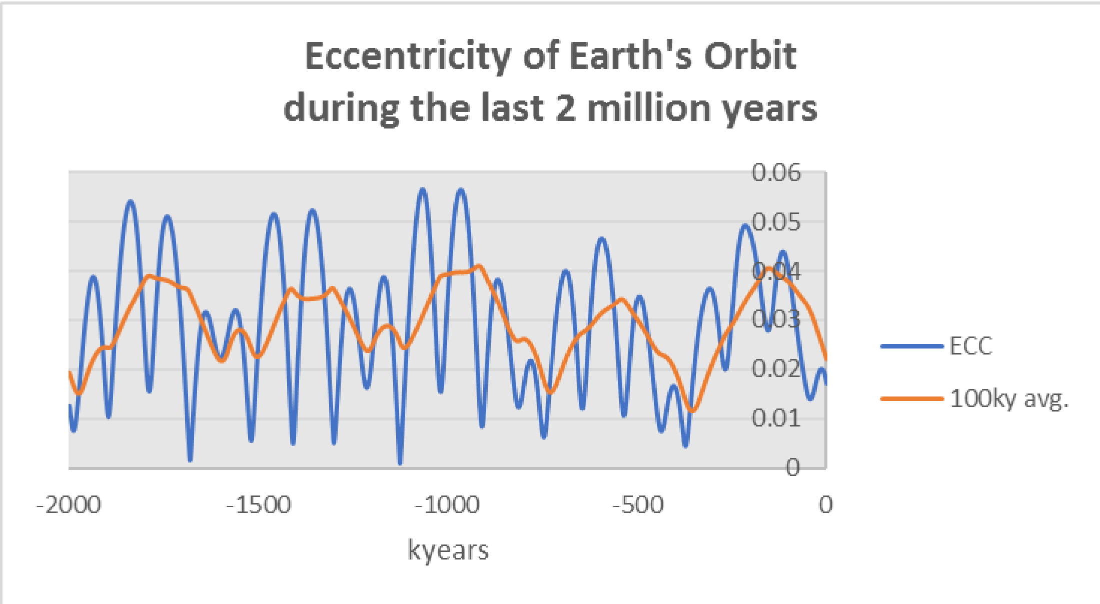


Figure 8.1.3 Eccentricity is changing in 100,000-year and 400,000-year cycles.

Today the eccentricity is 0.017 (Figure 8.1.4). The distance of the earth from the sun is + 1.7 % at aphelion and -1.7 % at perihelion from the average distance of 149,597,870,700 meters or one astronomical unit (AU).

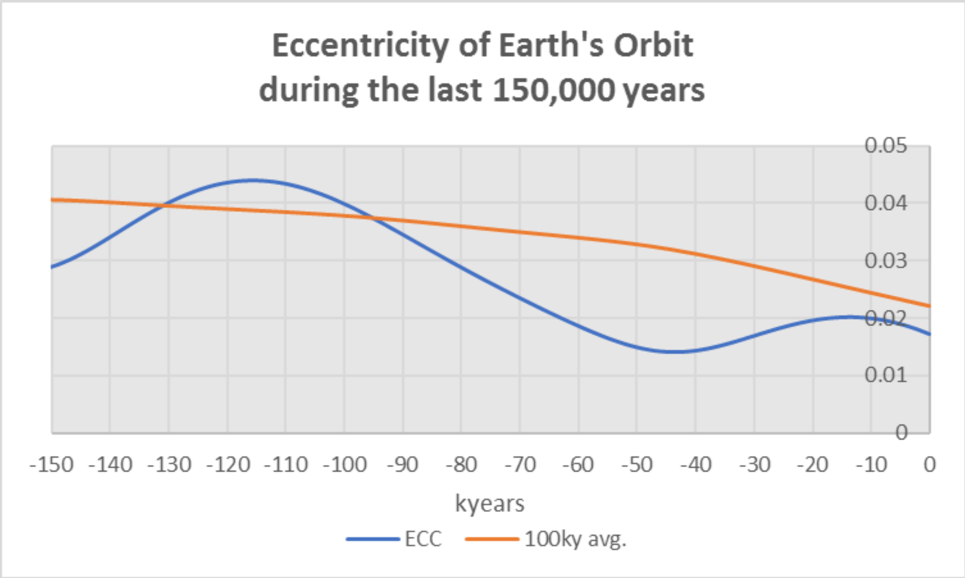


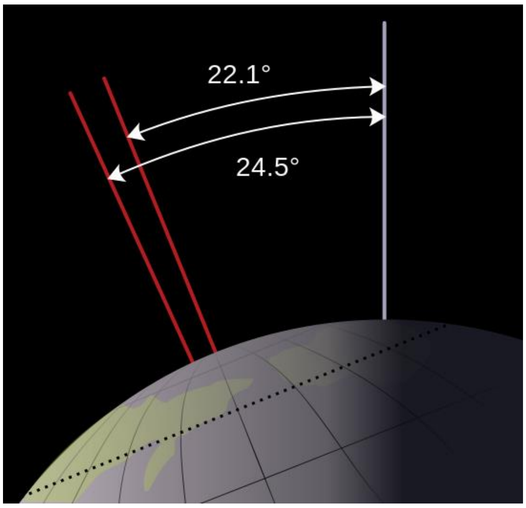
Figure 8.1.4 Eccentricity during the last 150,000 years.

Eccentricity was in last time in its minimum of 0.013 in 42,000BC in the middle of the ice age. Eccentricity reached its last peak of 0.0195 in 11,400BC. At the same time the peak value of ice volume has reached and the earth started its Holocene period (Figure 7.3.2).

Obliquity

Axis of the earth is tilted if compared with the ecliptic plane in which the earth is rotating round the sun (Figure 8.1.5. The axial tilt (obliquity) is changing with 41,000-year cycle and the last maximum (24.23^{o}) was experienced in about 9500 BP (Figure 8.1.6).

Figure 8.1.5 Tilt of the earth axis is changing in a 41,000-year cycle.



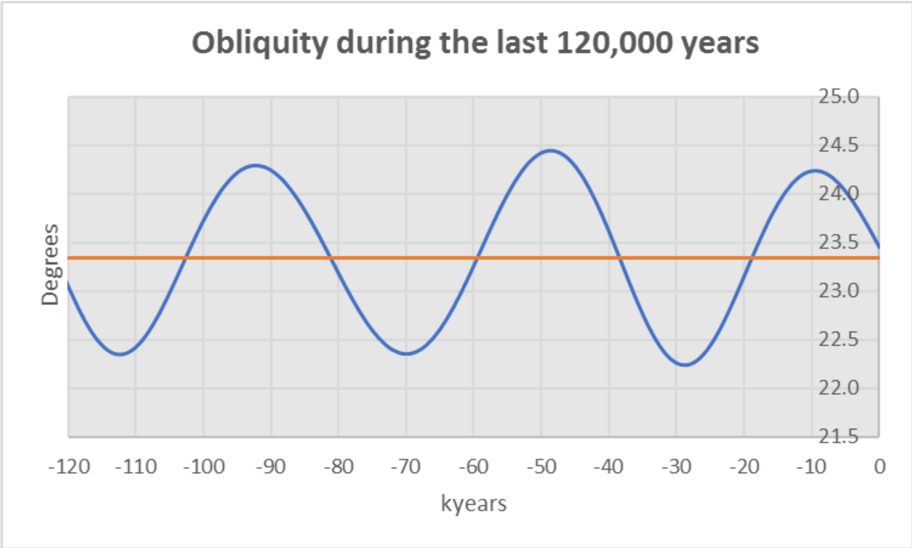


Figure 8.1.6 Obliquity (tilt) during the last 120,000 years. The present tilt is 23.45°.

It is also meaningful, if the largest obliquity happens in the same time, when the earth is in perihelion or aphelion. When the omega (longitude of perihelion) is 90°, winter occurs at perihelion. When the omega is 270°, summer occurs at perihelion. The earth is currently in perihelion during Nordic winter (101°. January 3, Figure 8.1.7).

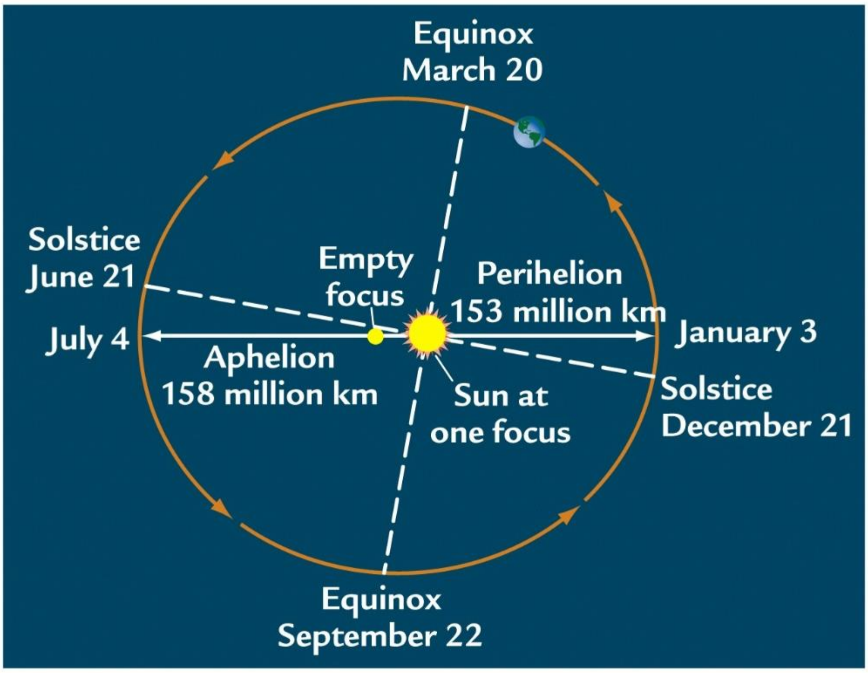


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Figure 8.1.7 Sun is in perihelion today at January 3. The sun is 153 million km from the earth. At aphelion sun is 158 million km from the earth

About 11.500 years ago, earth was in perihelion (270°) during the summer (Figure 8.1.8). The cycle of omega has 22,000-year duration. Summer was in perihelion (270°) during years 11,500BP, 33,500BP, 59,500BP, 82,500BP and 105,500BP. Winter is in perihelion (90°) during years 500BP, 22,500BP, 46,500BP, 71,500BP, 94,200BP and 116,200BP.

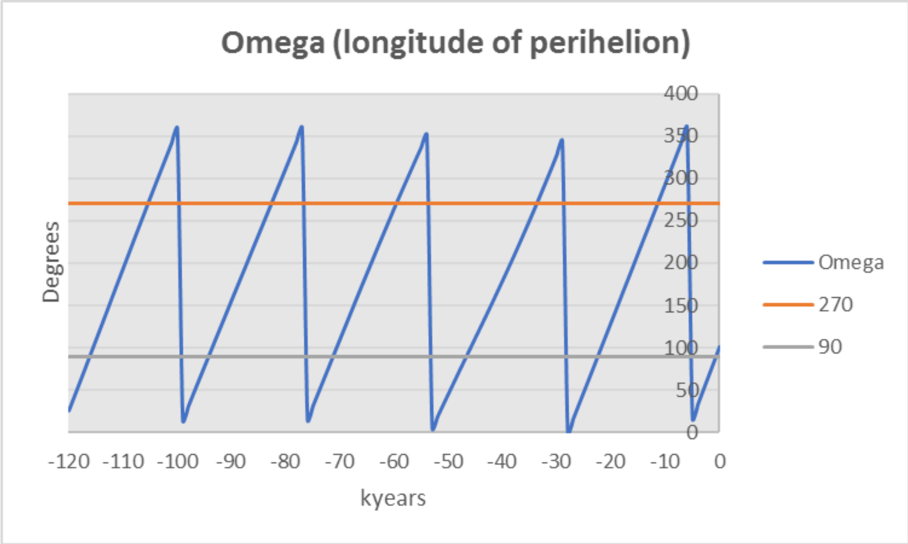


Figure 8.1.8 Longitude at perihelion (omega) during the last 120,000 years.

Precession

The third Milankovich parameter is precession, which is rotation of earth's axis in about 26,000-year cycle (Figure 8.1.9). This means that the axis of the earth is pointing towards North-Star Polaris and Vega in about 13,000-year intervals.

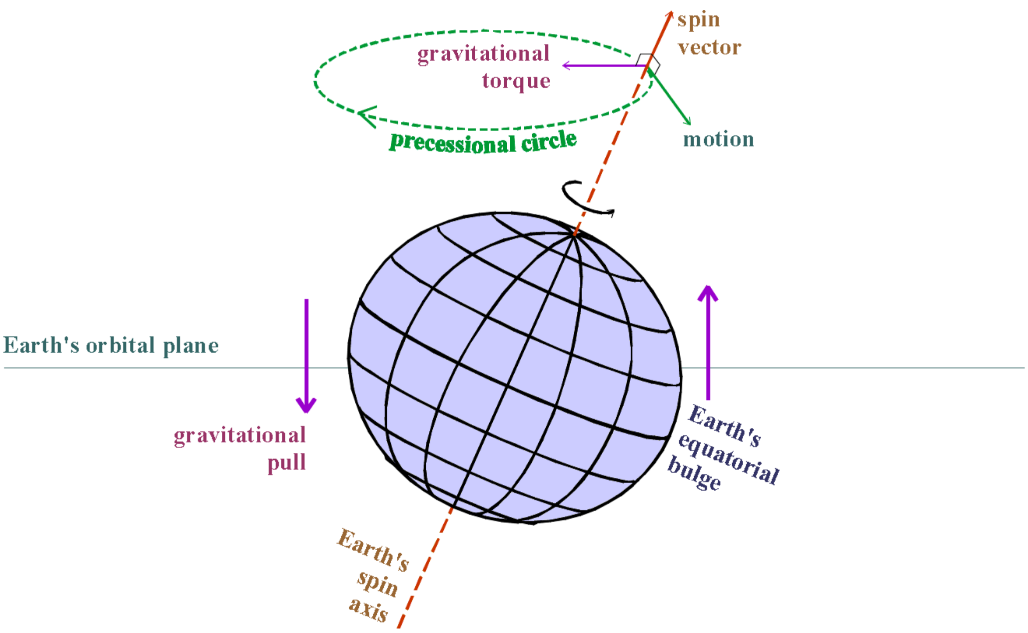


Figure 8.1.9 Precession is rotation of earth's axis so that the axis is pointing towards Polaris today and Vega after 13.000 years.

Tilt and precession do not affect the total solar irradiance, but they will change the insolation near the north pole and south pole. Thus, they will either cause accumulation of ice or smelting of ice depending of the omega (latitude of perihelion). The eccentricity is changing the total irradiance received by the earth and will cause overall global warming and cooling.

8.2 Climate changes in the past

Main indication of changes in solar irradiance is indicated by eccentricity of earth's orbit. Solar irradiance (S) seems to be function of eccentricity *(J. Laskar et. al. Orbital, precessional and insolation quantities for the Earth from -20Myr to + 20 Myr*).

(8.2.1) $S = S_o \times (1-e^2)^{1/2}$

Where S_o = solar annual average irradiance

e = eccentricity

Using the formula 8.2.1 the irradiance in the past two million years has been calculated in Figure 8.2.1. (Source of orbital data: Orbital Variations, 5,000,000 Years, Berger and Loutre 1991. https://www.ncdc.noaa.gov/data-access/paleoclimatology-data/datasets/climate-forcing). Because the eccentricity has been very small during the last 10,000 years, irradiance has been very high. There have been peaks also in about 310,000, 210,000 and 110,000 years ago or in about 100,000-year intervals.

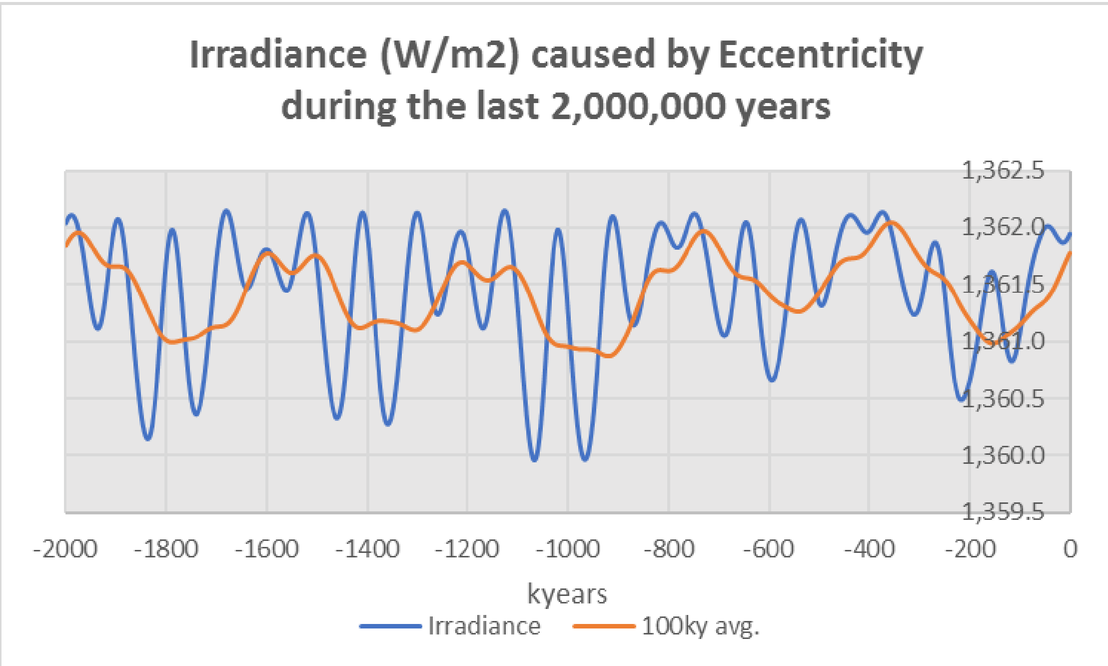


Figure 8.2.1 Changes in irradiance in the past caused by Earth's orbit.

The global temperature has followed changes in irradiance according to the formula dT = 1.23 x dTSI (See chapter 3.3). During the last two million years, the temperature has been at today's level in average only during peaks in about 100,000-year intervals (Figure 8.2.2). The last peak occurred about 400,000 years ago.

The 400,000-year rhythm in temperature changes can be found in 100,000-year average temperatures. The temperature has been around today's level for 50,000 years (Figure 8.2.3), but it was about 1.0 deg. C lower in about 120,000 years ago, when formation of the last ice age started.

There has been a small drop in global temperature about 13,500BP. Then smelting of ice stopped. In Finland, the glaziers were covering Finland until the 450 km long line from Hanko to Savonlinna (Figure 7.2.4). When the ice stayed in the same place for about 2000 years, sand was accumulated on the shore and formed Salpausselkä at the same time. Salpausselkä is sand formation, which is from Hanko to Savonlinna.

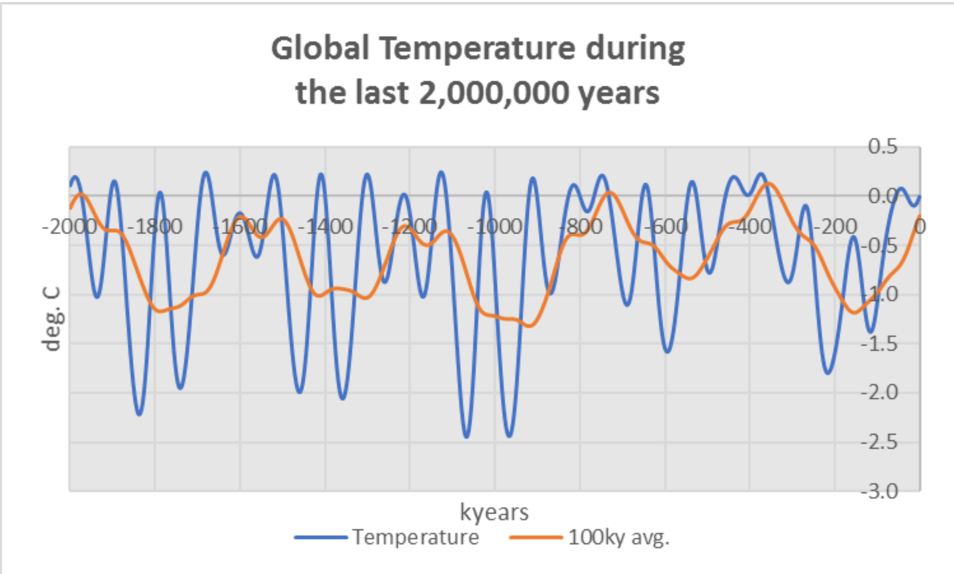


Figure 8.2.2 Changes in global temperature caused by changes in earth's orbit.

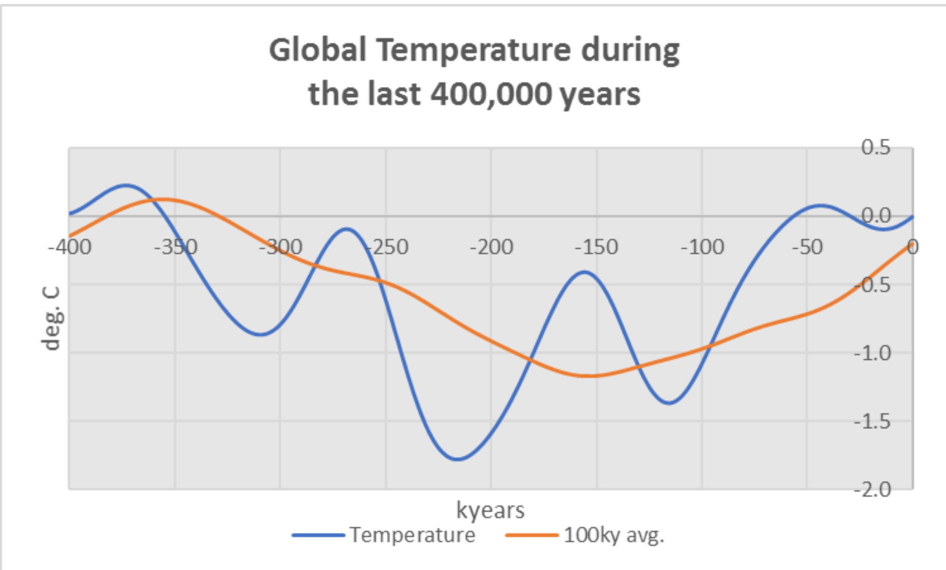


Figure 8.2.3 Changes in global temperature during the last 400,000 years caused by changes in earth's orbit.

Figure 8.2.4 Glaziers in Scandinavia in about 11,500BP. The formation of sand in Salpauselkä happened in years 12,000 – 10,000 BP.

This has been explained that the Gulf Stream had stopped, but the real reason might have been the temperature drop, which was caused by the change in irradiance. Irradiance was changing as a function of eccentricity (Formula 8.2.1). It is possible that the change in irradiance has caused the change in the Gulf Stream. Earlier the reason has been explained to be a fresh water pulse from smelting of the ice.

Changes in eccentricity, obliquity and precession for the last 120,000 years have been given in Figure 8.2.5. The decrease in eccentricity (upper diagram) is the same as already found in Figure 8.1.3.

The small peak in eccentricity can be found at about 10,000 – 12,000 years ago. At the same time, there was a peak in obliquity, which means that the tilt of earth's axel was in its maximum at about 24.2^o. This means that the summer was quite warm, but the winter was colder than normal. Arctic circle is today at 66^o 33'N. It was 11,000 years ago at 90^o – 24.2^o = 66.8^o level. This is about 15' minutes (30 km) south from the present Latitude.

There was also a minimum in precession index. These three parameters caused a drop in daily insolation at 65^o North Latitude, which about 600 km north from Helsinki. This explains the cooling, which happened certainly during years 12,000 – 10,000BP as the sand formations are still proving.

During these years 12,000 – 10,000 BP both eccentricity and obliquity peaked at the same time (Figure 8.2.5). The higher eccentricity decreased irradiance and the because the earth was at its closest position during the winter (omega was 270^o), sun did not warm the high latitudes above polar circle. In summer the sun was shining more but far away due to eccentricity of the earth's orbit.

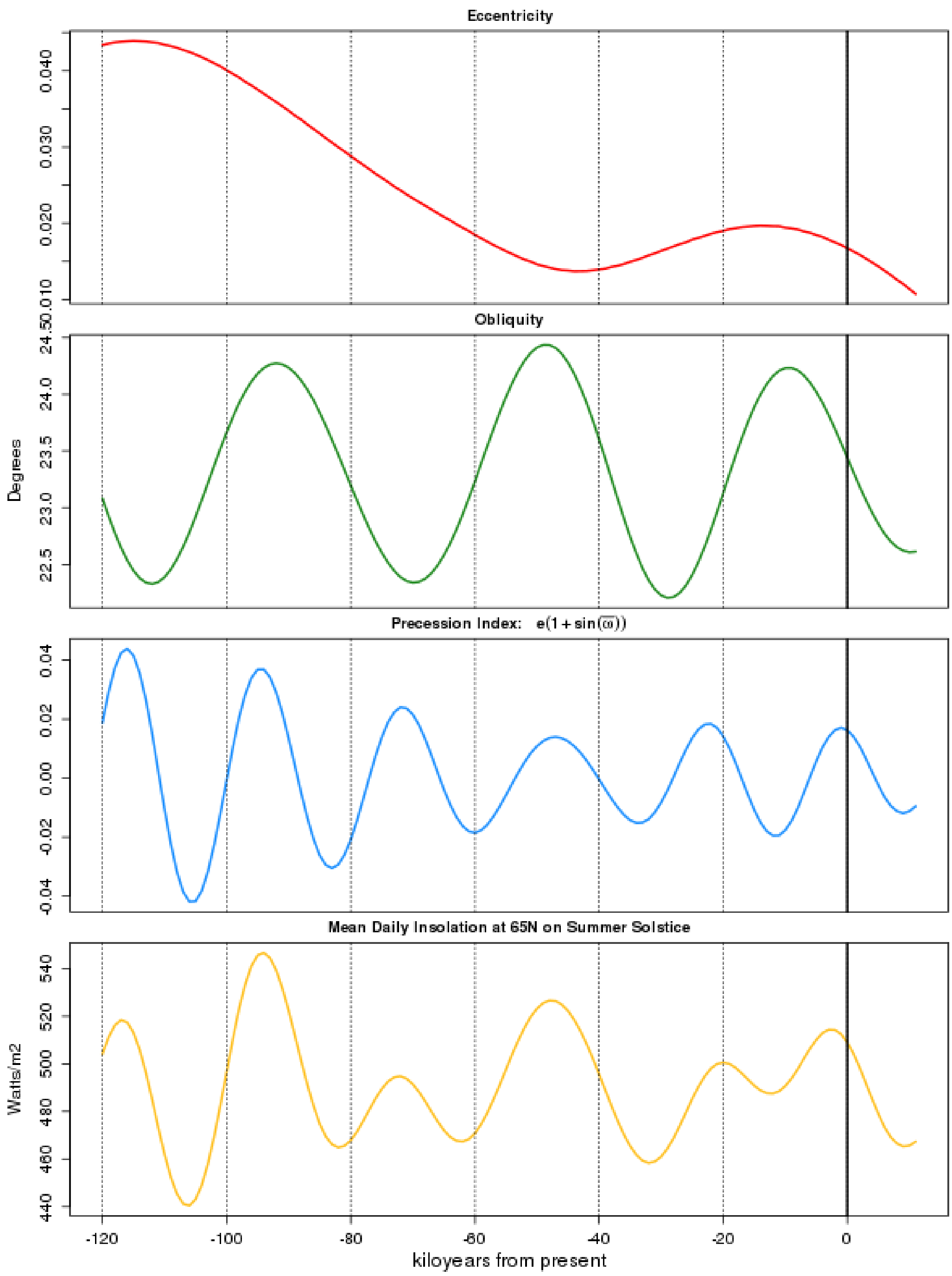


Figure 8.2.5 Eccentricity, obliquity, precession and insolation during the last 120.000 years (http://biocycle.atmos.colostate.edu/shiny/Milankovitch/, based on paper of J. Laskar et al. La2010: a new orbital solution for the long-term motion of the Earth).

The last age ages seem to have started, when the global temperature had dropped about one degrees below the present level (Figure 8.2.6). This happened about 120,000 years ago, when the volume of ice started to grow last time (see Figure 7.3.1). Before it, the same thing happened in about 230,000 years ago.

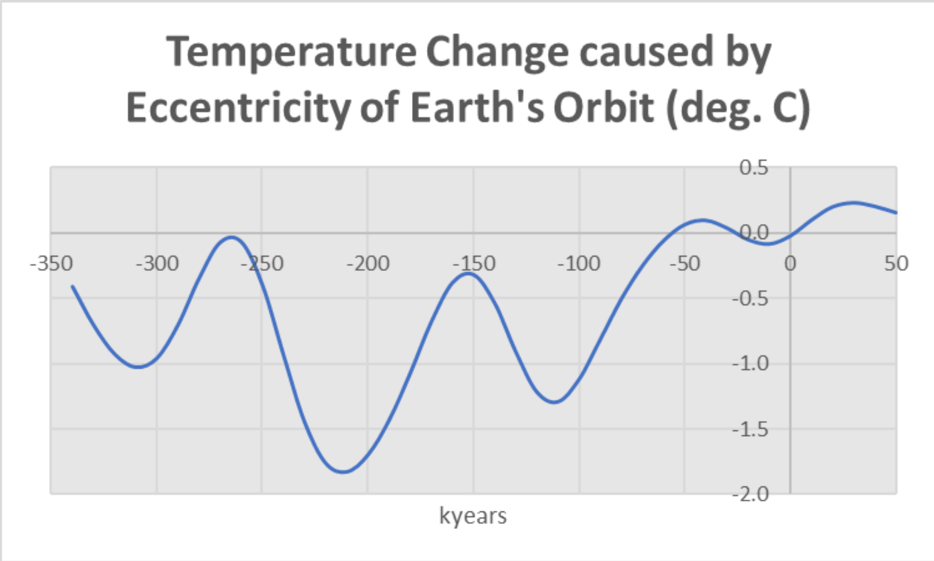


Figure 8.2.6 Last ice ages started when the global temperature was -1.0 degrees below the present level.

8.3 Changes in earth's orbit in the future

Eccentricity is approaching its minimum value of 0.0023 in about 25,000AD (Figure 8.3.1). The next peak value of 0.033 will be reached in about 156,000 years from today.

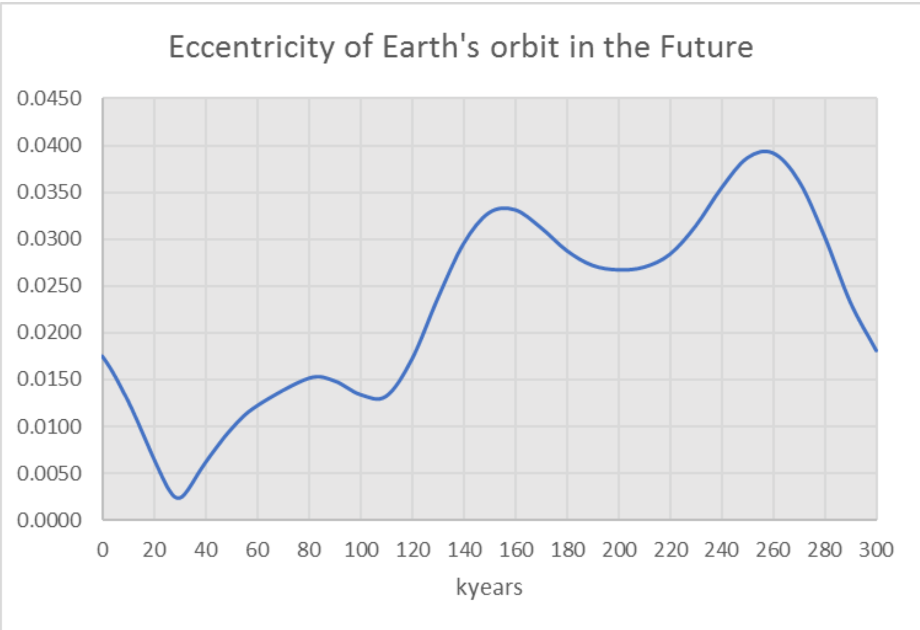


Figure 8.3.1 Eccentricity of earth's orbit in the future is dropping to 0.0023 in the year 25,000 AD (http://www.jgiesen.de/kepler/eccentricity1.html).

The formula (8.2.1) indicates that, if eccentricity is growing, annual average of solar irradiance is becoming smaller. This means that most of the time the earth is far from the sun. The future changes in solar irradiance have been calculated in Figure 8.3.2. Peak in irradiance can be seen in 28,000AD. After it irradiance starts declining and it will reach its minimum in about year 260,000AD.

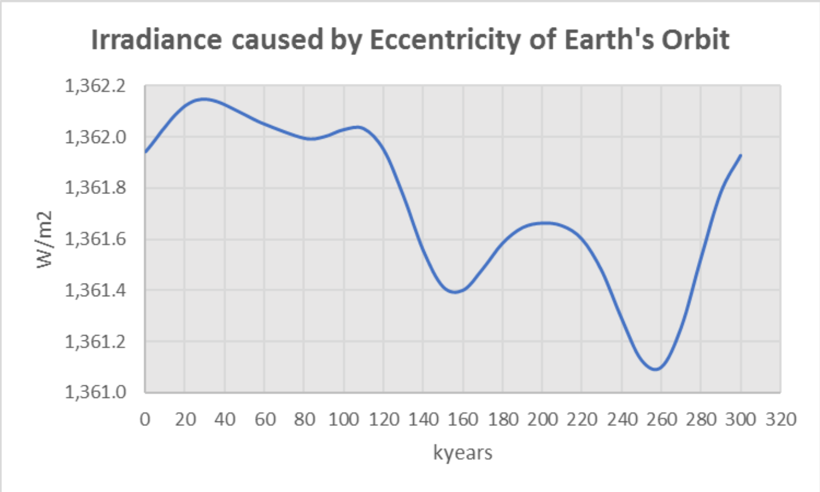


Figure 8.3.2 Changes in solar irradiance caused by eccentricity of earth's orbit.

Changes in total solar irradiance will cause global warming by formula dT = 1.23 x W. Eccentricity will cause global warming until the year 28.000AD (Figure 8.3.3). After this date the climate will start cooling. The cooling will be 0.7 deg. C in the year 160,000AD and about 1.1 deg. C in the years 250,000 – 260,000AD. This could cause a new ice age.

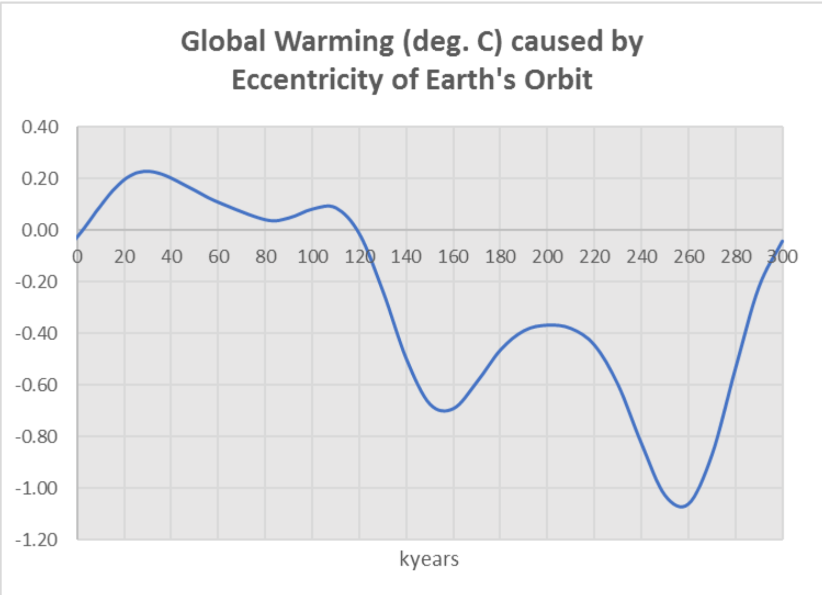


Figure 8.3.3 Temperature changes in the future caused by eccentricity.

All orbital parameters have been given in Figure 8.3.4. They indicate that daily insolation at 65N latitude during summer is decreasing at present, because obliquity is decreasing. Next minimum (470 W/m^2) will be reached in about 20,000 years from present. Then minimums will follow at 41,000-year intervals with the lowest point (440 W/m^2) at 250,000 years from present, when also precession index is at minimum and eccentricity at maximum value for 250,000 years.

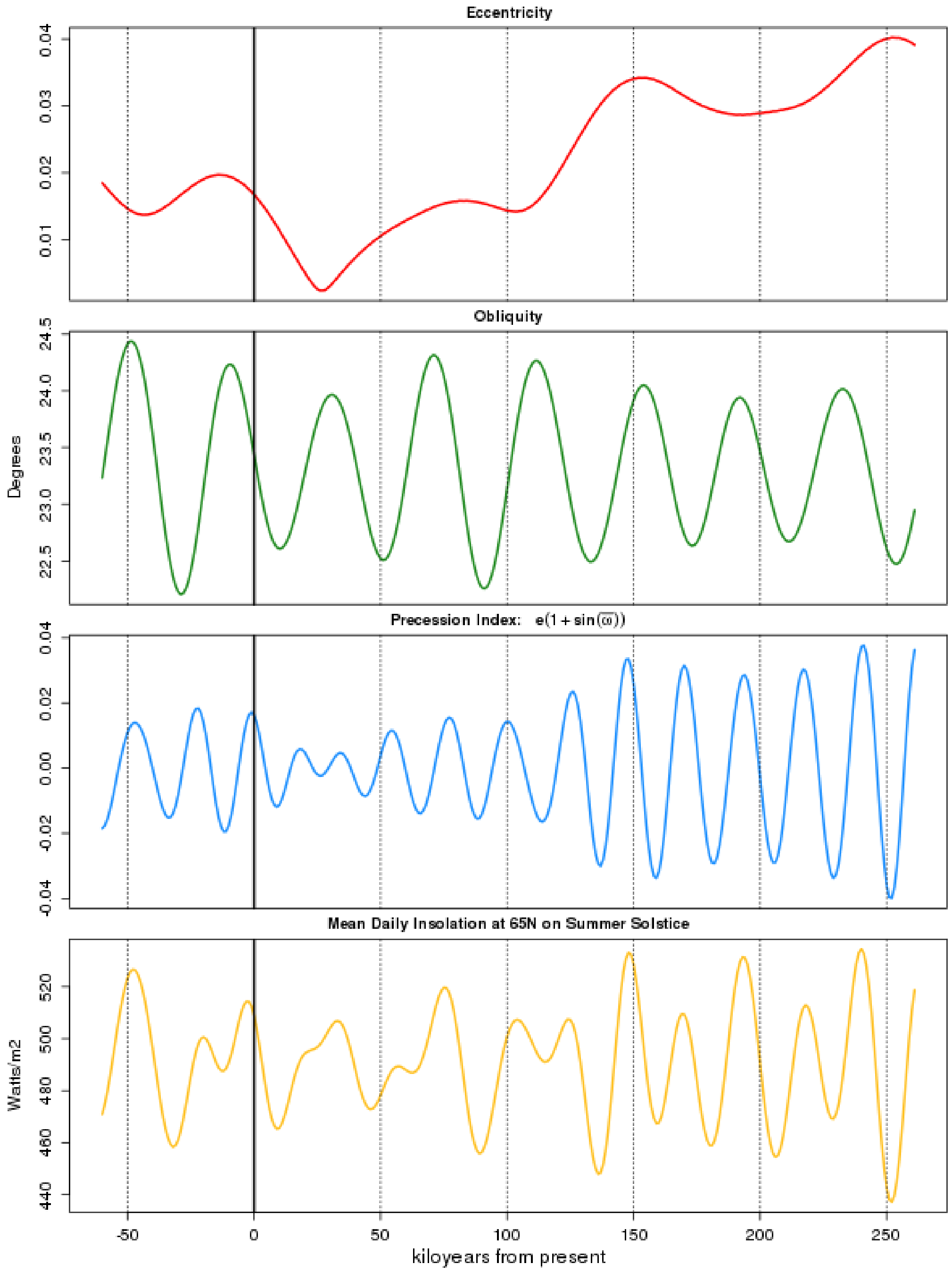


Figure 8.3.4 Milankovitch's cycle parameters in future years and mean daily insolation (Source: http://biocycle.atmos.colostate.edu/shiny/Milankovitch/).

8.4 Next ice age

The scientists have predicted for a long time that the next Ice Age will be coming following about 100,000-year cycle of solar irradiance. Some scientists warned about the coming Ice Age were starting in about 1965, when the global temperature (11-year average) has been cooled from the year 1958 almost constantly (Figure 8.4.1).

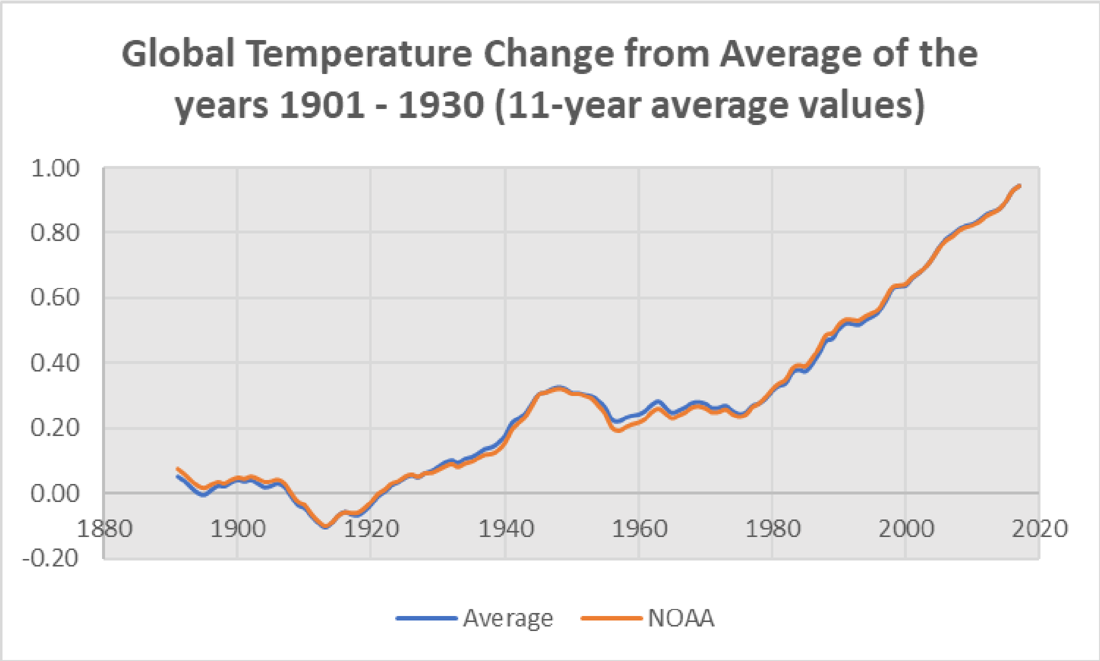


Figure 8.4.1. 11-years average of global temperature change from average of 1901-1930.

The warnings of Ice Age changed to warnings of global warming after the year 1975, when the 11-year average temperature started rising again. This is still the main concern of the most scientists. The global temperature has been rising with linear trend since 1980 from 0.3 to 0.9 deg C during the last 37 years or about 0.17 deg. C/decade.

After the year 2005, when the solar irradiance has been declining (Figure 8.4.2), some scientists have predicted that a new Ice Age might be coming or at least there will be a cool period ahead, which can be compared with the Maunder minimum between years 1650 – 1700.

Another reason for Ice Age is predicted from the solar obliquity and precession, which will cause declining of daily insolation in norther summers at 65 N (Figure 8.4.3). The isolation will decrease from about 510 W/m^2 to about 460 W/m^2.

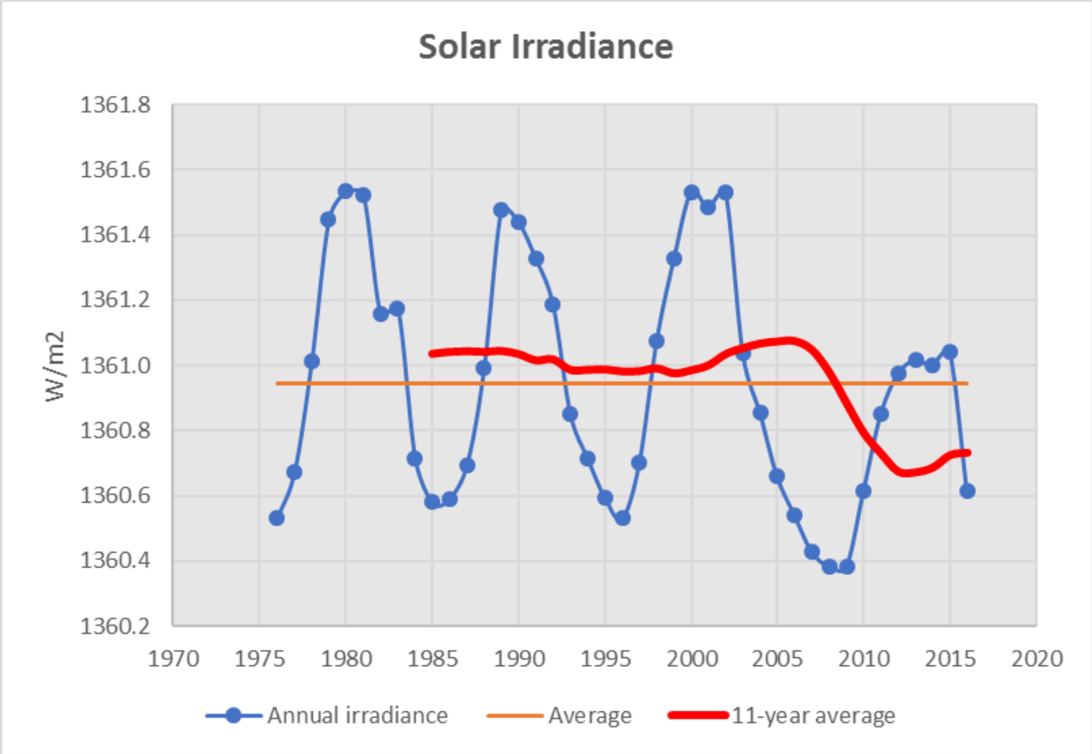


Figure 8.4.2 Total Solar Irradiance (TSI) has measured by the satellites (see chapter 3.3).

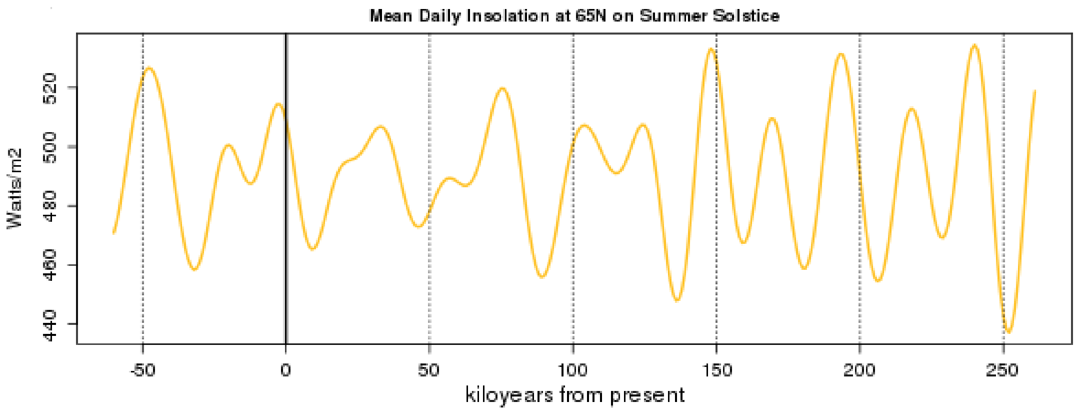


Figure 8.4.3 Daily insolation during the next 250,000 years on northern summer at 65N.

Radiative forcing of CO_2 will cause rise in global temperature and will compensate the possible decline in solar forcing. Depending on, how much releases of carbon will be in the future.

As was already found in chapter 4 that the CO_2 emissions will rise the concentration of CO_2 in the atmosphere (Figure 8.4.4). By the year 2300 the CO_2 concentration will be lower than today. CO_2 forced warming will be valid only for a short period, because the seas will be absorbing the CO_2 in the air.

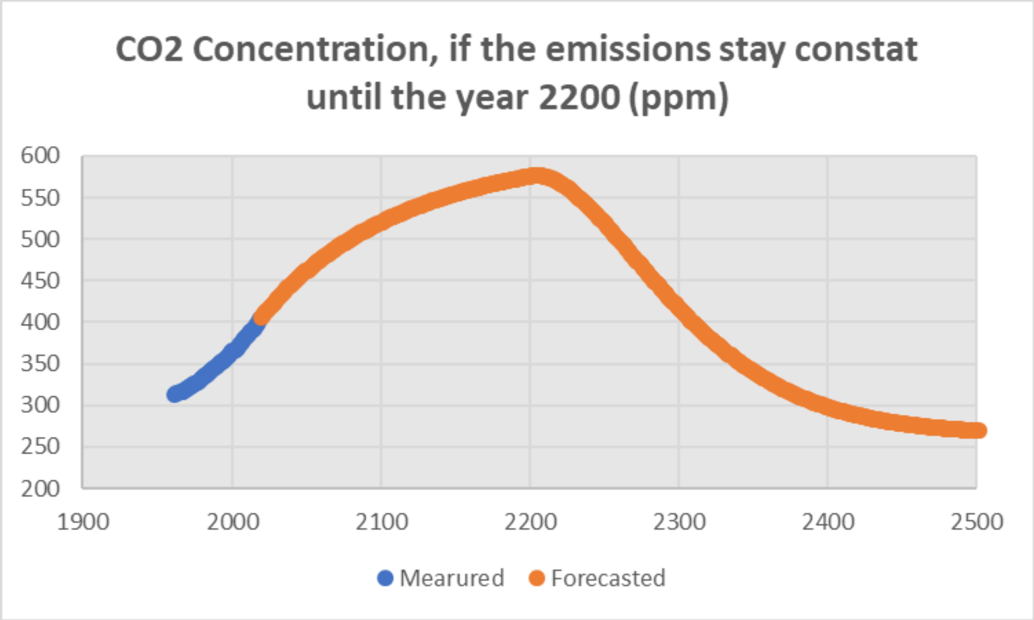


Figure 8.4.4 CO_2 concentration in air with mass balance model.

CO_2 has only limited effect on the global temperature in the long perspective (Figure 8.4.5). Even if the emissions will stay at present level until the year 2160, the temperature will drop back to today's level after year 2280, because the fossil fuel resources will be burned by then.

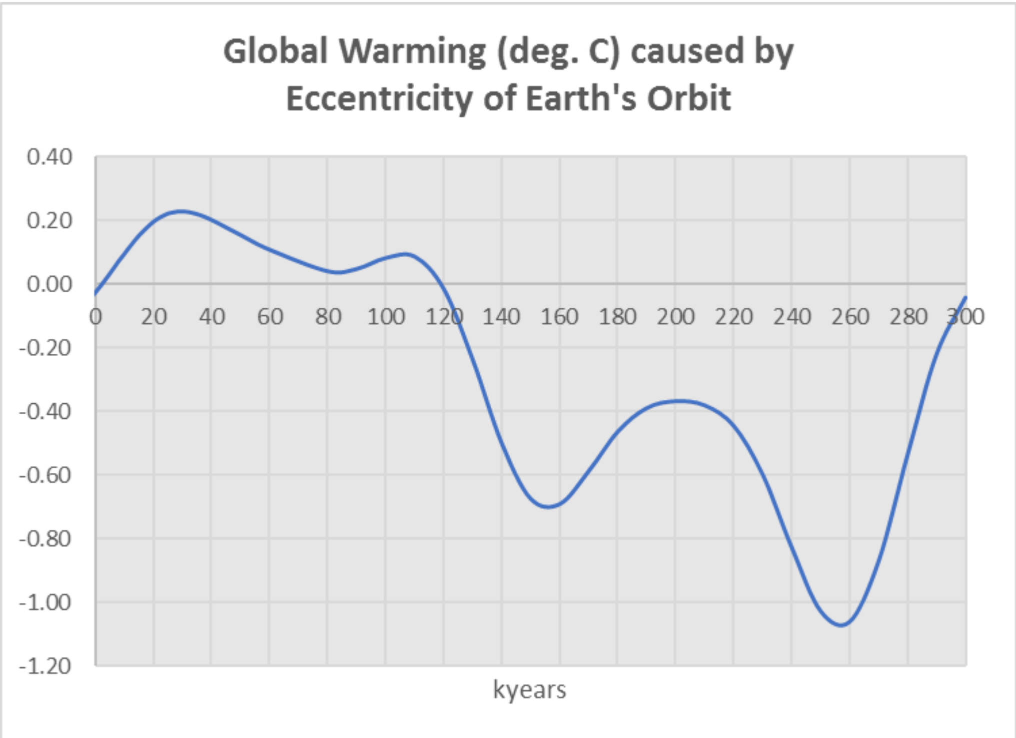


Figure 8.4.5 Global warming caused by the eccentricity of earth's orbit.

The most important factor in the long range will be global warming and cooling caused by the eccentricity of earth's orbit. The global temperature will be in the year about 1.0 deg. C lower than today (Figure 8.4.5).

CO_2 emissions cannot prevent the next Ice Age. It will be coming in about 250,000 years from today, when the global temperature will decrease more than 1 deg. C.

9 TARGET PLAN FOR 2050

9.1 Targets

196 countries negotiated the **Paris Agreement**, under which they committed to taking steps to limit the increase in global average temperature this century to well below 2 degrees Celsius over preindustrial levels, and ultimately to limit that increase to 1.5 degrees C in 2015. Under the agreement, each signatory submits its own national plan, setting targets for emissions reductions and specifying pathways by which it aims to meet those targets.

However, the countries have not made their national plans so that even 2-degree limit can be achieved. China is the largest emitter and it is planning to increase its CO2 emissions until the year 2030. The second largest emitter, USA has withdrawn totally from the Paris agreement. It seems unlikely that even this 2-degree limit can be achieved. However, it is possible to limit global warming to two degrees starting fro, the average temperature from the years 1901-1930.

We can prevent the critical two-degree C warming by decreasing CO_2 emissions at least with 2 % annually or with target reduction plan (Figure 9.1.1). With more than 2 % annual saving strategy or 50 % reduction today, the peak temperature will stay below 2 deg. C by the year 2070.

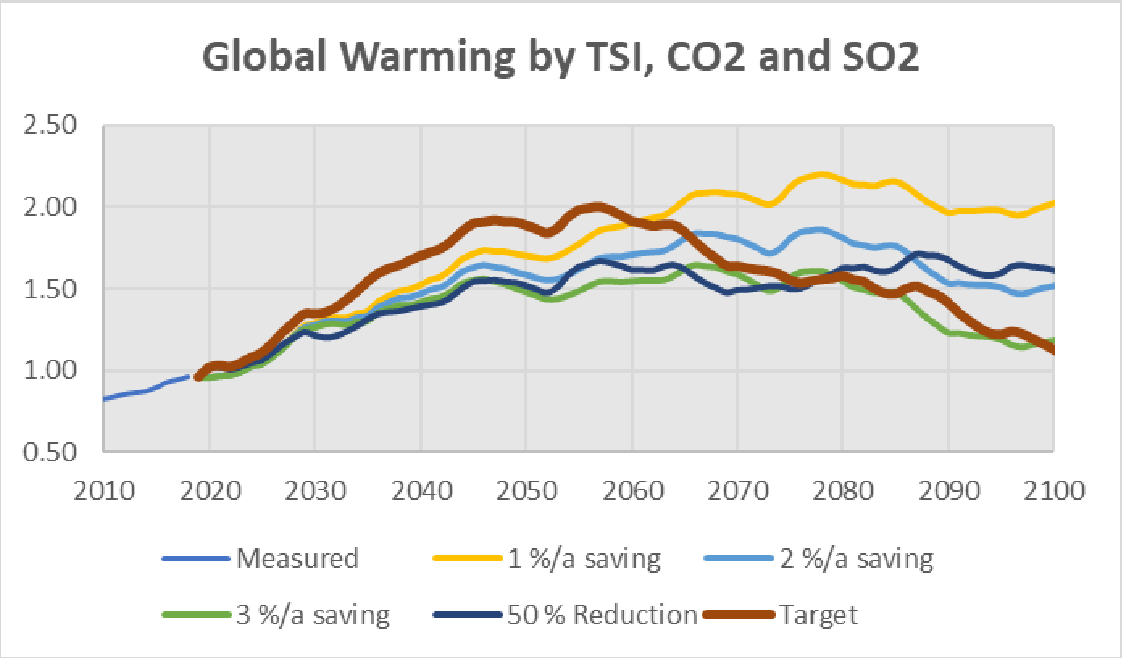


Figure 9.1.1 Temperature rise until the year 2100.

With 2 % annual savings, the emissions will be 18 Gt/a in the year 2050 (Figure 9.1.2). The same result will be achieved, if the emissions will be reduced 50 % today or with the target plan, where the peak emissions will be achieved in the year 2025.

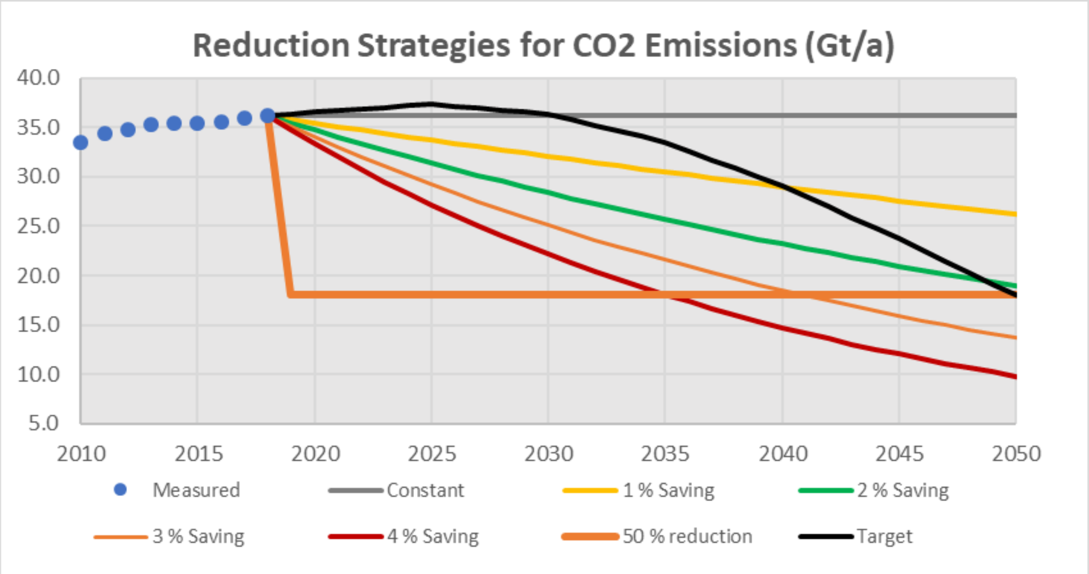


Figure 9.1.2 Reduction of CO_2 emissions should be at least 1 % annually.

The world population will be 10 billion (Figure 9.1.3), thus the 18 Gt target means that emissions should be below 1.8 tons per capita in each country.

Target will be to keep temperature rise below 2 deg. C. This target can be achieved, if CO_2 emissions will be saved in average more than 2 % annually or with the target plan.

Target for the year 2050 is less than 18 $GtCO_2$/a emissions for 10 billion people. This is 1.8 t/capita. All nations should reduce their emissions below 1.8 t/capita target.

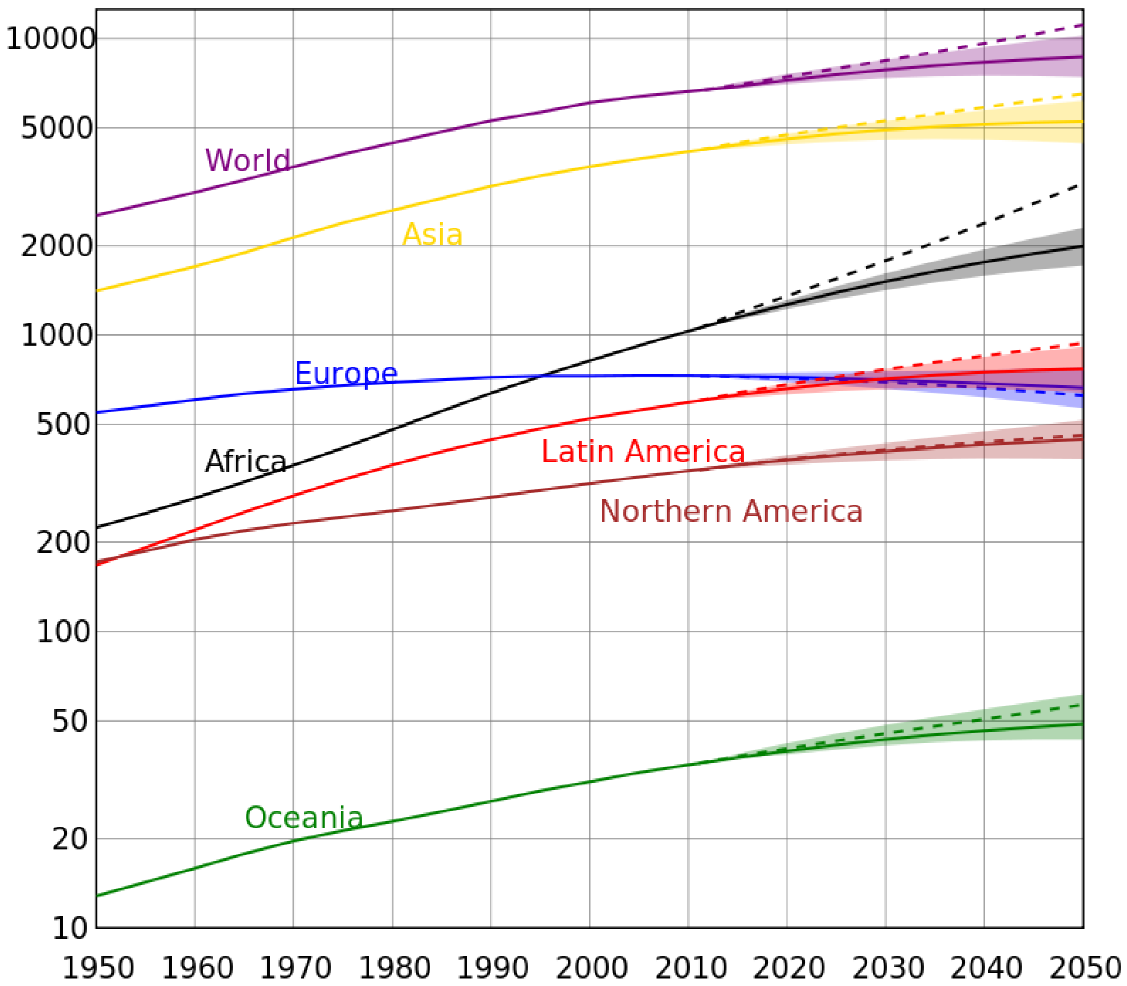


Figure 9.1.3 UN population forecast predicts about 9 billion for the year 2050.

9.2 Action plans

Actions needed

1. Decarbonize Electricity Generation

The world energy use should be changing to use electric energy and the main source of energy. This means that electricity should be generated by non-fossil sources by hydro, wind, solar and nuclear energy.

2. Decarbonize traffic

Oil has been the main source of traffic, which has been mainly powered by internal combustion engines. Vehicles should be converted from oil to electric.

3. Decarbonize homes

Homes have been heated mainly by oil and gas. They should be converted to use electricity and heat pumps. New houses should be built from wood instead of concrete.

4. Increase carbon sinks

World forests have been storing carbon more than atmosphere. The forests have been acting as carbon emitters and should be converted to carbon sinks.

However, it is not possible to start to limit the CO_2 emissions today, because there are several countries which are still increasing their emissions. The CO_2 emissions will be increasing until the year 2025 at about 37.4 $GtCO_2$ and will then reduced to about 18 $GtCO_2$ (1.8 t/capita) by the year 2050 (Figure 9.2.1).

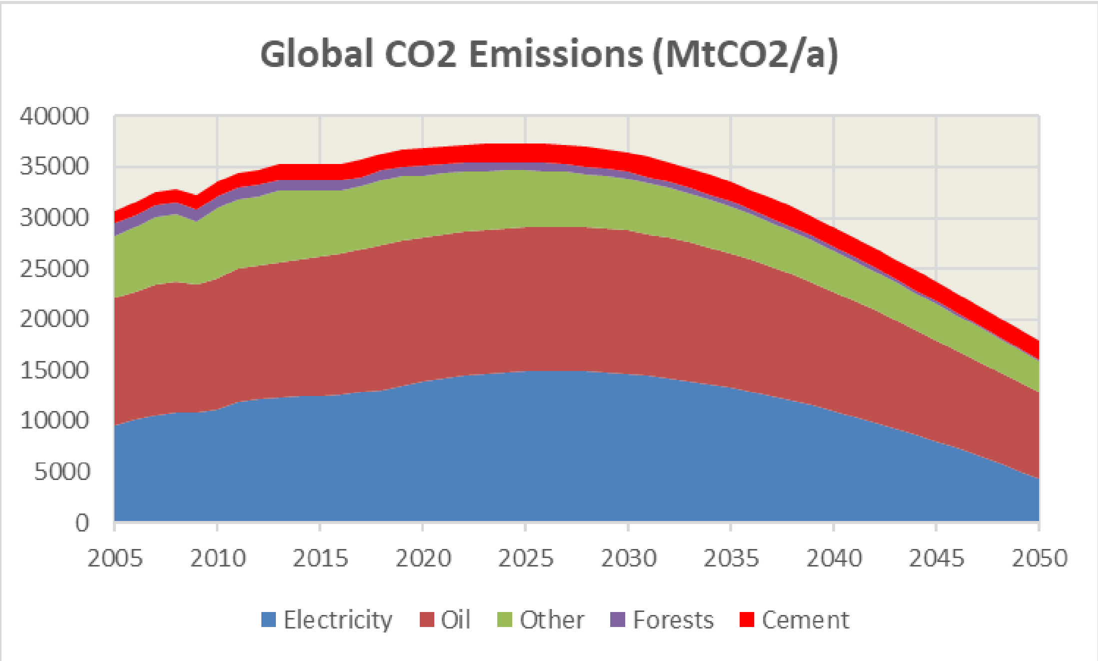


Figure 9.2.1 Global CO_2 emissions by sources.

The global emissions have been evaluated in main areas in chapter 14, which include about 66 % of global emissions. It could be noted that the actions of China will be the most important, because China is producing about 40 % of global emissions and is stll increasing them until the year 2025 (Figure 9.2.2)

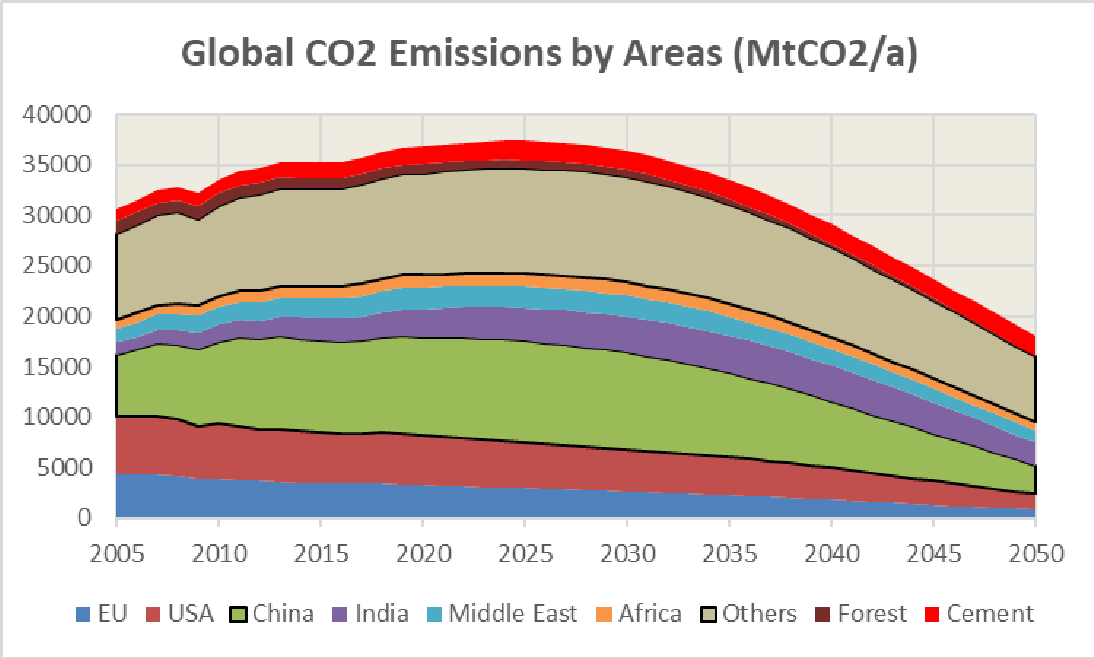


Figure 9.2.1 Global CO_2 emissions by areas.

9.3 Targets for individual countries

The reductions in emissions should happen as soon as possible to avoid global temperature rise to reach 2 deg. C. The global emissions should be reduced from the 36.5 Gt today to 18 Gt or with 50 %. This corresponds 2 % reductions annually. If the reductions will start in the year 2019, there are 32 years available before the critical year 2050, when the emissions should be 18 Gt or 1.8 tons per capita.

Groping the countries with CO_2 emissions

The countries have been grouped according their emissions. The largest 22 emitters, which have more than 10 tons per capita. They will need at least 5.2 % annual reductions to reach 1.8 t/capita level by 2050 (Table 9.3.1).

Table 9.3.1 Countries with the largest emissions per capita.

	Country	2018 t/capita	2050 t/capita	Save %	Save %/a
1	Singapore	39.6	1.8	95%	9.2%
2	Qatar	37.4	1.8	95%	9.0%
3	United Arab Emirates	28.9	1.8	94%	8.3%
4	Kuw ait	23.3	1.8	92%	7.7%
5	Estonia	19.6	1.8	91%	7.2%
6	Luxembourg	17.6	1.8	90%	6.9%
7	Saudi Arabia	17.0	1.8	89%	6.8%
8	Australia	16.8	1.8	89%	6.7%
9	US	15.3	1.8	88%	6.5%
10	Trinidad & Tobago	15.0	1.8	88%	6.4%
11	Canada	15.0	1.8	88%	6.4%
12	Oman	14.7	1.8	88%	6.4%
13	South Korea	13.6	1.8	87%	6.1%
14	Kazakhstan	13.4	1.8	87%	6.1%
15	Turkmenistan	13.4	1.8	87%	6.1%
16	China Hong Kong SAI	13.4	1.8	87%	6.1%
17	Total North America	12.2	1.8	85%	5.8%
18	Taiw an	12.0	1.8	85%	5.8%
19	Netherlands	11.8	1.8	85%	5.7%
20	Belgium	11.1	1.8	84%	5.5%
21	Russian Federation	10.7	1.8	83%	5.4%
22	Iceland	10.4	1.8	83%	5.3%

The countries with 5 - 10 tons per capita emissions should reduce their emissions at least with 3.3 % annually to reach 1.8 ton/capita level. (Table 9.3.2).

Countries with 1.8 – 5 tons pe capita need to reduce their emissions 0 – 3 % annually to achieve 1.8 t/capita (Table 9.3.3).

The countries with less than 1.8 tons per capita can increase their emissions.

Table 9.4.2 Countries with 5 - 10 tons per capita emissions.

	Country	2018 t/capita	2050 t/capita	Save %	Save %/a
23	Czech Republic	9.6	1.8	81%	5.1%
24	Japan	9.0	1.8	80%	4.9%
25	Germany	8.7	1.8	79%	4.8%
26	Poland	8.5	1.8	79%	4.7%
27	Total Middle East	8.3	1.8	78%	4.7%
28	Finland	8.3	1.8	78%	4.7%
29	Israel	8.2	1.8	78%	4.6%
30	Ireland	8.0	1.8	78%	4.6%
31	Iran	8.0	1.8	77%	4.5%
32	Malaysia	7.8	1.8	77%	4.5%
33	New Zealand	7.5	1.8	76%	4.4%
34	South Africa	7.3	1.8	75%	4.3%
35	Cyprus	6.9	1.8	74%	4.1%
36	Norway	6.8	1.8	74%	4.1%
37	Austria	6.8	1.8	73%	4.1%
38	Greece	6.8	1.8	73%	4.1%
39	EU	6.7	1.8	73%	4.0%
40	China	6.6	1.8	73%	4.0%
41	Slovenia	6.5	1.8	72%	3.9%
42	Denmark	6.3	1.8	72%	3.8%
43	Spain	6.3	1.8	71%	3.8%
44	Total Europe	6.2	1.8	71%	3.8%
45	Belarus	6.0	1.8	70%	3.7%
46	Bulgaria	6.0	1.8	70%	3.7%
47	Slovakia	5.9	1.8	70%	3.6%
48	United Kingdom	5.9	1.8	69%	3.6%
49	Italy	5.6	1.8	68%	3.5%
50	Chile	5.2	1.8	66%	3.3%
51	Other Europe	5.2	1.8	66%	3.3%
52	Portugal	5.2	1.8	65%	3.3%

Table 9.4.2 Countries with less than 5 tons per capita emissions.

	Country	2018 t/capita	2050 t/capita	Save %	Save %/a
53	Hungary	4.8	1.8	63%	3.0%
54	Turkey	4.7	1.8	62%	3.0%
55	France	4.6	1.8	61%	2.9%
56	Total World	4.4	1.8	59%	2.8%
57	Thailand	4.3	1.8	58%	2.7%
58	Switzerland	4.3	1.8	58%	2.6%
59	Ukraine	4.2	1.8	57%	2.6%
60	Sweden	4.2	1.8	57%	2.6%
61	Lithuania	4.1	1.8	57%	2.6%
62	Croatia	4.0	1.8	55%	2.5%
63	Latvia	4.0	1.8	55%	2.5%
64	Total Asia Pacific	4.0	1.8	55%	2.5%
65	Argentina	3.9	1.8	54%	2.4%
66	Iraq	3.8	1.8	53%	2.3%
67	Venezuela	3.8	1.8	53%	2.3%
68	Romania	3.6	1.8	50%	2.2%
69	Mexico	3.5	1.8	49%	2.1%
70	North Macedonia	3.5	1.8	48%	2.0%
71	Non-OECD	3.4	1.8	47%	1.9%
72	Algeria	3.2	1.8	44%	1.8%
73	Uzbekistan	3.2	1.8	44%	1.8%
74	Azerbaijan	3.2	1.8	44%	1.8%
75	Other Caribbean	2.8	1.8	37%	1.4%
76	Total S. & Cent. Amer	2.4	1.8	25%	0.9%
77	Vietnam	2.3	1.8	22%	0.8%
78	Egypt	2.2	1.8	20%	0.7%
79	Ecuador	2.2	1.8	18%	0.6%
80	Indonesia	2.0	1.8	10%	0.3%
81	Brazil	2.0	1.8	9%	0.3%
82	Colombia	2.0	1.8	9%	0.3%
83	India	1.8	1.8	1%	0.0%

10 DECARBONIZE ELECTRICITY

10.1 World Electricity generation

Main sources of world electricity generation in 2018 were coal and natural gas (Figure 10.1.1). Oil, gas and coal had 64 % market share of all electricity generation.

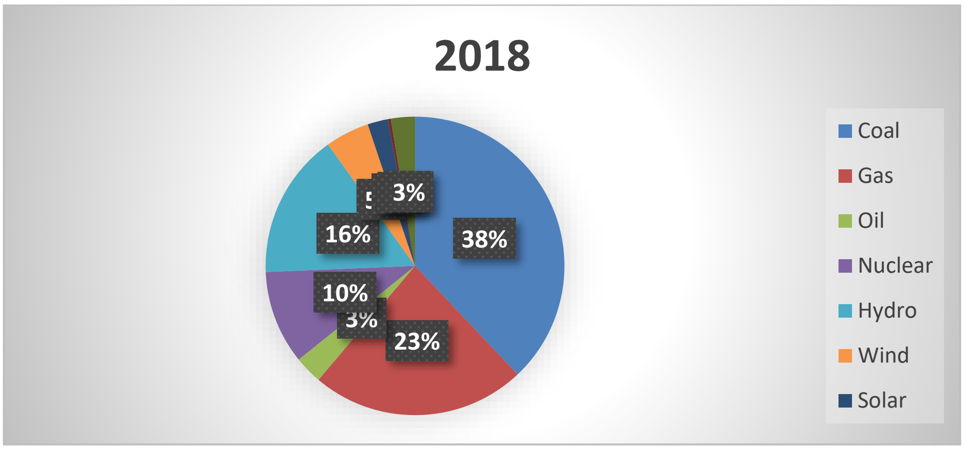


Figure 10.1.1 Main sources of world electricity (Source: BP Statistics).

During the last eight years the production of carbon free electricity generation has increase faster (34 %) than fossil sources (18 %) (Figure 10.1.2). Solar generation has been growing 42 %/a, wind power 18 %/a and other sources 5 %/a.

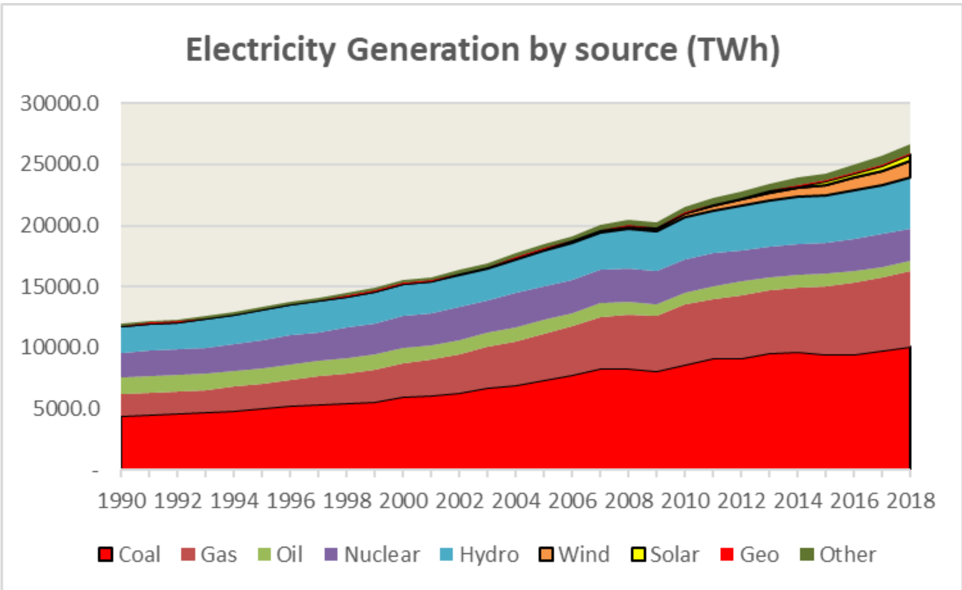


Figure 10.1.2 Sources of electricity in 1990 - 2018 (Source: BP Statistics).

World electricity generation will grow from 26,600 TWh in 2018 to 45,000 TWh by 2050. The growth will be covered mainly by renewable technologies (Figure 10.1.3). Fossil fuel generation will have their peak by the year 2028 (Figure 10.1.4). By 2050 fossil generation will be near 5,000 TWh, which or lower figure than in the year 2000.

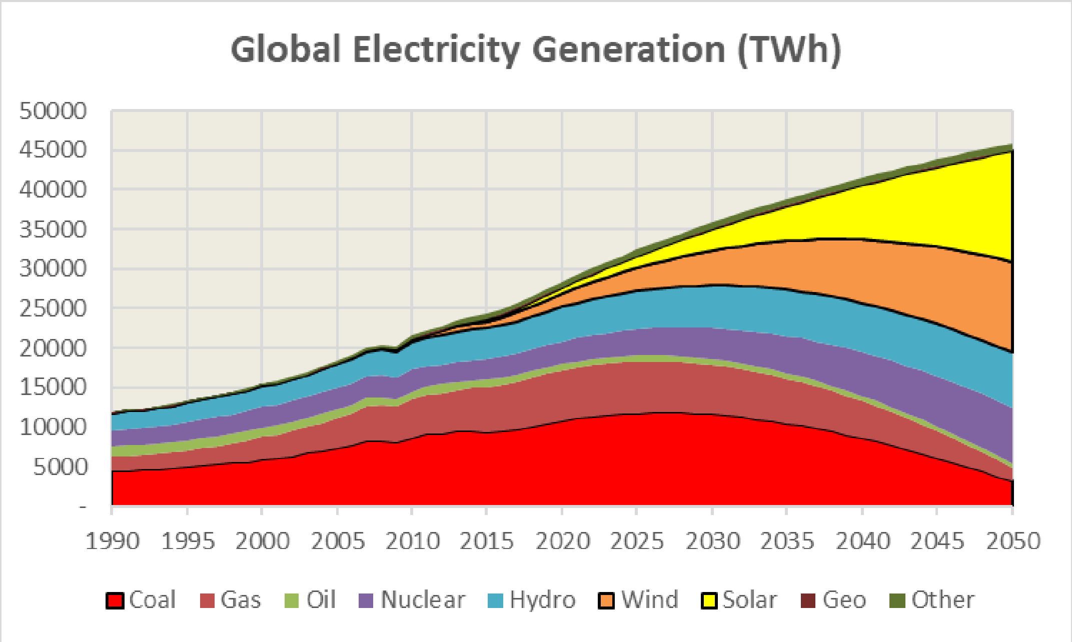


Figure 10.1.3 Electricity generation by sources.

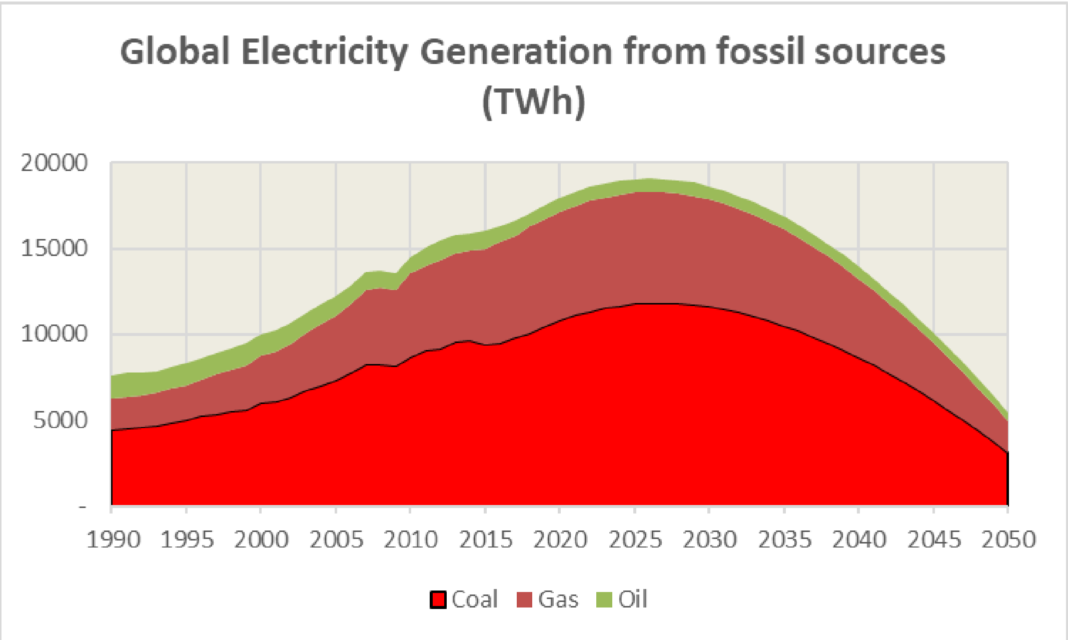


Figure 10.1.4 Electricity generation by fossil fuels.

10.2 CO2 emissions from electricity generation

Global CO_2 emissions from electricity generation have been increasing from 6000 million tons CO_2 to 13 Gt in 2018. CO_2 emissions of electricity generation will drop from 15 Gt in 2018 to about 4.2 Gt by 2050 (Figure 10.2.1). This will mean that the specific emissions of electricity generation will drop from 500 g/kWh to 90 g/kWh by 2050 (Figure 10.2.2).

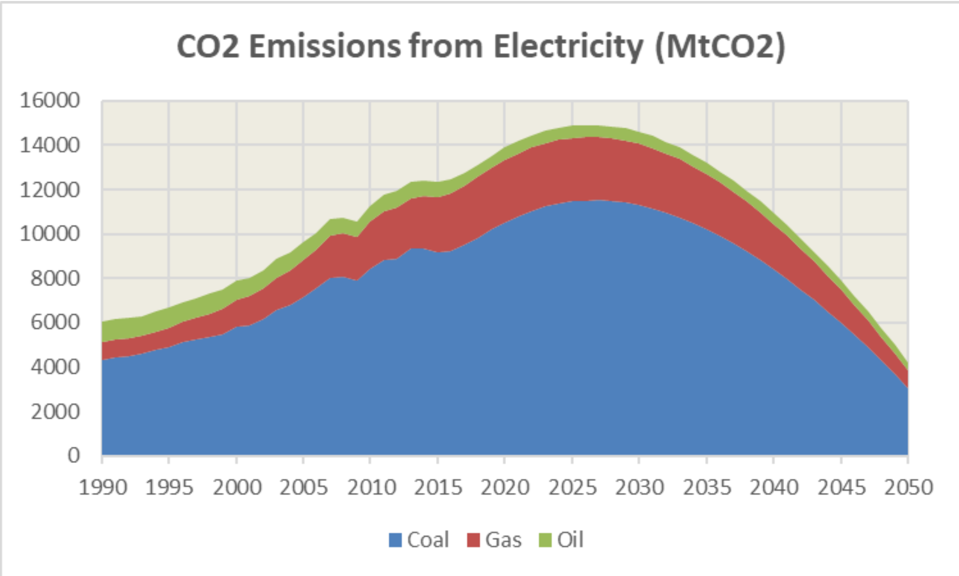


Figure 10.2.1 CO_2 emissions of electricity generation.

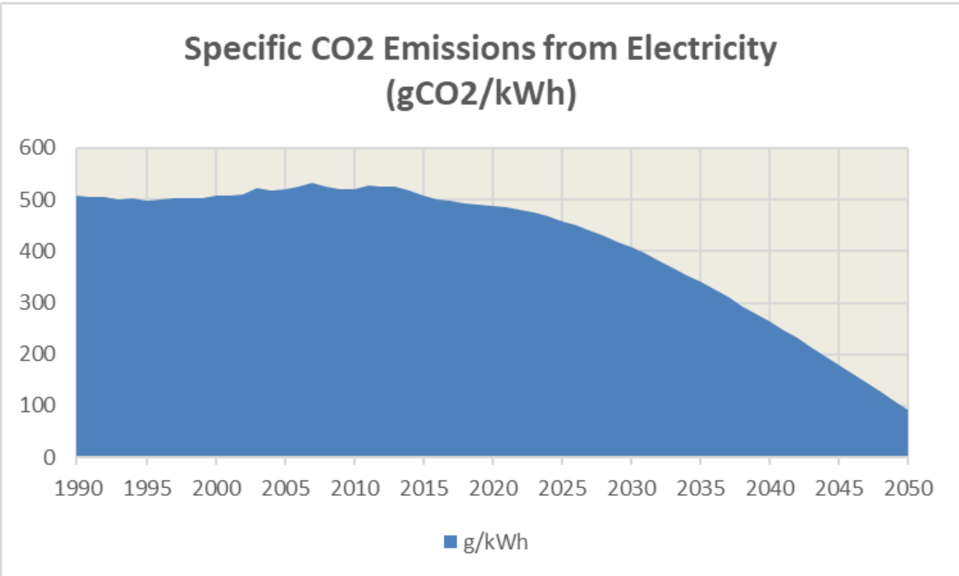


Figure 10.2.3 Specific emissions of electricity generation.

10.3 Investments in new technologies

Wind power

Decarbonizing electricity generation will mean huge investments in electricity generation technologies. Wind power capacity addition will rise to 120 GW annually (Figure 10.3.1). Cumulative capacity additions in wind power after the year 2000 will be rising to 4000 GW by 2050 (Figure 10.3.2).

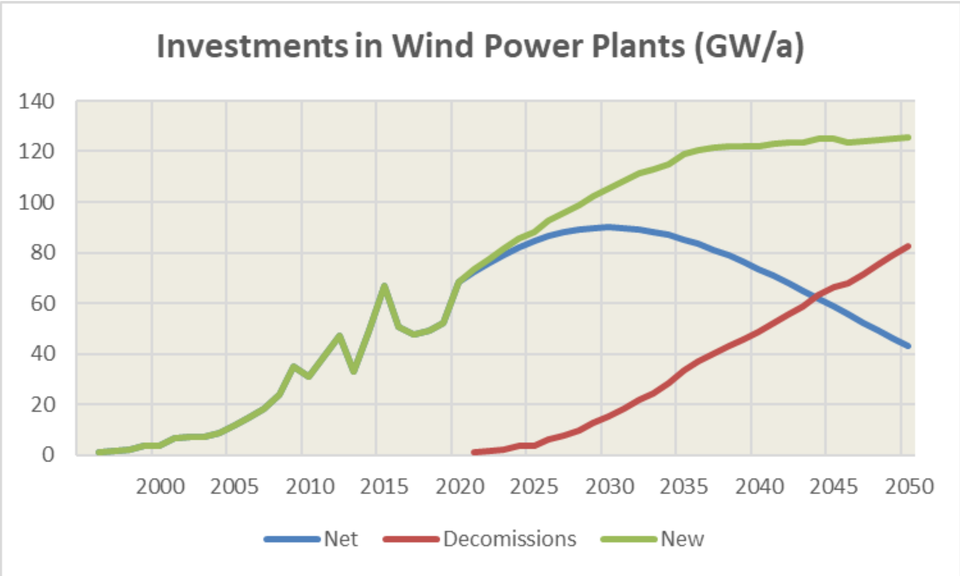


Figure 10.3.1 Capacity additions in wind power plants annually (GW/a)

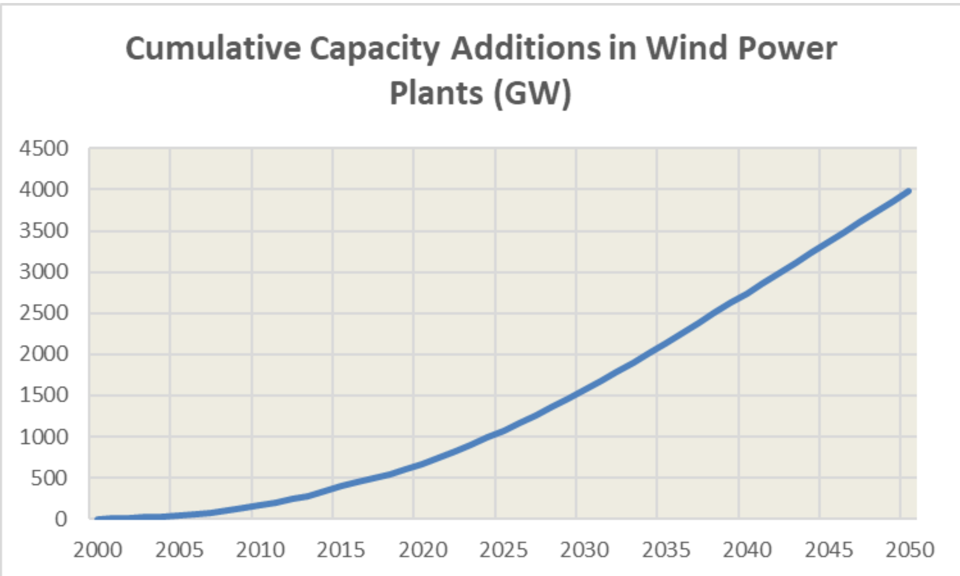


Figure 10.3.2 Cumulative capacity additions in wind power.

Cumulative investment cost in wind power plants will increase near 3700 billion euros (Figure 10.3.3).

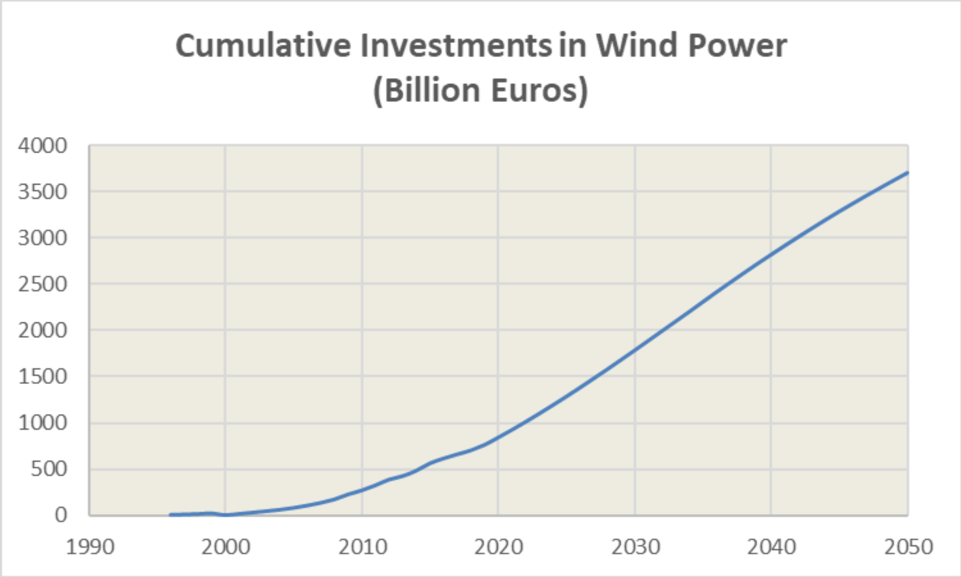


Figure 10.3.3 Cumulative investments in wind power until 2050.

Solar power

Solar power will have the largest share of the electricity generation in the future. This will be coming from the fact that the costs of solar panels have been dropping according to Swanson law (Figure 10.3.4).

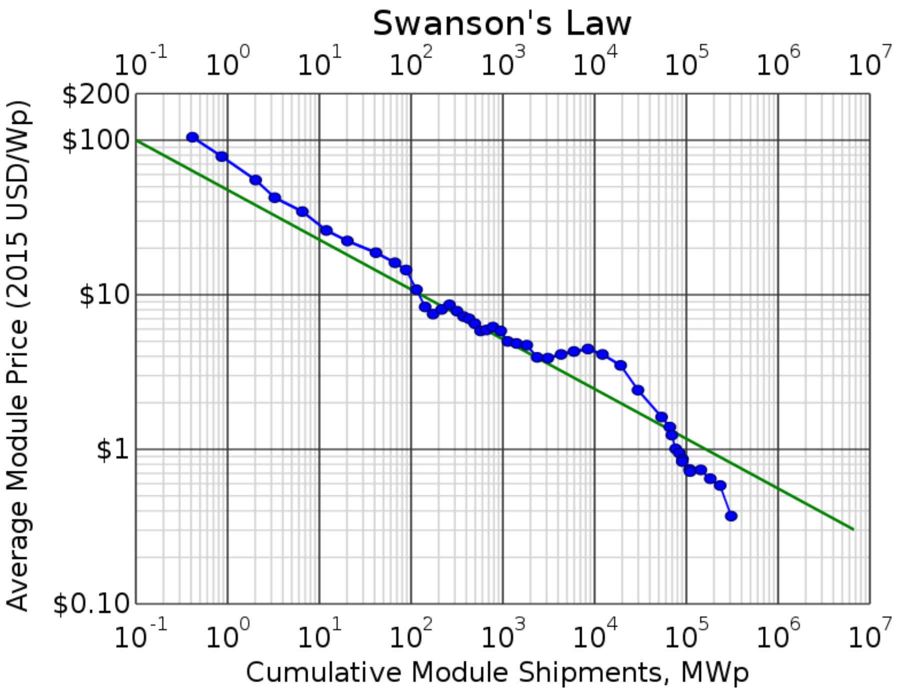


Figure 10.3.4 Swanson's law indicates that costs of solar module in decreasing.

If the production will increase by the factor of 1000, the price will be reduced by 90 %. The shipments are increasing from 1000 MW in the year 2000 to about 100,000 MW in 2020 or by factor of 1000 and the price of module will drop from about $5000/kW to about $500/kW. This price is so low that the generation costs

Capacity additions in solar power plants will increase from todays 100 GW/a annually to near 900 GW/a annually by 2050 (Figure 10.3.5).

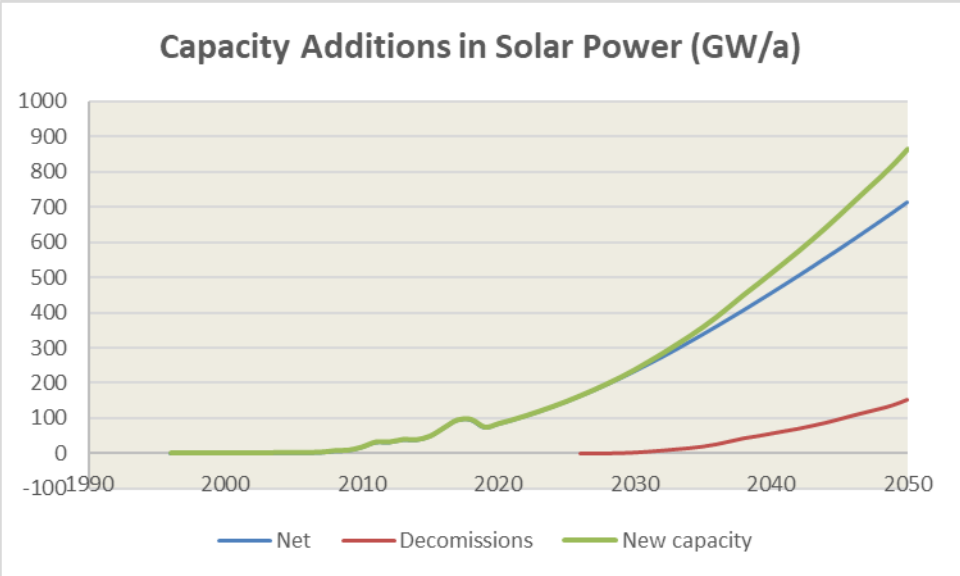


Figure 10.3.5 Capacity additions in solar power (GW/a).

Cumulative capacity additions for solar power will reach 13,000 GW y 2050 (Figure 10.3.6) Cumulative investments in solar power will reach 12,000 billion euros by 2050 (Figure 10.3.7).

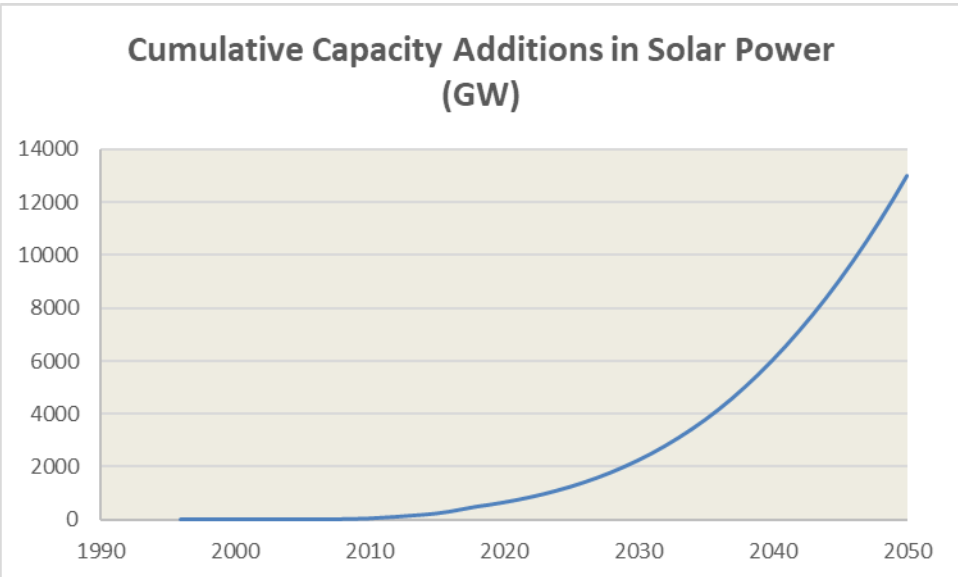


Figure 10.3.6 Cumulative capacity additions in solar power.

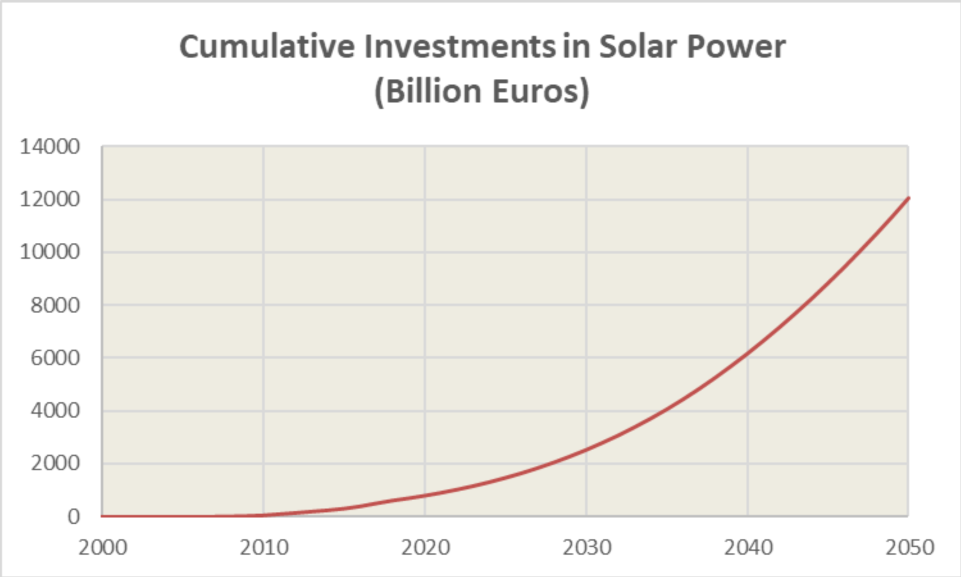


Figure 10.3.7 Cumulative investments in solar power by 2050.

Nuclear power

Capacity additions for nuclear power will be reaching 10 GW after the year 2020 and 30 GW after 2040 (Figure 10.3.8). Cumulative capacity added after 2000 will reach 900 GW by 2050 (Figure 10.3.9).

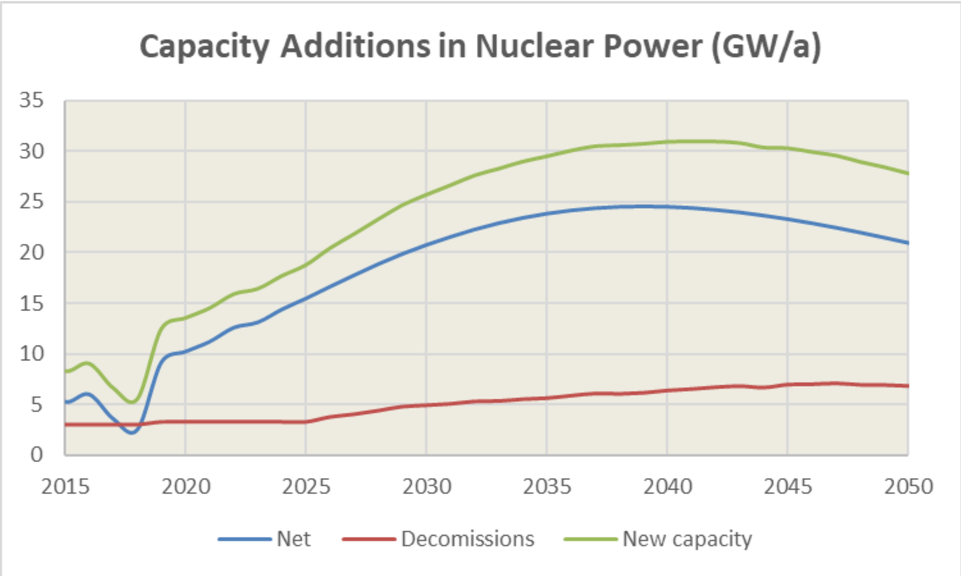


Figure 10.2.8. Capacity additions in nuclear power.

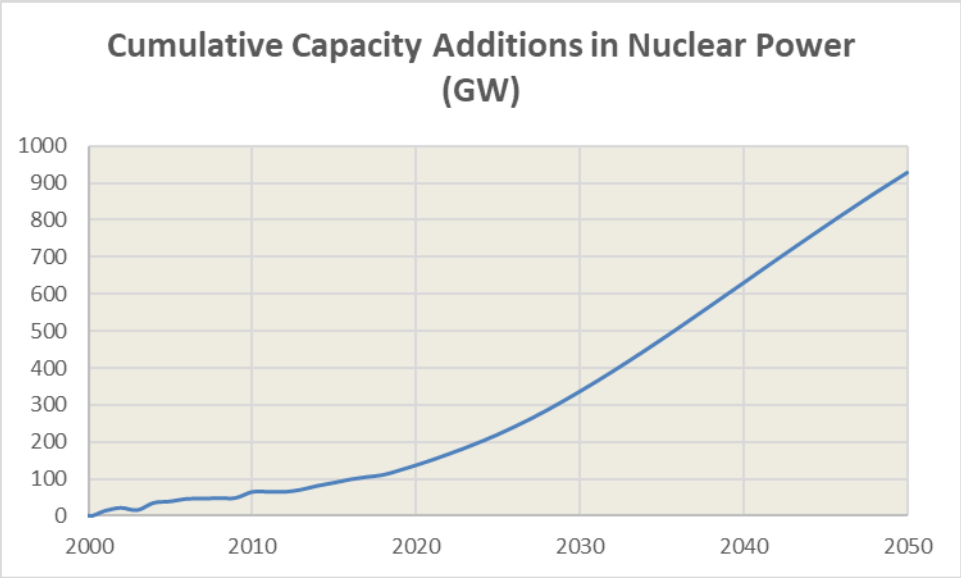


Figure 10.3.9 Cumulative capacity additions in nuclear power.

Cumulative investments needed for nuclear power would rise to 3400 Billion Euros by 2050 (Figure 10.3.10).

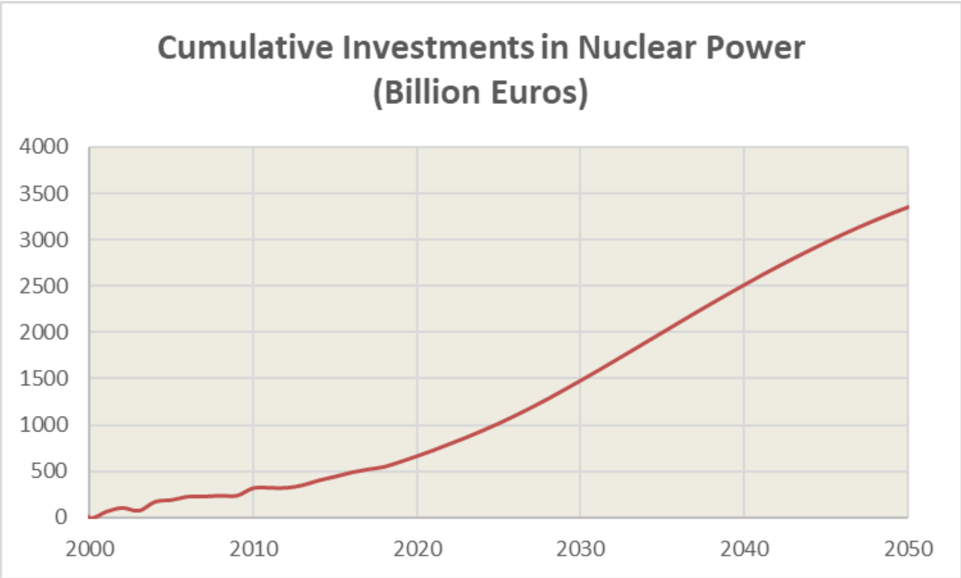


Figure 10.2.10 Cumulative investments in nuclear power by 2050.

Total investments

Total cumulative investments needed for wind, solar and nuclear power would rise to 20,000 Billion Euros by 2050 (Figure 10.3.11). More than half of the investments will be used for solar power generation.

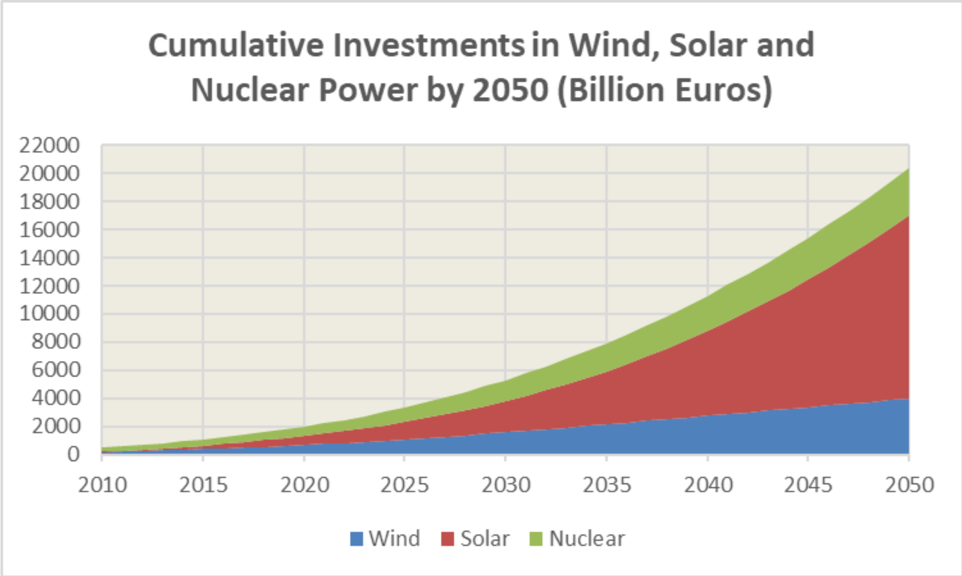


Figure 10.3.11 Cumulative investments in wind, solar and nuclear power by 2050.

11 DECARBONIZING TRAFFIC

11.1 Consumption of light distillate oil

Consumption of light distillate oil has increased from 1000 million tons in 1990 to 1630 million tons by 2018 (Figure 11.1.1). The growth has been linear with annual growth of 22.5 million tons increase annually.

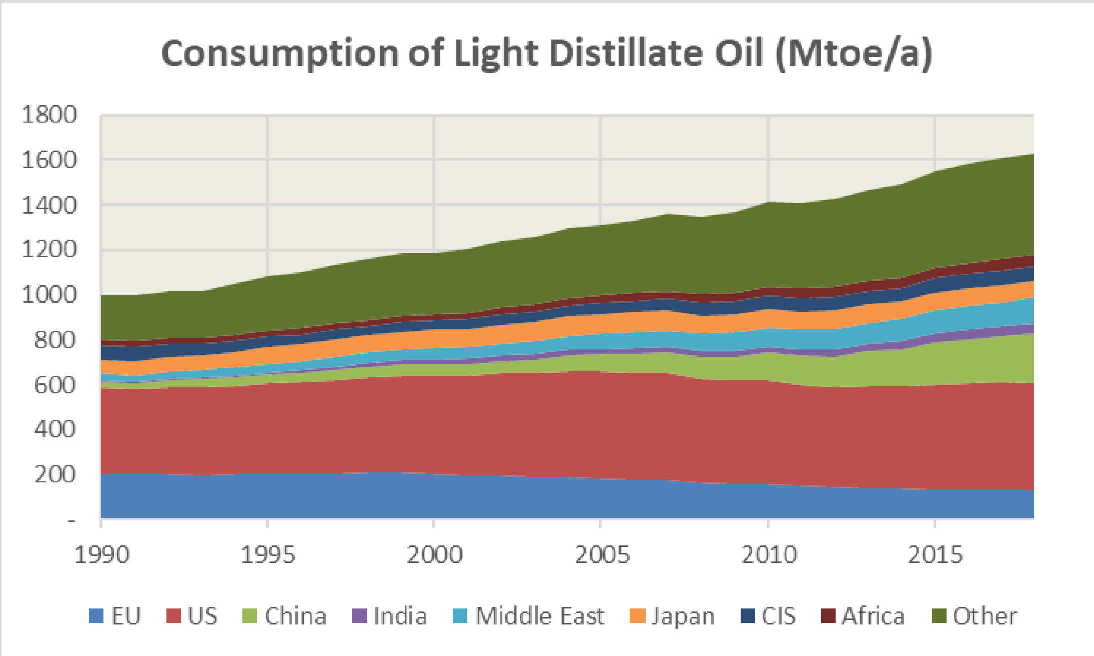


Figure 11.1.1 Consumption of light distillate oil products.

11.2 Cars on the roads

There are 1000 million cars driving on the roads, which almost all use light distillate oils. It is mostly gasoline in personal cars and middle distillate diesel in light duty vehicles. However, plug-in electric vehicles (PEV) are increasing their market share rapidly. In 2018 already 1.8 million (2.3 %) of total 79 million cars registered were PEVs (Figure 11.2.1).

The market share of PEVs in sales was the highest in Norway (49 %) followed by Iceland (19 %), Sweden (8 %), Netherlands (6.5 %) and Finland (4.7 %) (Figure 11.2.2). However, market share of PEVs was 4.5 % in China, but only 2.5 % in USA. It is also useful to know that the market shares of PEVs was only 1.9 % in Germany and 1.0 % in Japan, which have been major exporting countries.

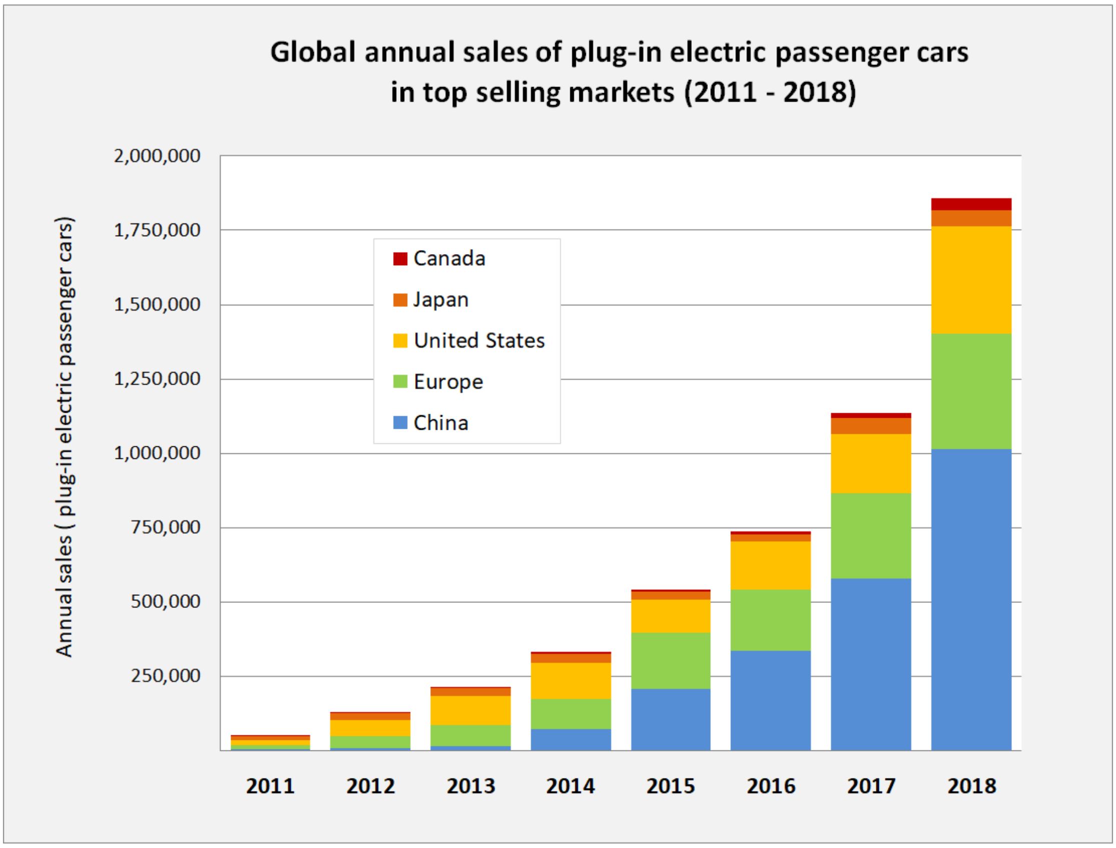


Figure 11.1.2 Market share of Plug-in cars (Source https://upload.wikimedia.org/wikipedia/commons/f/f7/Global_plug-in_car_sales_since_2011.png

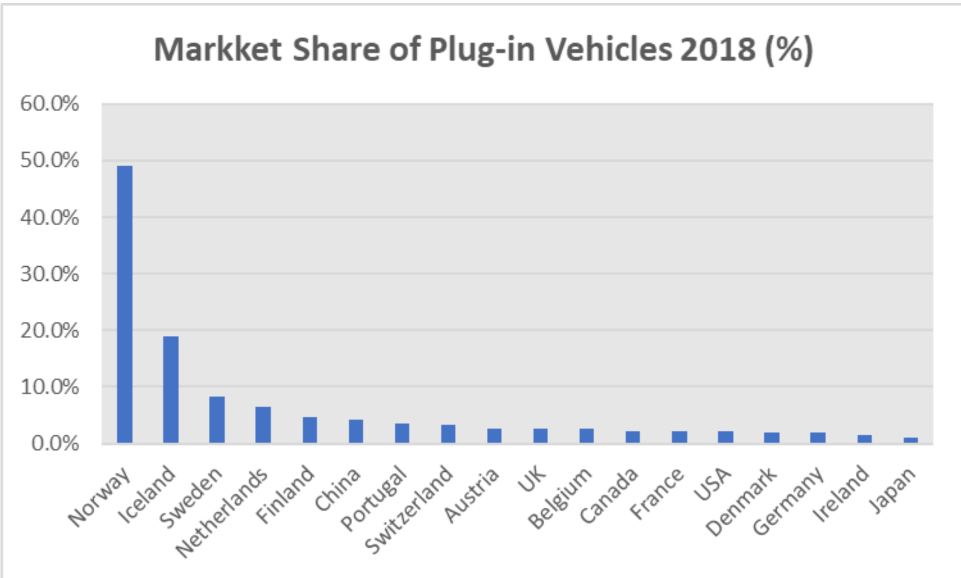


Figure 11.2.3 Market share of plug in vehicles in some countries (Source Wikipedia

https://en.wikipedia.org/wiki/Electric_car_use_by_country*).*

It is interesting to note that the PEV market has created new players from China. From 13 most sold models five are made in China (Table 12.2.1).. Eight of 13 models were battery electric Vehicles (BEV). The most sold BEV models have been Nissan, Tesla and BAIC EC. The most sold PHEVs were Mitsubishi Outlander, Chevrolet Volt and Toyota Prius PHV.

Table 12.2.1 Most sold PEV model until December 2018.

	Model	Type	BEV	PHEV	Total
1	Nissan Leaf	BEV	380,000		380,000
2	Tesla Model S	BEV	263,504		263,504
3	Mitsubishi Outlander	PHEV		186,996	186,996
4	Chevrolet Volt	PHEV		186000	186,000
5	Toyota Prius PHV	PHEV		174,586	174,586
6	BAIC EC-Series	BEV	172,844		172,844
7	Tesla Model 3	BEV	147,819		147,819
8	BYD Qin	PHEV		136,818	136,818
9	Renault Zoe	BEV	133,645		133,645
10	BMW i3	BEV	133,397		133,397
11	Tesla Model X	BEV	120,739		120,739
12	Chery eQ	BEV	119,000		119,000
13	BYD Tang	PHEV		101,518	101,518
	Total		1,470,948	785,918	2,256,866

Global sales of new motor vehicles are growing to 300 million by 2050 (Figure 11.2.4). After the year 2045 all vehicles will be plug-in electric vehicles. About 60 % of vehicles on the roads will be PEVs by 2050 (Figure 11.2.5).

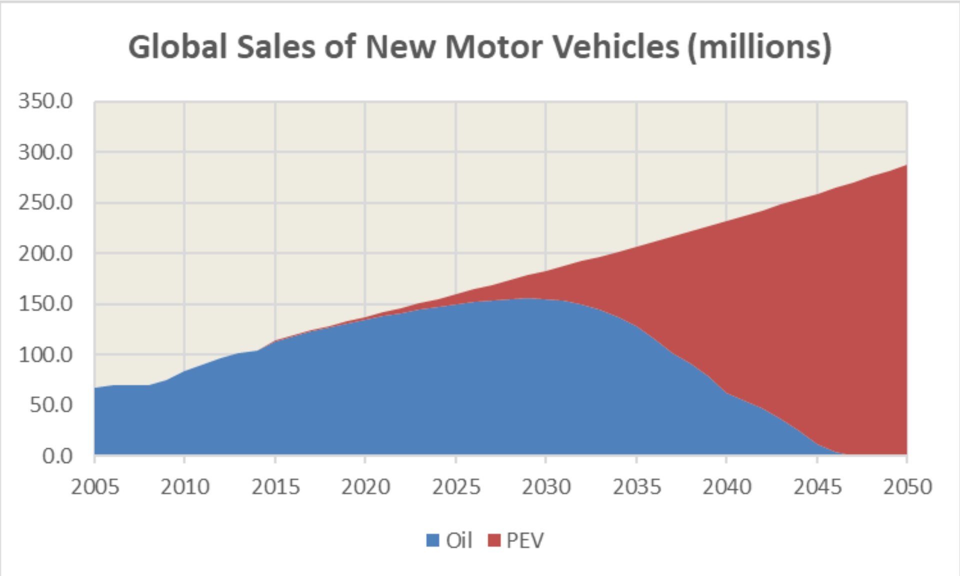


Figure 11.2.4 Market share of new cars.

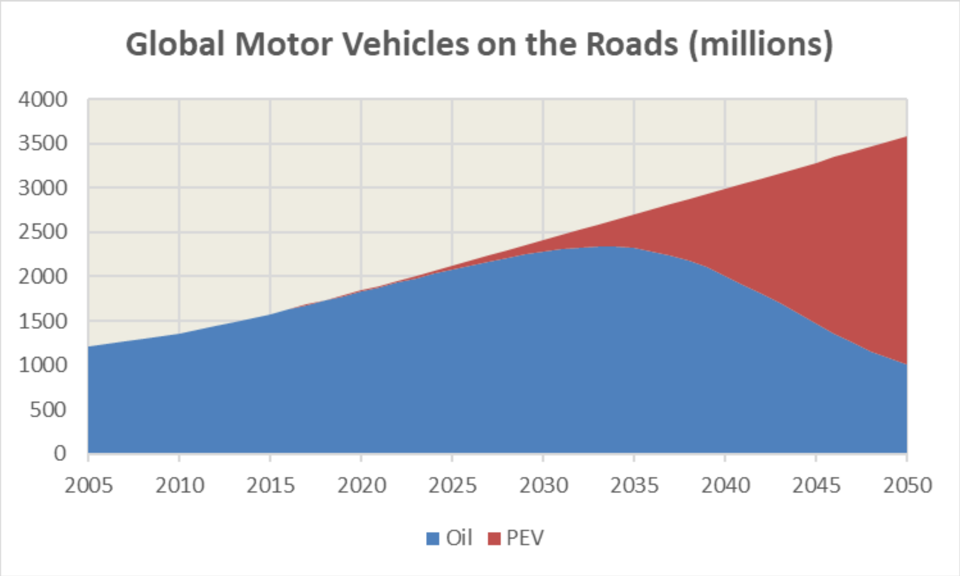


Figure 11.2.5 Type of cars on the roads.

Consumption of oil will start to decrease after 2030 and use of oil will drop to 3000 Mtoe by 2050 (Figure 11.2.6). Middle distillates are mainly used by commercial vehicles and in heating of houses. Commercial vehicles will be also converted to electricity, but also fuel cells can be used, after hydrogen production of will be produced by the excess electricity of solar and wind power eventually.

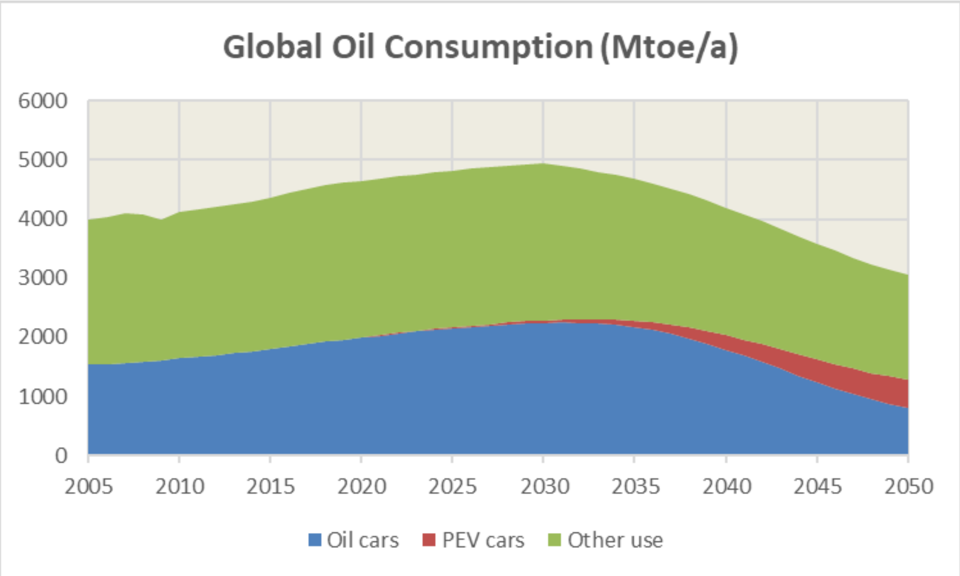


Figure 11.2.6 Consumption of oil (Mtoe).

The CO_2 emissions from oil are continuing to increase from 13 Gt in 2018 to about 15 Gt by 2030 (Figure 11.2.7). Then finally the emissions will be about 9,5 Gt by 2050.

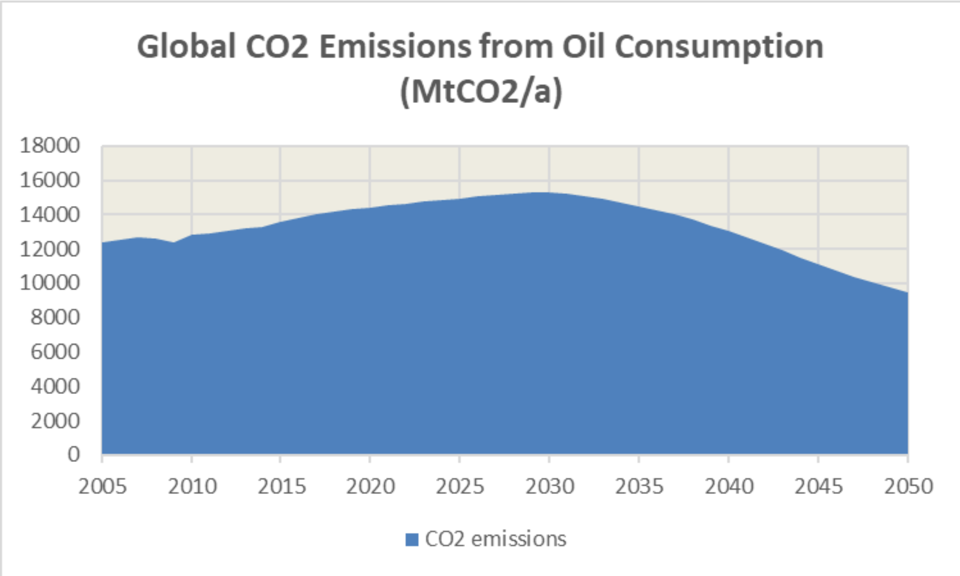
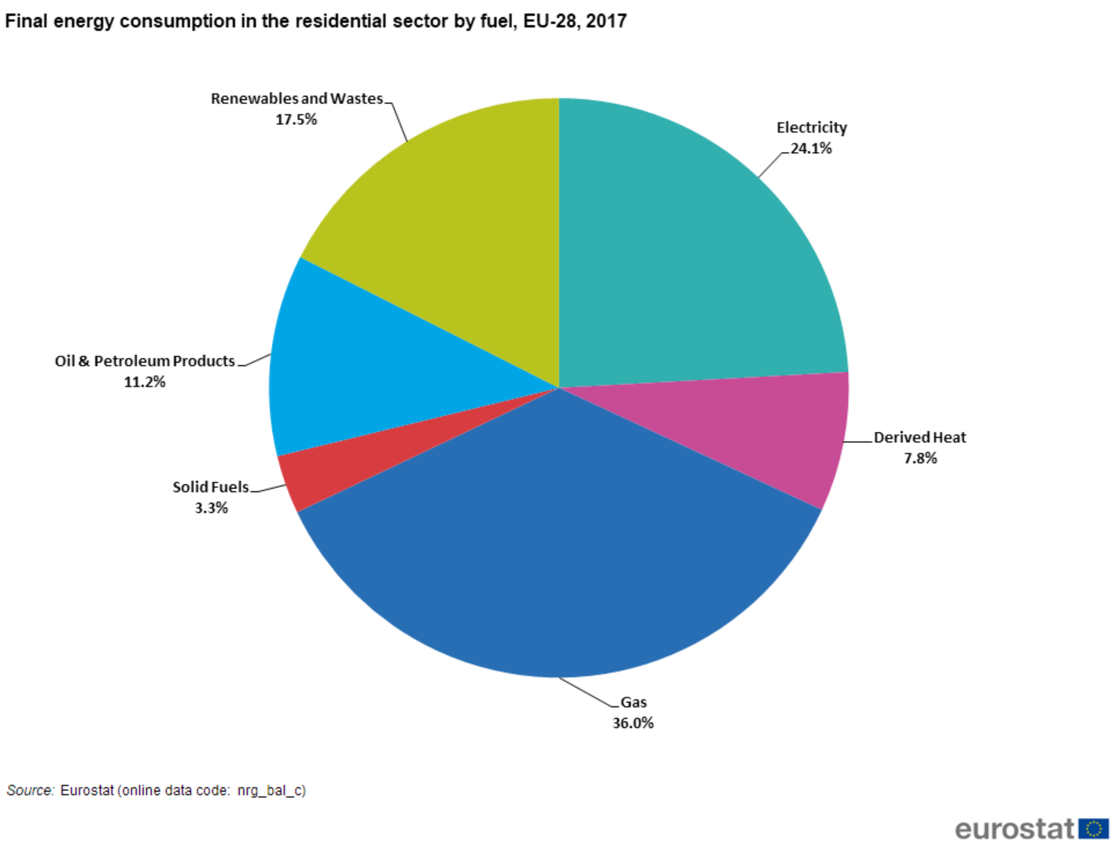


Figure 11.2.7 CO_2 emissions from oil consumption.

12 DECARBONIZING HOUSEHOLDS

12.1 Energy used by households

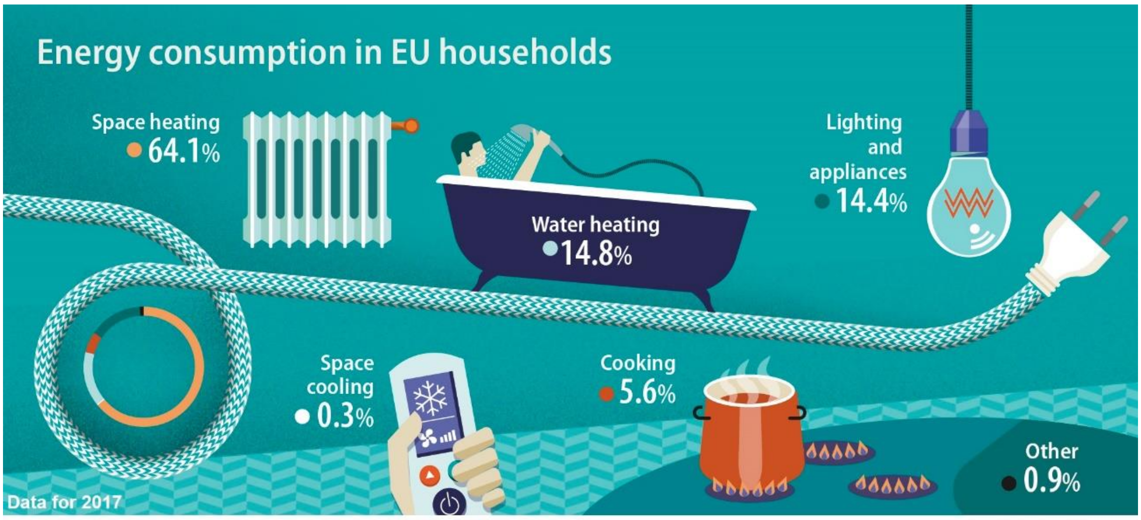
Energy consumption of households in EU accounts about 27 % of final energy in 2017. The largest source of energy in households was natural gas (36 %), electricity (24 %) and renewable and waste energy (17 %) (Figure 12.1.1).



Final 12.1.1 Sources of final energy consumption in households in 2017 (Source Eurostat).

Fossil fuels gas (36 %) and petroleum products (11 %) accounted 47 % of the final energy. Also, electricity and derived fuels include CO_2-emissions. Average CO_2 content of electricity in EU is about 290 g/kWh in 2018. However, it is decreasing near zero by 2050.

Largest users of household energy were space heating (64 %) and water heating (15 %), which accounted about 79 % of energy consumption (Figure 12.1.2). Heating was mainly covered by natural gas and this a reason, why gas was the largest source of household energy.



ec.europa.eu/eurostat

Figure 12.1.2 Energy consumption in EU households in 2017 (Source Eurostat).

Share of fuels in the final energy consumption in the residential sector, 2017
(%)

	Electricity	Derived Heat	Gas	Solid fuels	Oil & petroleum products	Renewables and Wastes
EU-28	**24.1**	**7.8**	**36.0**	**3.3**	**11.2**	**17.5**
Belgium	19.2	0.0	40.8	1.0	31.0	8.0
Bulgaria	41.3	14.7	2.9	6.8	1.1	33.2
Czechia	18.2	14.8	27.9	11.7	0.6	26.8
Denmark	18.7	36.8	13.0	0.0	4.7	26.8
Germany	19.5	7.8	38.2	0.9	20.1	13.5
Estonia	17.7	33.8	5.9	0.2	1.0	41.4
Ireland	26.5	0.0	21.5	12.4	38.1	1.5
Greece	38.2	1.2	8.2	0.1	28.2	24.1
Spain	39.0	0.0	24.3	0.5	17.3	18.9
France	33.7	3.3	27.9	0.1	13.1	21.9
Croatia	22.7	4.9	20.2	0.2	5.8	46.3
Italy	17.1	2.8	52.5	0.0	6.3	21.3
Cyprus	42.5	0.0	0.0	0.0	36.3	21.2
Latvia	11.9	31.1	9.3	0.8	4.6	42.2
Lithuania	16.8	32.6	10.6	3.9	3.8	32.3
Luxembourg	15.3	0.0	45.5	0.1	32.8	6.3
Hungary	15.4	7.9	47.2	2.2	1.2	26.1
Malta	70.0	0.0	0.0	0.0	17.4	12.6
Netherlands	20.0	2.9	71.0	0.0	0.4	5.6
Austria	22.5	11.8	22.0	0.3	15.8	27.6
Poland	12.6	19.6	18.2	32.9	3.0	13.7
Portugal	42.1	0.0	9.7	0.0	16.4	31.8
Romania	14.1	10.5	31.5	0.4	3.7	39.8
Slovenia	25.5	7.1	10.6	0.0	12.0	44.8
Slovakia	20.0	21.4	54.5	1.6	0.4	1.9
Finland	33.6	28.8	0.5	0.1	6.2	30.9
Sweden	51.7	34.8	0.5	0.0	0.3	12.7
United Kingdom	24.4	0.7	62.0	1.4	6.3	5.1
Iceland	16.7	79.6	0.0	0.0	0.9	2.8
Norway	83.3	2.7	0.2	0.0	1.6	12.2
Montenegro	42.0	0.0	0.0	0.9	0.5	56.7
North Macedonia	50.3	6.6	0.0	0.3	2.3	40.5
Albania	51.2	0.0	0.0	0.0	21.8	27.0
Serbia	41.6	13.8	6.7	8.0	1.7	28.2
Turkey	21.1	0.0	50.2	8.9	1.1	18.8
Bosnia and Herzegovina	39.1	9.1	3.6	10.0	4.3	33.9
Kosovo *	34.5	1.7	0.0	1.8	1.9	60.2
Moldova	10.7	8.8	17.2	4.0	4.4	54.9
Ukraine	18.3	16.1	53.7	1.3	0.3	10.2
Georgia	15.9	0.0	55.5	0.0	1.1	27.4

*This designation is without prejudice to positions on status, and is in line with UNSCR 1244 and the ICJ Opinion on the Kosovo declaration of independence.

Source: Eurostat (online data code: nrg_bal_c)

eurostat

Final energy Consumption of US households has been about 250 Mtoe annually (Figure 12.1.3). About 44 % this has been electricity and 43 % naturals gas. Fossil fuels natural gas (43 %) and oil (8 %) are together more than half of total, but their share has been decreasing constantly.

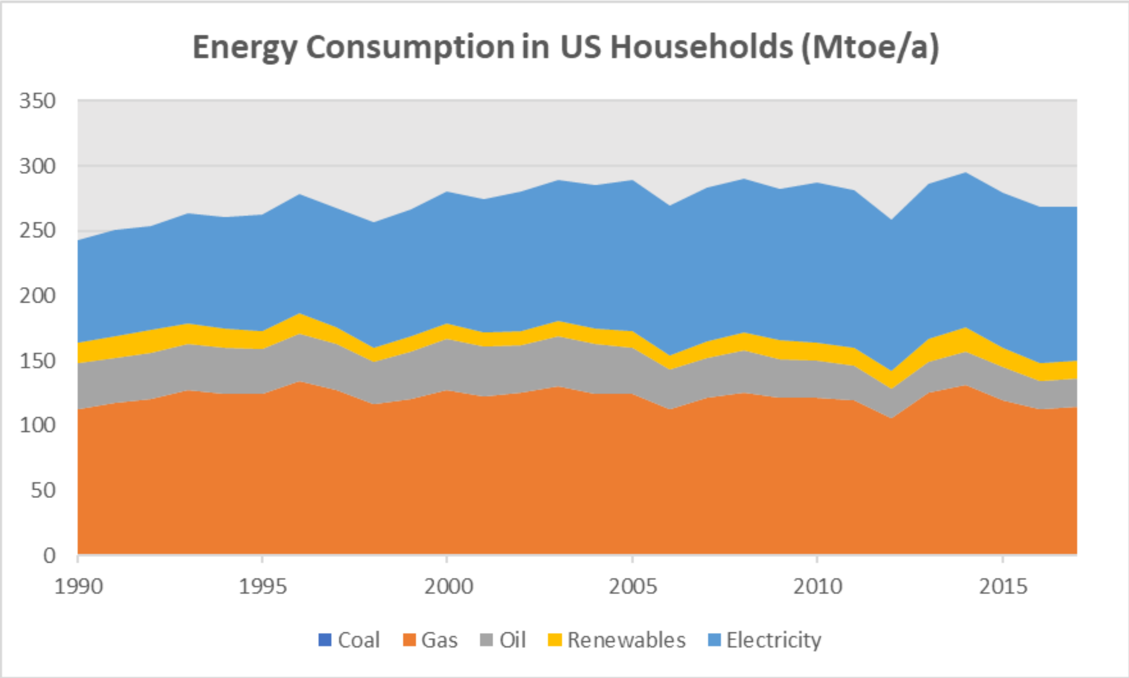


Figure 12.1.3 Energy consumption of US households (Source EIA).

12.2 Zero emission log houses

Heating of spaces and hot water has been the major consumer in households. This can be converted to heat pumps. When a typical 120 sq. meters (1330 sq. feet) will need about 15,000 kWh of heat for space and hot water heating, with a heat pump only 5000 kWh of electricity will be needed to supply this heat. A house will need 15,000 kWh of heat and 10,000 kWh of this will come from ground.

With a heat pump the total electricity consumption of a single-family house will be about 6000 – 10,000 kWh. With CO_2-contents of 100 g/kWh of electricity in the future the emissions will be 0,6 – 1,0 tCO2/house. It will be also possible to make a major part of houses CO_2 free by installing solar panels on the roofs and make the house CO_2 free.

House can be a carbon storage, if it will be built by wood. Modern log houses are made with 270 mm (11 inch) logs. The area of walls is 193 square meters (2200 sq. feet) and the volume of wood in 70 cubic meters. Total volume of wood in the house 85 cubic meters and the wood contains 67 tons of carbon dioxide (Table 12.2.1).

Because the CO_2 content in the electricity will decrease about 2 % annually, the specific emissions will be about 50 g/kWh in 2030, 20 g/kWh in 2040 and 9 g/kWh in 2050 (Figure 12.2.2). After 2070 emissions will be practically zero.

Figure 12.2.1 Log house walls are 100 % wood (Source: Honkarakenne).

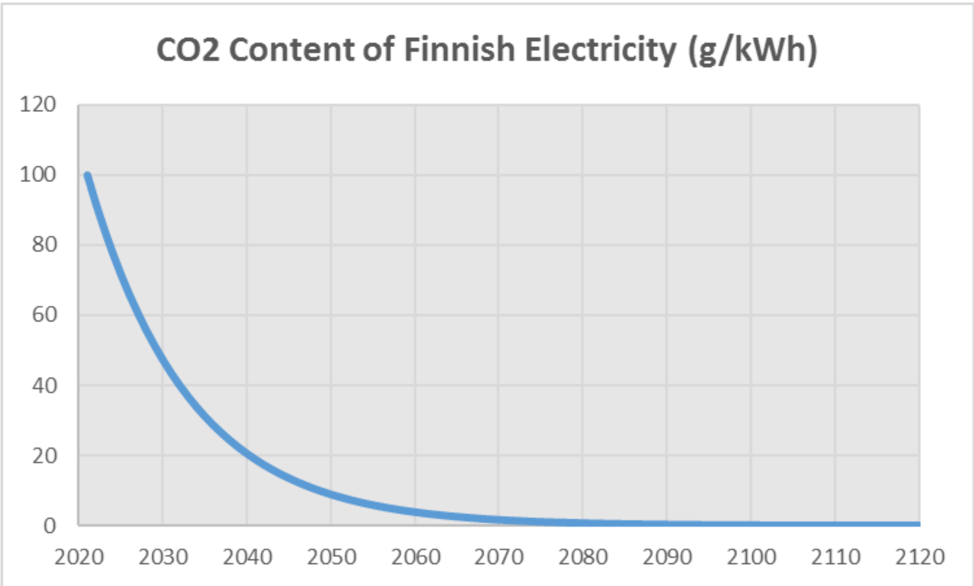


Figure 12.2.2 CO_2 Content of electricity decreases 2 % annually and from 100 g/kWh to zero by 2070.

Table 12.2.1 Carbon dioxide balance during building phase of log houses (Source: Hirsitalotoimialan ekokilpailukyky tarkastelu - hirsitalomallin puumateriaalien elinkaariarviointi käsittäen hiilijalanjäljen, energiataseen ja päästöt Katri Behm, Tarja Häkkinen).

Log houses	Floors	1	1	2	2
	Logs (mm)	180	270	180	270
Wood content					
Area of walls	m2	90	90	193	193
Volume of walls	m3	38	48	51	70
Other wood	m3	8	8	13	15
Total wood	m3	46	56	64	85
CO2-emissions	tons	3	4	5	6
CO2-storage	tons	-38	-46	-52	-67
Net CO2 emissions	tons	-35	-42	-47	-61

If the house will need 15.000 kWh of heat and the heat will be produced with a heat pump, the electricity consumption will be about 5000 kWh annually. Household electricity consumption is also 5000 kWh/year and the total electricity consumption will be 10000 kWh annually. With the present average CO_2 content of electricity (100 g/kWh) in Finland, the house will emit about 1.0 ton of CO_2 annually (Table 12.2.2).

Table 12.2.2 CO_2 emissions during living in a log house during the first year

Log houses	Floors	1	1	2	2
	Logs (mm)	180	270	180	270
Heat consumption	MWh	12	10	18	15
Electricity consumption					
Household	MWh	4	4	5	5
Heat pump	MWh	4	3	6	5
Total	MWh	8	7	11	10
CO2 emissions					
CO2 content	kg/MWh	100	100	100	100
CO2 emissions	tons/year	0.80	0.73	1.10	1.00

Cumulative lifetime CO_2 emissions of the log houses will be zero or even negative, if the houses will be built wilt 270 mm logs and heated with a heat pump (Figure 12.2.3). The best result will be achieved with two floor houses and 270 mm logs. Then the lifetime net emissions of log house are -17 tons of CO_2. This can be utilized for traffic or food.

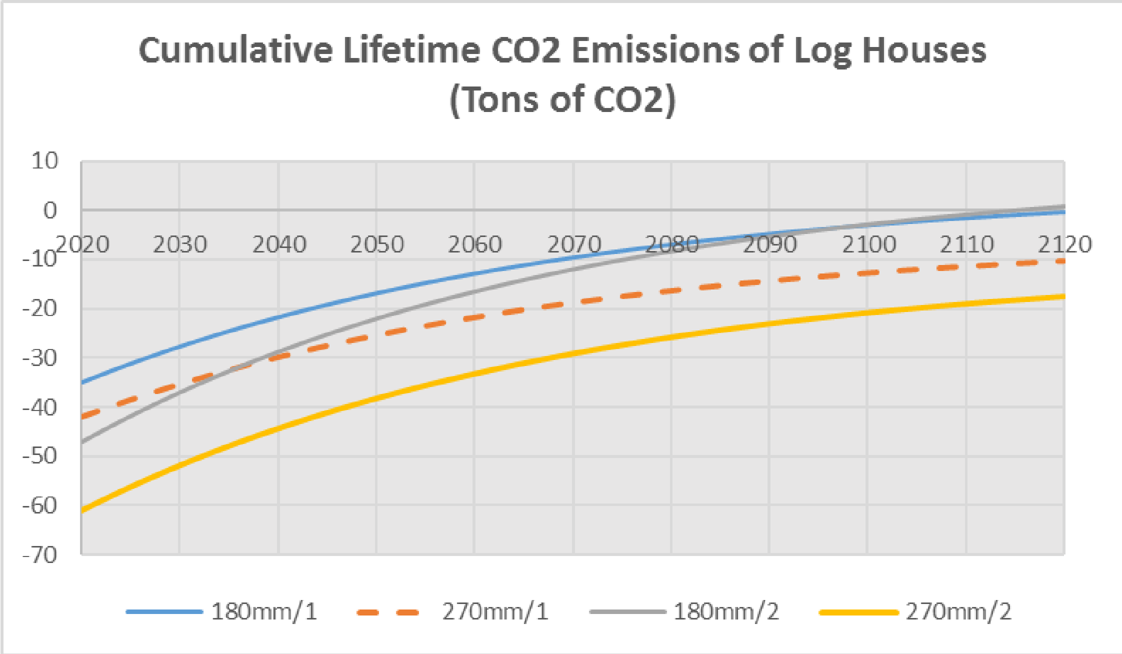


Figure 12.2.3 Cumulative lifetime CO_2 emissions of heat pump heated log houses in Finland depending of log size (180 or 270 mm) and number of floors (1 or 2).

13 INCREASING CARBON SINKS

13.1 Forests

Area of forests has been declining constantly since 1990 and is about 4 000 million hectares in 2015 (Figure 13.1.1). However, there are many countries which have increased their forest area (Figure 13.1.2). They have increased the forest area in average about 4 million hectares annually. But the countries, which have decreased their forest losses about 6 million hectares annually are causing that the net losses are 2 million hectares per years.

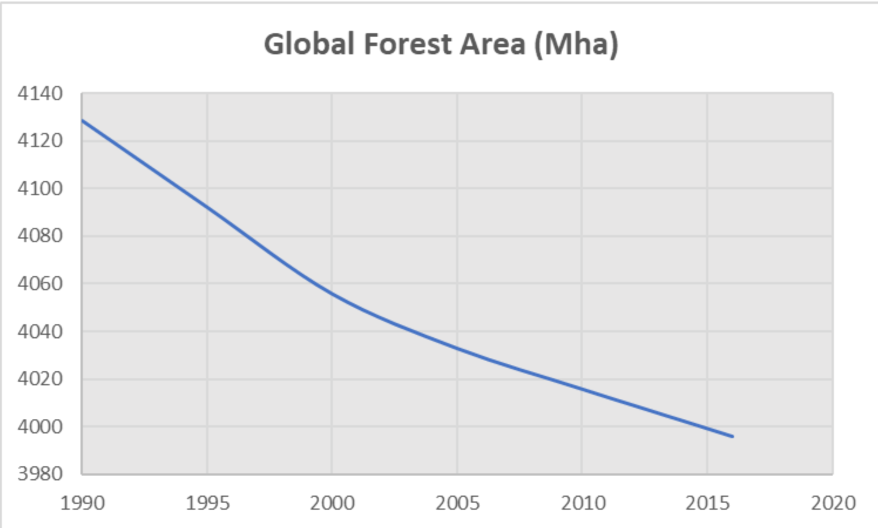


Figure 13.1.1 Global forest area (Mha).

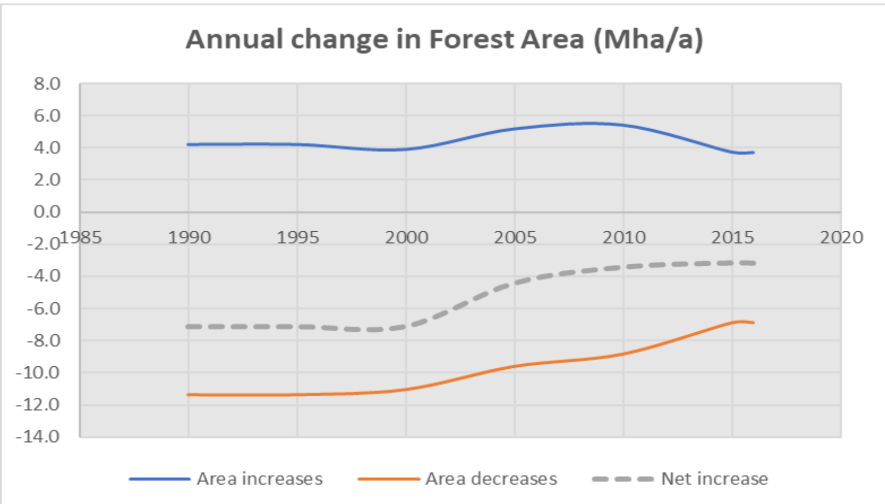


Figure 13.1.2 Annual changes in forest area.

World forests are absorbing CO_2 during their entire lifetime. The mass of CO_2 stored in the living forests is today about 1080 Gt (Figure 13.1.2). It can be compared to CO_2 in the atmosphere, which mass is about 3200 Gt at 410 ppm concentration (Figure 4.5.1).

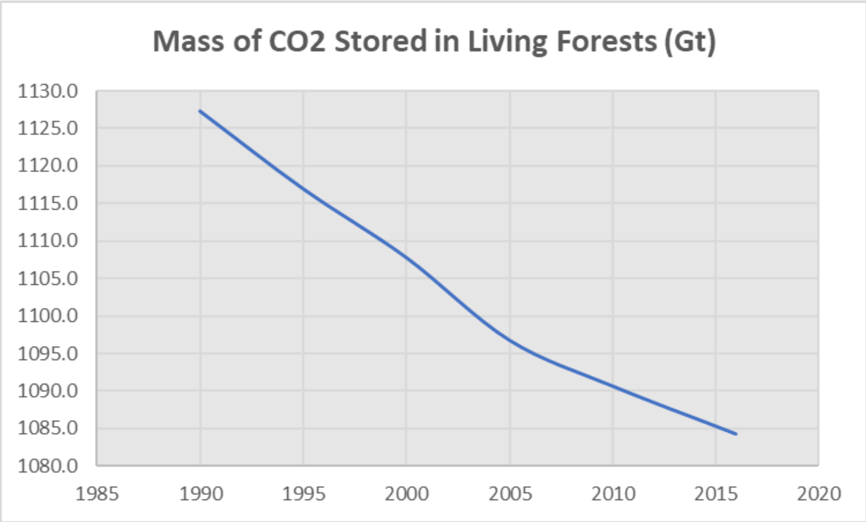


Figure 13.1.2 Mass of CO_2 stored in living forests.

Because of the mass of carbon in the forests has been declining, forest have been action as emitters of CO_2. The net emissions have been bout 1 $GtCO_2$ annually (Figure 13.1.2).

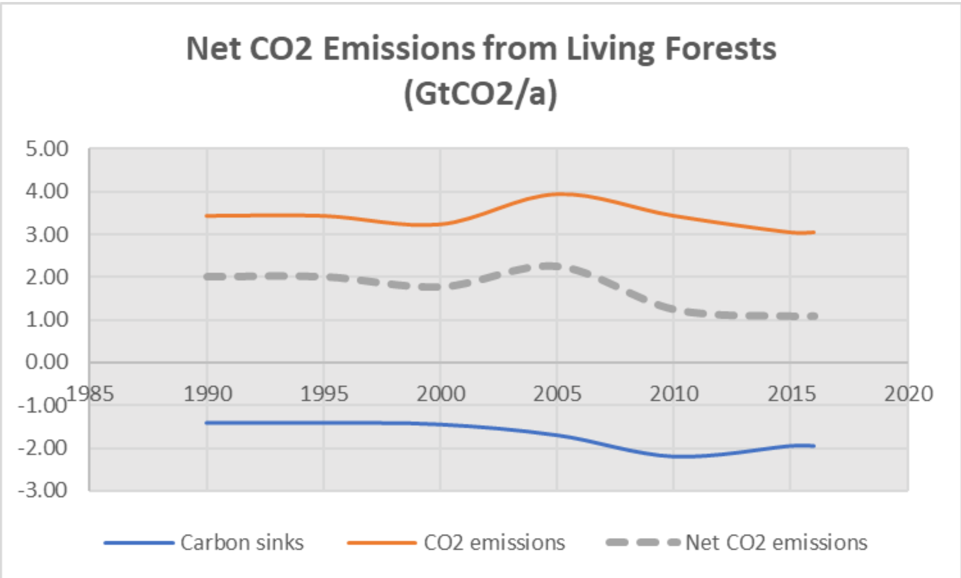


Figure 13.1.2 CO_2 emissions of living forests.

Carbon sink has been increasing from 1.5 Gt/a to near 2.0 Gt/a in 2016. Carbon sink has been in average about 1.75 $GtCO_2$ during years 1990 – 2017 (Table 13.1.1). USA and China have had the largest carb sinks.

Table 13.1.1 60 countries which have carbon sinks.

CO2 storage in living forests during years 1990-2016				
	Countries	**Mt/a**	**Countries**	**Mt/a**
1	United States of America	413.9	31 Austria	8.1
2	China	338.9	32 Croatia	7.2
3	Russian Federation	74.7	33 Philippines	7.1
4	Japan	68.9	34 Slovenia	6.3
5	France	59.6	35 Slovakia	6.1
6	India	55.5	36 Morocco	5.4
7	Poland	51.6	37 Uzbekistan	5.0
8	Germany	46.8	38 Lithuania	4.0
9	Spain	41.4	39 Hungary	3.9
10	Republic of Korea	40.0	40 Bhutan	3.9
11	Turkey	39.5	41 Azerbaijan	3.8
12	Romania	39.3	42 Ireland	3.7
13	Viet Nam	35.9	43 CÃ´te d'Ivoire	3.5
14	Italy	35.3	44 Costa Rica	3.3
15	Chile	32.1	45 Switzerland	2.3
16	Belarus	30.9	46 Bangladesh	2.3
17	Ukraine	29.3	47 Estonia	2.2
18	Sweden	23.5	48 Greece	2.2
19	Gabon	21.8	49 Belgium	2.2
20	Norway	21.2	50 Malaysia	2.1
21	Finland	20.8	51 French Polynesia	1.9
22	New Zealand	20.7	52 Netherlands	1.8
23	Uruguay	18.8	53 Fiji	1.7
24	Cuba	15.7	54 Puerto Rico	1.6
25	United Kingdom	15.3	55 Syrian Arab Republic	1.6
26	Bulgaria	12.6	56 Bosnia and Herzegovi	1.6
27	Australia	12.4	57 Iraq	1.4
28	Latvia	11.2	58 Rwanda	1.2
29	Serbia	10.4	59 Denmark	1.1
30	Dominican Republic	9.2	60 Algeria	1.0
	Total	**1647.0**		**99.3**

13.2 Production of saw wood

Carbon can be also stored in houses which have been built using wood or logs as was presented in chapter 12.2. Production of saw wood has been about 450 million cubic meters annually (Figure 13.2.1).

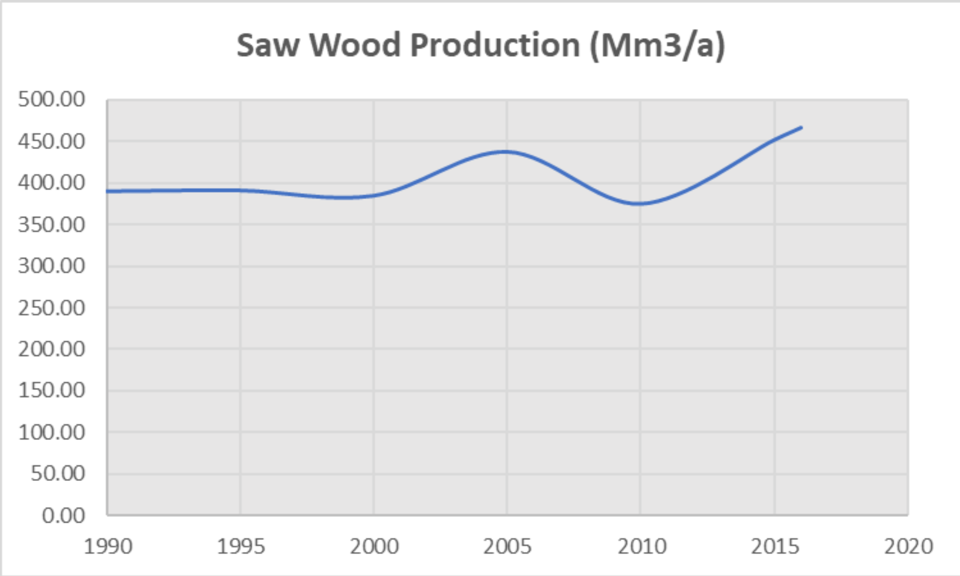


Figure 13.2.1 Production of saw wood (Mm3 annually.

Top five producers USA, China, Canada, Russia and Germany are producing more than half (250 Mm3) of all saw products (Figure 13.2.2). It should be noted that China has increased its production considerably after the year 2005 and this has increased the global production.

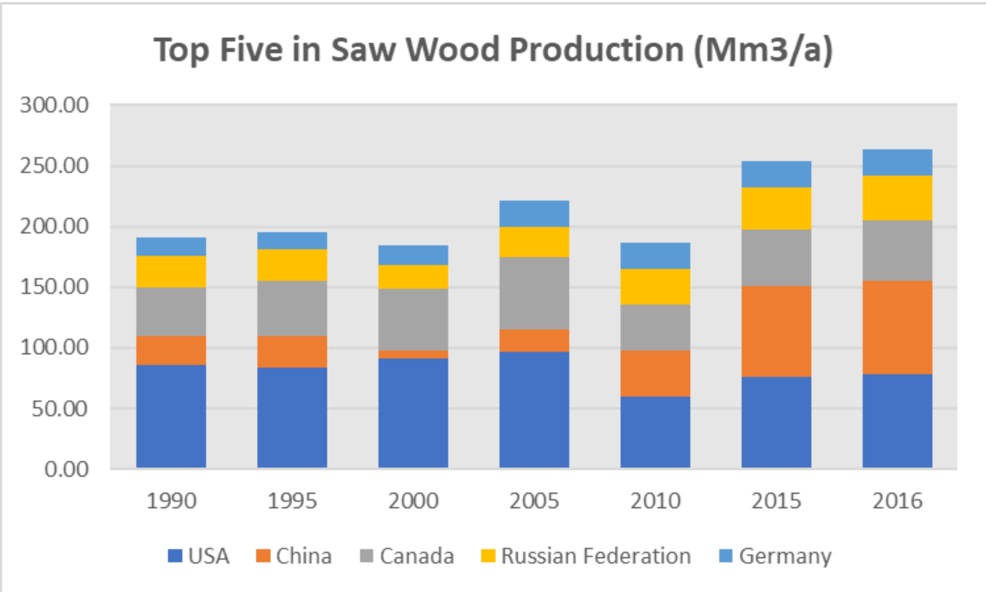


Figure 13.2.2 Top five producers of saw wood.

The saw wood is acting as a carbon sink soring about 0.8 tons of CO_2 per cubic meter of saw wood. This means the total carbon sink of saw wood is about 375 million tons of CO_2.

13.3 Growing wood for energy and carbon sink

Wood can be used for fueling heat boilers and electricity generation. The cost on wood as a fuel has been about 20 €/MWh in Finland, where about 27 % of energy is produced from wood. The import price of coal has been about 10 €/MWh, but after adding the costs for CO_2-allowances 25 €/tCO2 (0.34 x 25= 9 €/MWh) the price of coal would be about the same.

However, there are several countries in which the trees grow much faster than in Finland. In Finland wood is growing 107 million m^3 annually and there are about 22.8 million hectares of forest, thus the forests are growing in average 4.7 m^3/ha. This corresponds about 10 MWh/ha.

Finnish company UPM has started to cultivate eucalyptus forests in Uruguay for their new three billion-dollar pulp plant. In Uruguay the trees grow about five times faster than in Finland. This would mean that the yield will be about 25 m^3/ha or about 50 MWh/ha. The costs of wood energy would be then only about 5 €/MWh, which is about half of the import price of coal. This in so low that electricity can be generated from wood at the fuel costs of 15 €/MWh. There are several countries, which can start to cultivate eucalyptus trees for energy. This would be a huge potential but needs companies like UPM to start the progress.

Carbon sinks

Another opportunity will be to start to cultivate forests just for carbon sinks. If the trees are growing 25 m^3/ha, they could store about 25 t/ha carbon dioxide. If the price of forest is 1000 €/ha, then the costs of wood will be about 10 % x 1000 €/ha / 25 m^3/ha = 4 €/m3. The one cubic meter of wood can store about one ton of CO_2. Thus, the costs of cultivating wood for CO_2 sink is only at price of 4 euros/tCO_2. This is much less than the price of CO_2 allowances in Europe (25 €/t).

Probably better way is to build the pulp factories in those countries, in which fast growing trees can be used as a material for pulp and change those countries, which use pines and spruces to produce log houses. Log house industry is growing in Finland about 10 % annually and 25 % of single-family houses were made from logs in 2018.

Now, also multifamily houses are made from wood. A typical multifamily house is built in a factory with modules, where on apartment is a single module. The modules are then assembled on the site quickly. Typical seven floor apartment house is built within a years as concrete houses needs two years. Construction of the first five floor wooden apartment house (Figure 13.3.1) in city of Espoo was started in January 2019 and the house will be ready in January 2019, just 13 months after signing of the construction contract.

14 SCENARIOS FOR COUNTRIES

14.1 Targets for EU

EU has been very active in setting targets for energy saving and CO_2 emissions. The target has been to reduces CO_2 emissions 20 % from 1990 to 2020. This goal will be achieved.

The next target will be to limit CO_2 emissions 40 % from 1990 level by the year 2030. The it has been discussed but not agreed yet that EU wants to be carbon neutral by 2050. In the evaluations in this is possible, if the emission will be about 1.8 tons per capita. EU has possible 500 milljon inhabitants, in which case the emissions should be less than 900 MtCO2 by the year 2050. The emissions form fossil fuels were 3440 MtCO2 in 2018, which will mean that the reductions should be 74 % or about 4 % annually.

Electricity

EU will become free from CO_2 emissions in electricity generation by 2050. One possible scenario can be realized by adding more wind and solar power which will replace fossil fuels (Figure 10.1.4). Peak of fossil electricity generation has been achieved already in the year 2008. In 2050 about 39 % of electricity will be generated by wind, 20 % by solar, 14 % by nuclear and 13 % by hydro power plants.

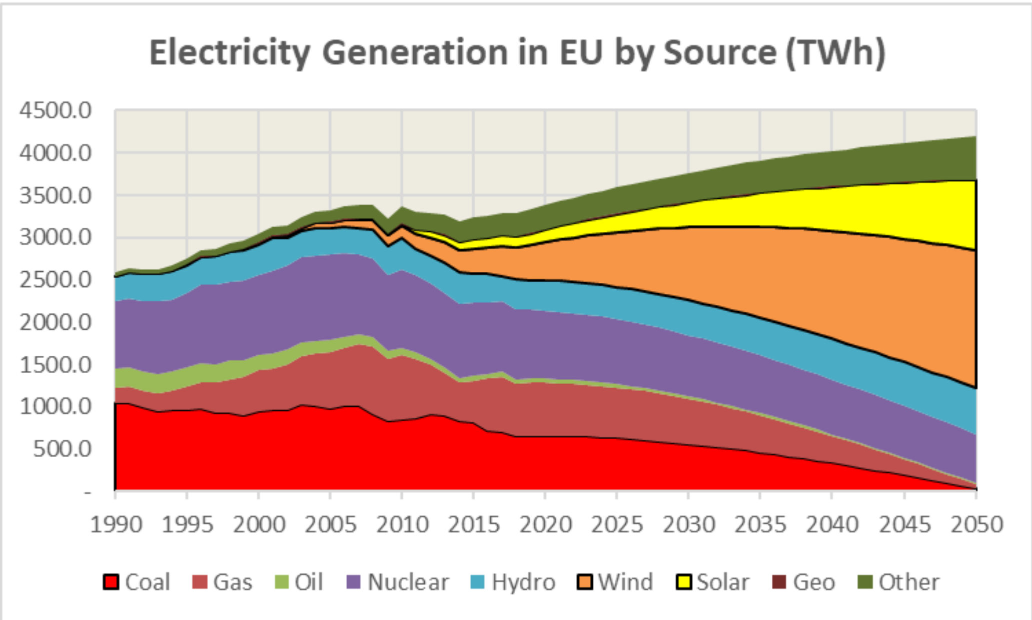


Figure 14.1.1 Electricity generation in EU by 2050.

The emissions from electricity generation could drop from 950 $MtCO_2$ to about 70 $MtCO_2$ or with 93 % from 2018 level (Figure 14.1.2). Specific emissions from electricity will drop from 280 g/kWh in 2018 to zero by 2050 (Figure 14.1.3).

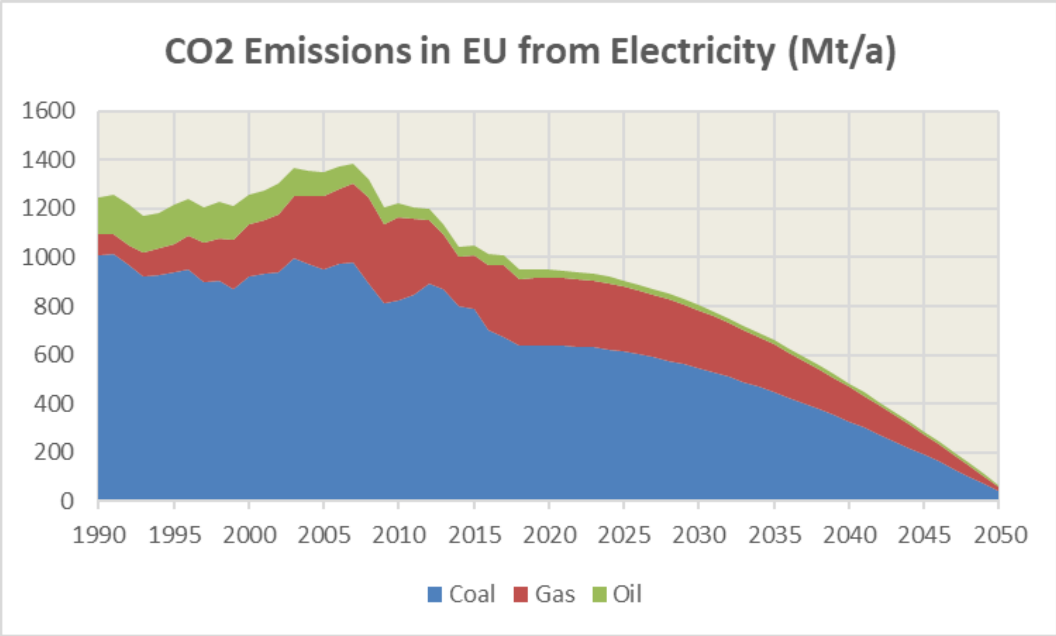


Figure 14.1.2 CO_2 emissions from electricity generation in EU.

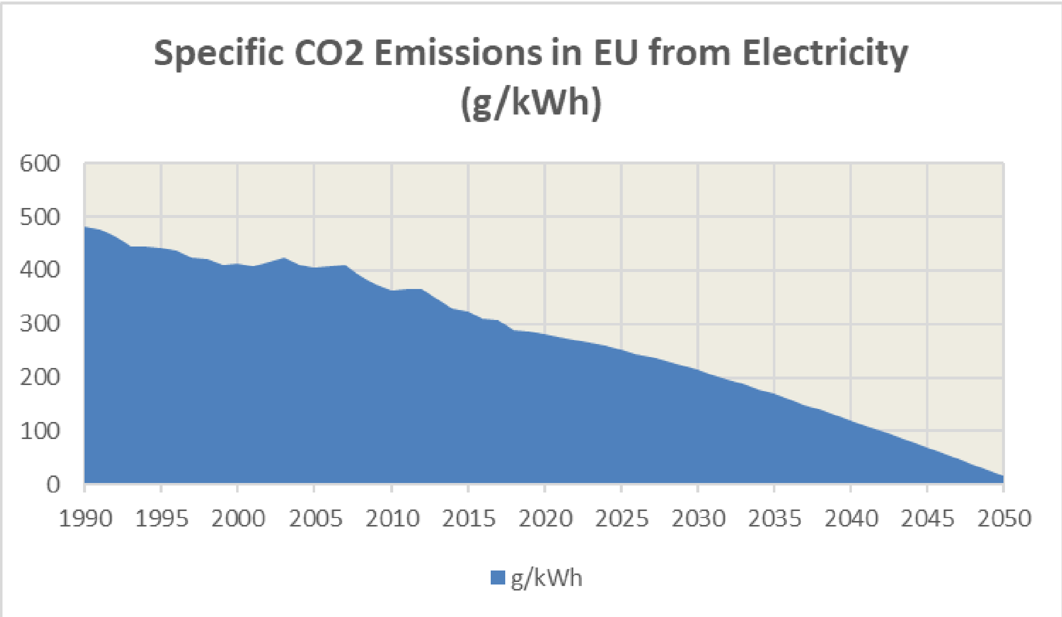


Figure 14.1.3 Specific CO_2 emissions from electricity in EU.

Oil

Market share of new cars in EU is developing so the by 2040 all new cars will be plug-in Electric Vehicles (PEV) (Figure 14.1.4)

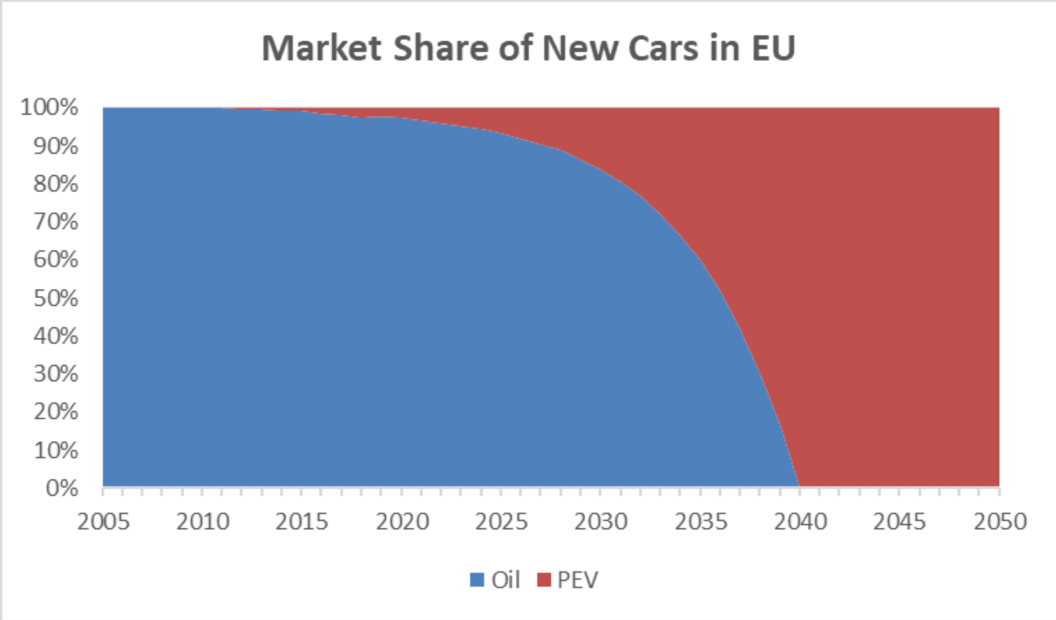


Figure 14.1.4 Market share of new cars in EU.

Cars in the roads will be changing in EU from oil so that 90 % will be PEVs by 2050 (Figure 14.1.5). Consumption of oil in EU will be reduced from 600 Mtoe in 2018 to 200 Mtoe in 2050 (Figure 14.1.6).

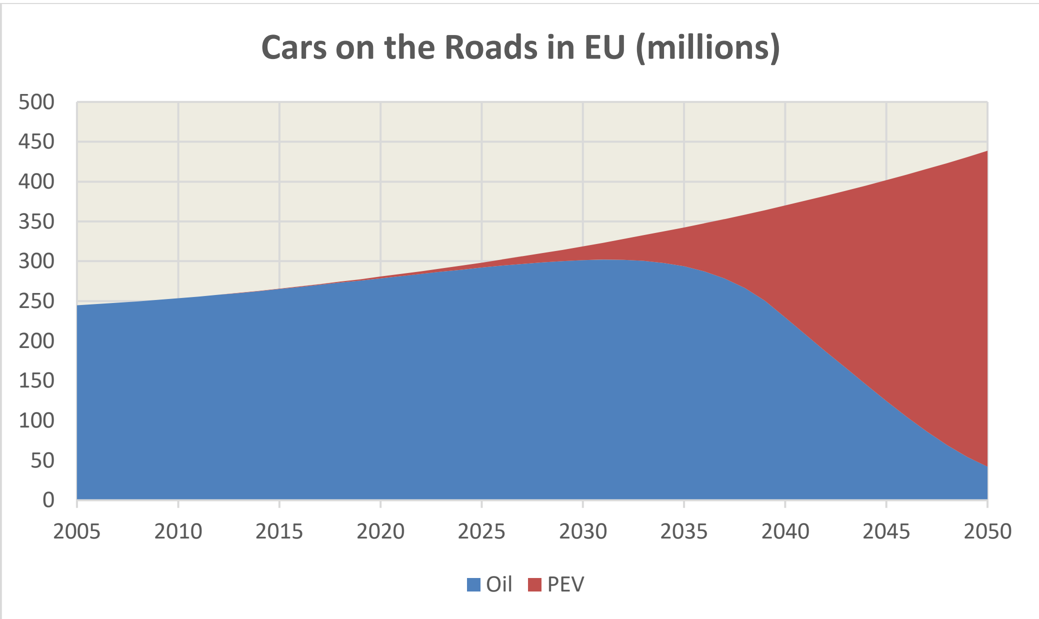


Figure 14.1.5 Cars on the roads in EU.

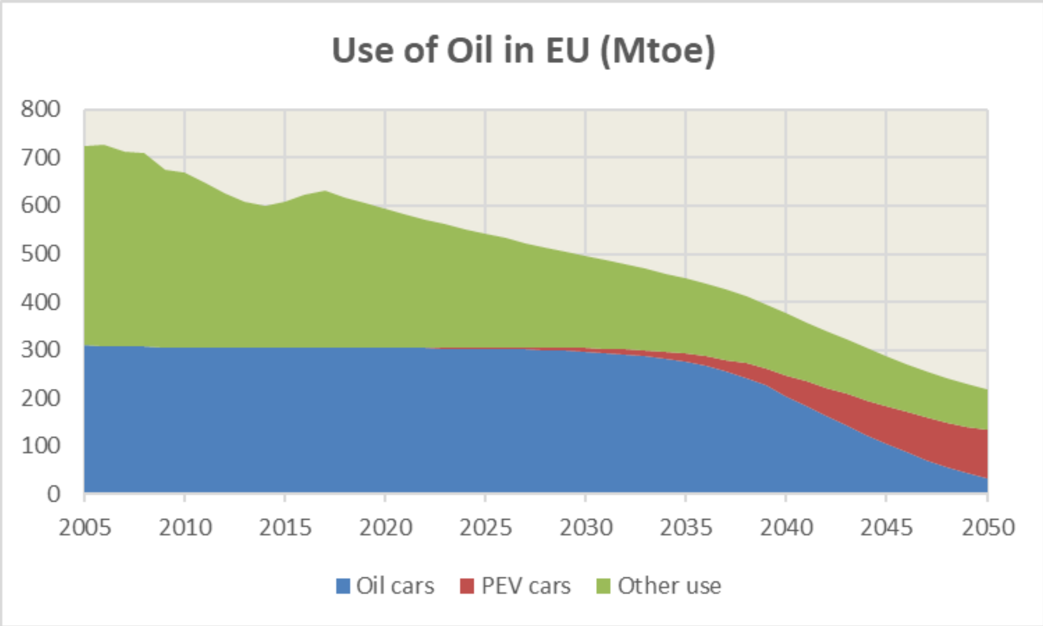


Figure 14.1.6 Oil consumption in EU.

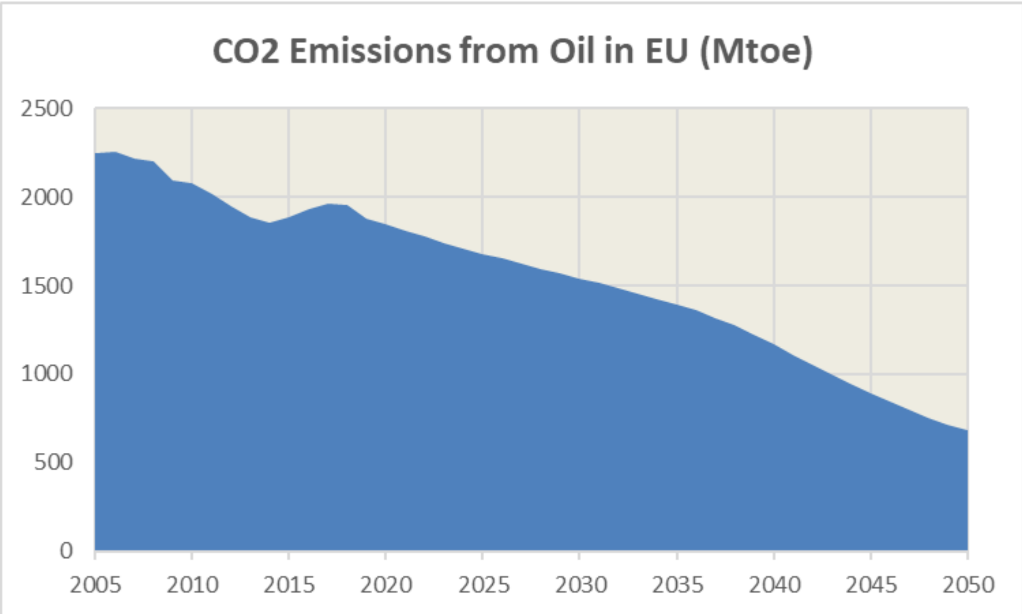


Figure 14.1.7 CO2 emissions from oi in EU.

The CO_2 emissions in EU will drop from 3400 $MtCO_2$ to about 850 $MtCO_2$ per year (Figure 14.1.8). This will be about 1.7 tCO_2/capita for 500 million inhabitants. Oil had 55 % of emissions in EU in 2018 but about 75 % by 2050.

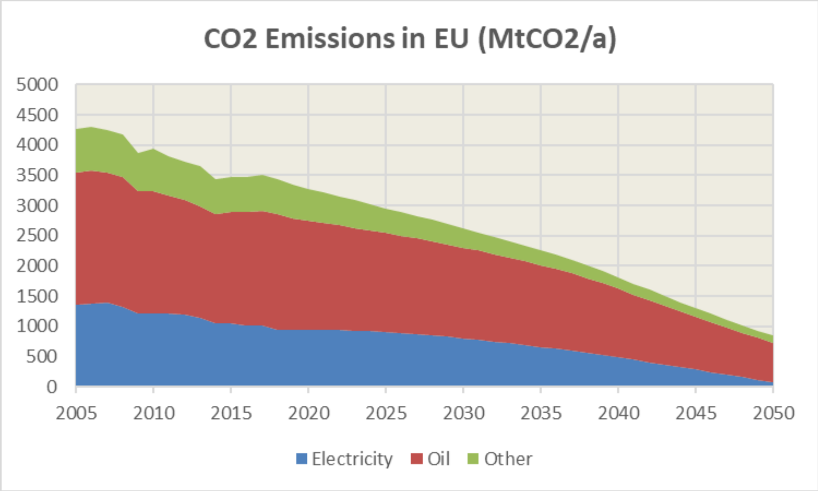


Figure 14.1.8 CO_2 emissions from fuels in EU.

14.2 Targets for USA

USA is a country with 16 t/capita CO_2 emissions and needs to reduce them from 5080 t to 540 Mt (1.8 t/capita) or with 90 %) by 2050. This could be realized, if electricity generation and cars will be converted to CO_2 free sources.

Electricity in USA

USA can follow EU and can reach coal neutrality in electricity generation by 2050 (Figure 14.2.1). The peak in fossil electricity generation was achieved in the year 2008. Solar and wind electricity will have a major contribution in US future electricity.

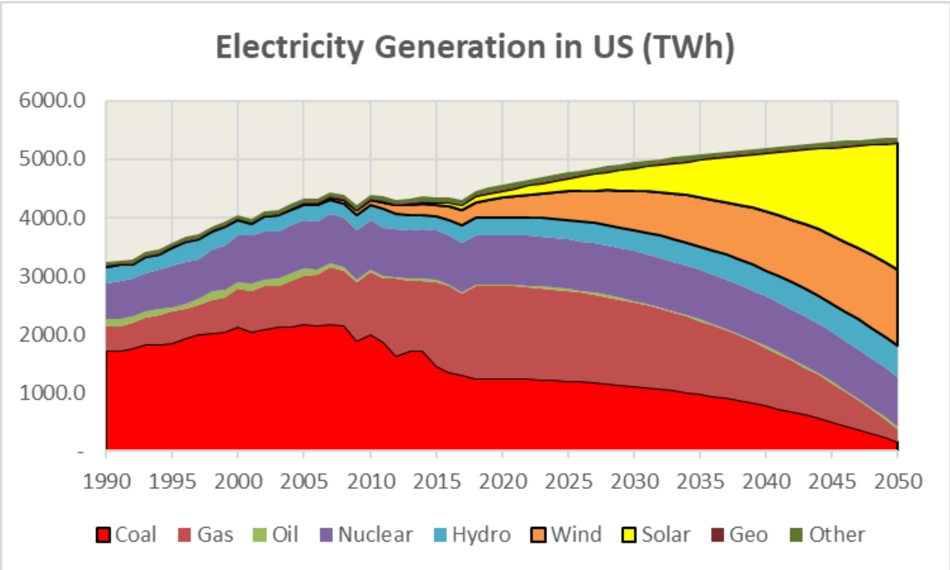


Figure 14.2.1 Electricity generation in USA.

This will mean than the CO_2 emissions from electricity generation would decrease from about 2930 million tons to about 200 million tons by 2050 (Figure 14.2.2). Specific emissions from electricity generation will decrease from 500 g/kWh to 50 g/kWh by 2050 (Figure 14.2.3).

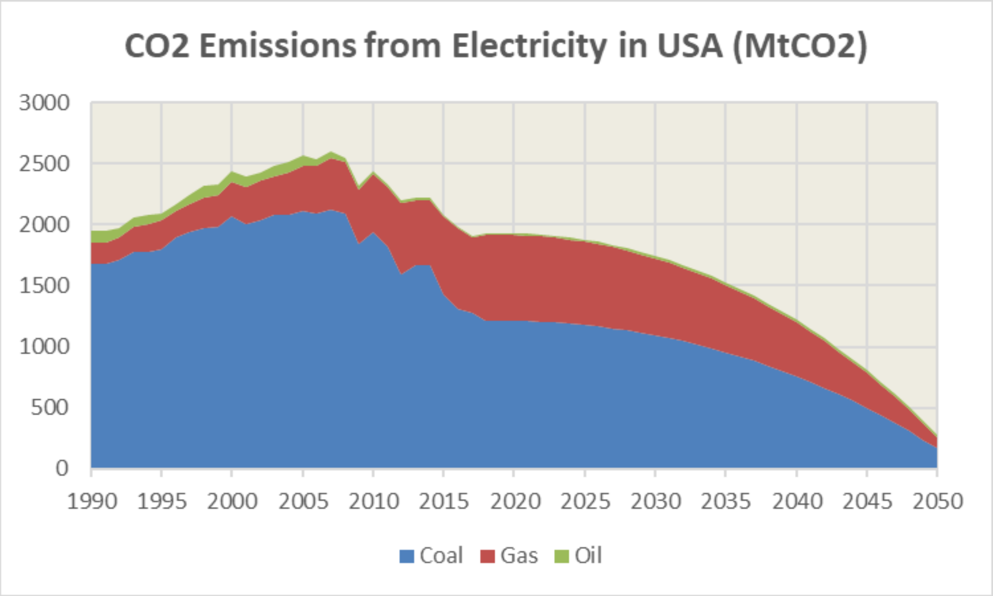


Figure 14.2.2 Emission from electricity generation ($MtCO_2$).

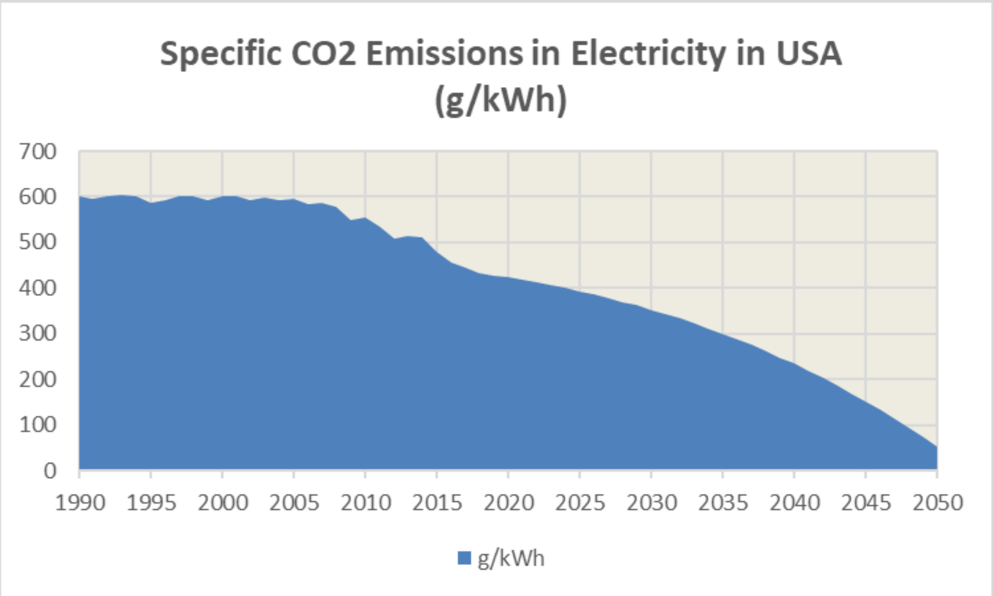


Figure 14.2.3 Specific emissions from electricity generation in USA.

Oil

Oil consumption is mainly concentrated in car industry. Car industry is changing from oil to Plug-in vehicles (PEV). The market share of PEV cars will be 100 % by 2050 (Figure 14.2.4).

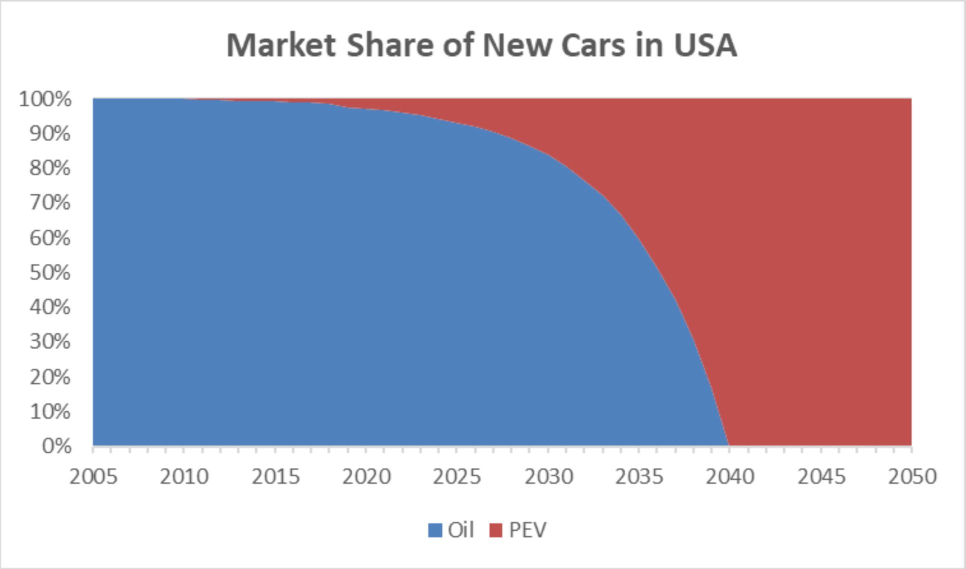


Figure 14.2.4 Market share of new cars in USA.

This will mean all cars on the roads will be PEVs by 2050 (Figure 14.2.5). The oil consumption will decrease from 900 Mtoe in 2018 to about 150 Mtoe by 2050 (Figure 14.2.6).

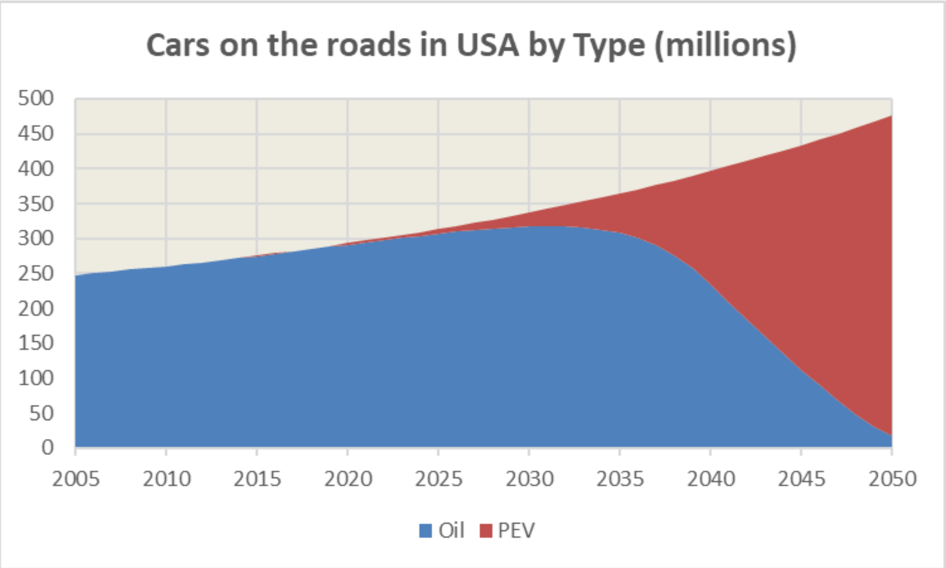


Figure 14.2.5 Vehicles by energy source in US roads (millions).

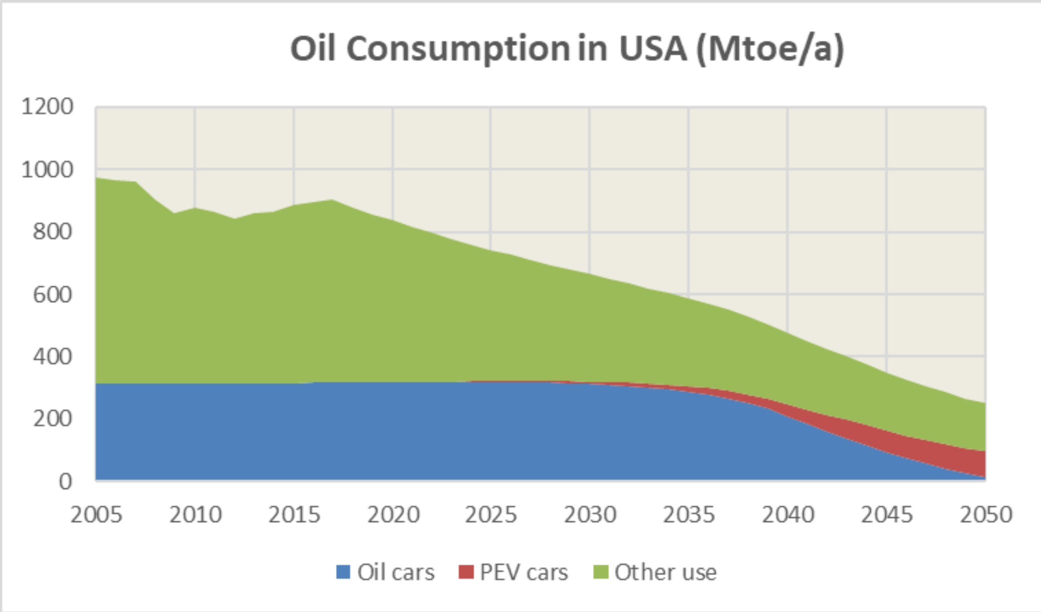


Figure 14.2.6 US oil consumption (Mtoe/a).

CO_2 emissions from oil in USA will drop from 2850 $MtCO_2$ in 2018 to about 800 MtCO2 by 2050 (Figure 14.2.7).

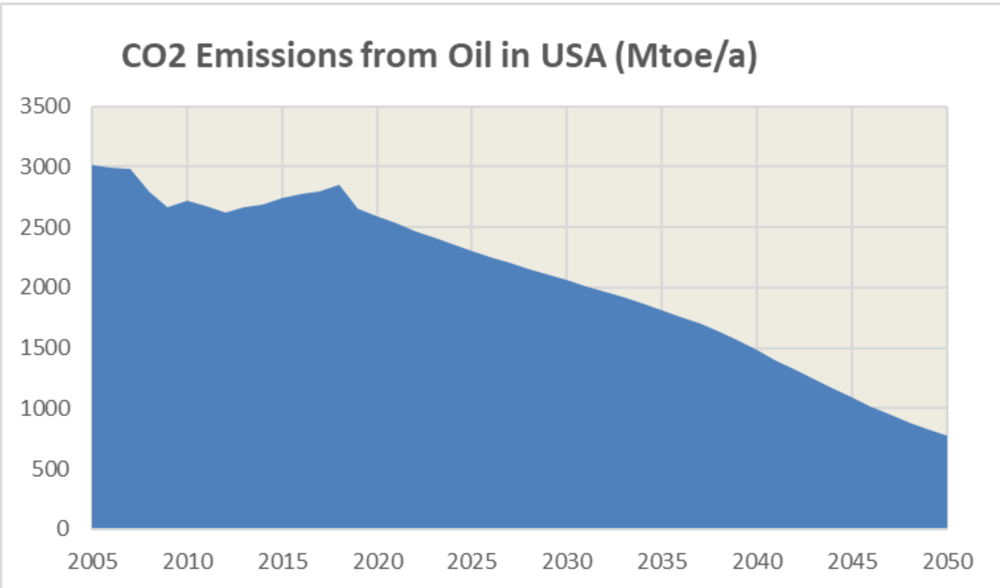


Figure 14.2.7 CO_2 emissions from oil in USA.

Total CO_2 emissions

CO_2 emissions from fuels in USA will be decreasing from 5000 million tons in 2018 to about 1500 million tons in 2050 (Figure 14.2.8). If the population in USA will be about 440 millions in 2050, emissions are about 3.4 tons/capita. This about double from target of 1.8 t/capita. One possibility is to change oil from mineral oil to bio oil.

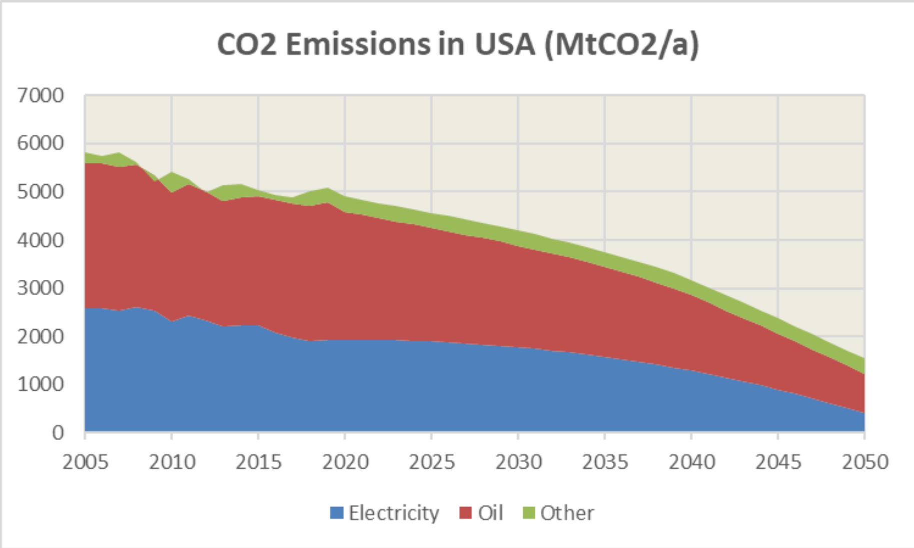


Figure 14.2.8 CO_2 emissions from fuels in USA.

14.3 Targets for China

Target for China is to reduce the CO_2 emissions from todays 9420 $MtCO_2$ (6.6 t/capita) to 2570 Mt (1.8 t/capita). The reduction needed will be 73 % or 4 % annually. This should be possible.

Electricity generation

Electricity generation in China will increase from 7120 TWh to 16.000 TWh by 2050 (Figure 14.3.1). The specific consumption will be about 12,000 kWh/capita.

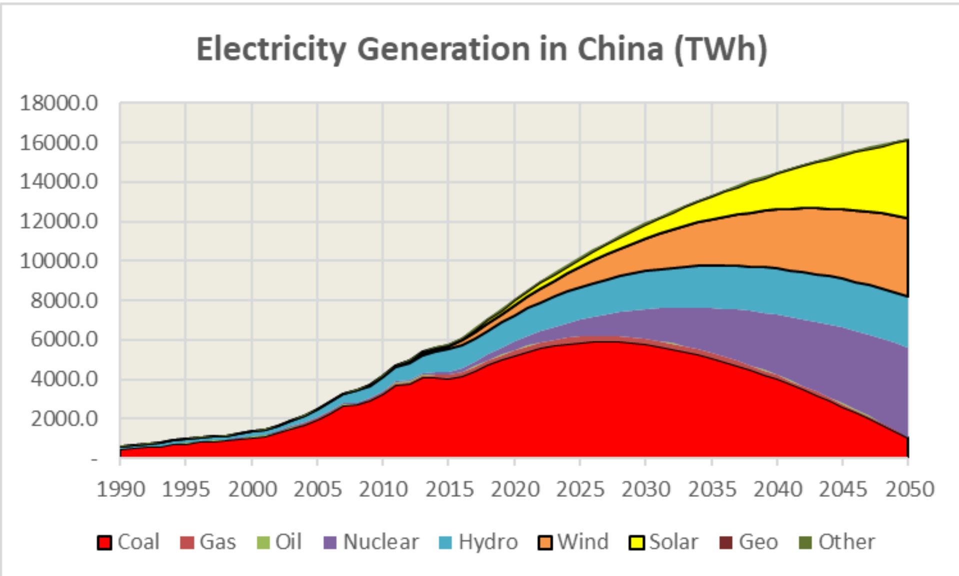


Figure 14.3.1 Electricity generation using coal, gas and oil in China.

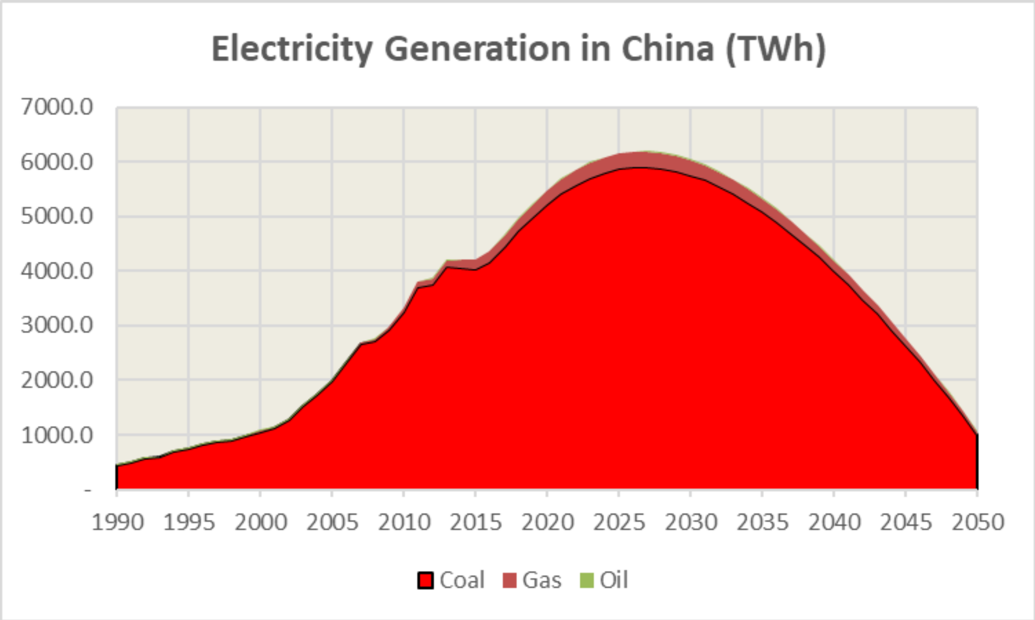


Figure 14.3.2 Electricity generation with fossil fuels in China.

Electricity generation using coal, gas and oil plants will be increasing until 2026 to about 6200 TWh but will then start to degrease to 1100 TWh in 2017 by the year 2050 (Figure 14.3.2). This will mean that CO_2 emissions from electricity generation will have a peak at 5850 MtCO2 and will then start to decrease to 1000 million tons in 2050 or to less than 1 ton per capita (Figure 14.3.3).

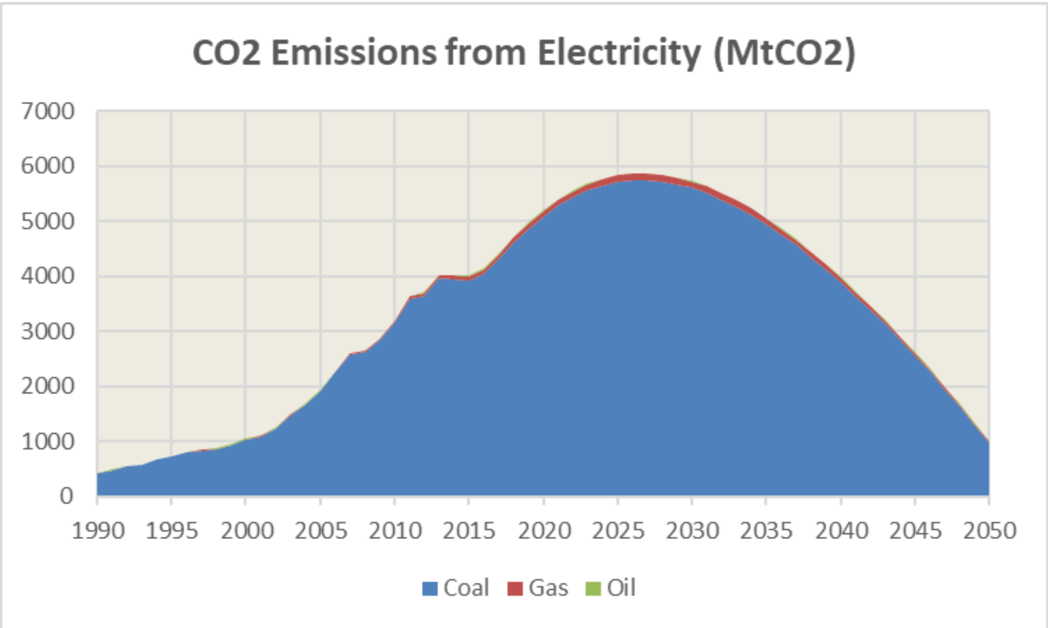


Figure 14.3.3 CO_2 emissions from electricity generation in China.

Oil

Market share of new cars will be changing to 100 % of PEV cars until 2037 (Figure 14.3.4). By the year 2030 about 50 % of new cars will be PEVs.

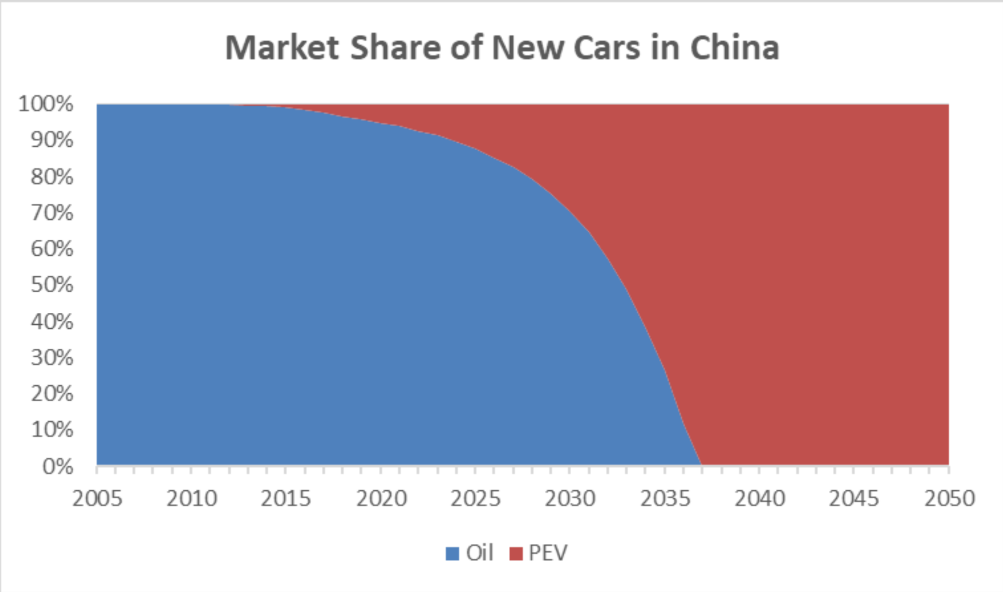


Figure 14.3.4 Market share of new cars in China.

Cars in the Chinese roads will be increasing from about 300 million in 2018 to about 550 million in 2050 (Figure 14.3.5). China will be leading the PEV race and by 2044 all cars could be PEVs. Oil consumption in China will drop to about 250 million tons by 2050 (Figure 14.3.6).

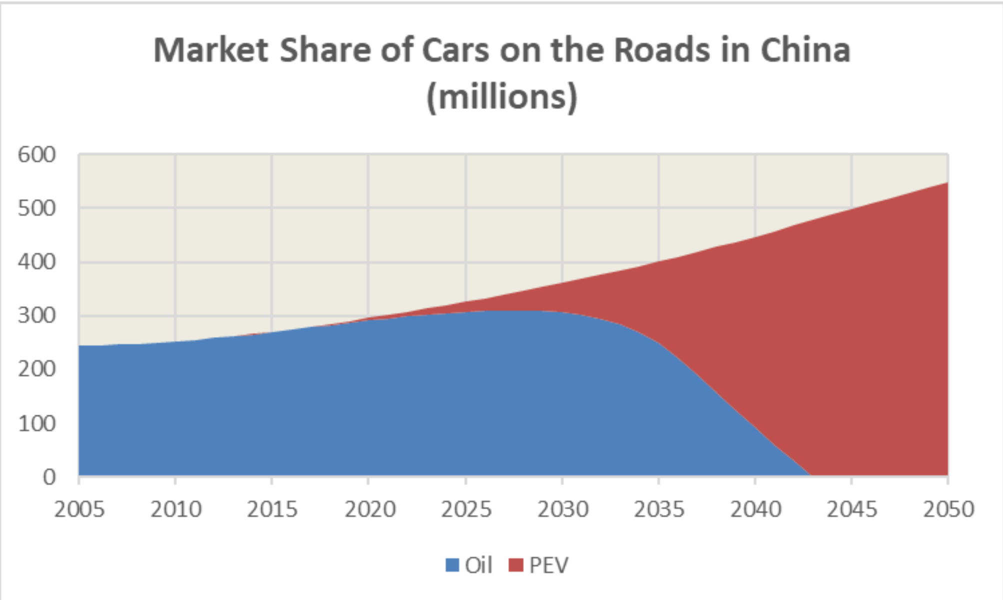


Figure 14.3.5 Cars on the roads in China.

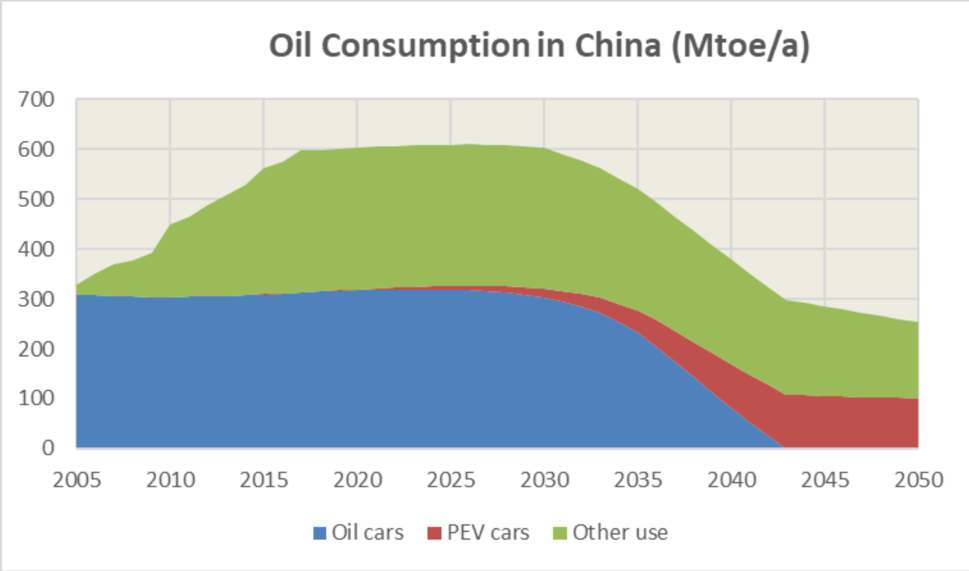


Figure 14.3.6 Oil consumption in China.

CO_2 emissions from oil consumption will drop from 1900 MtCO2 in 2018 to 800 MtCO2 by 2050 (Figure 14.3.6).

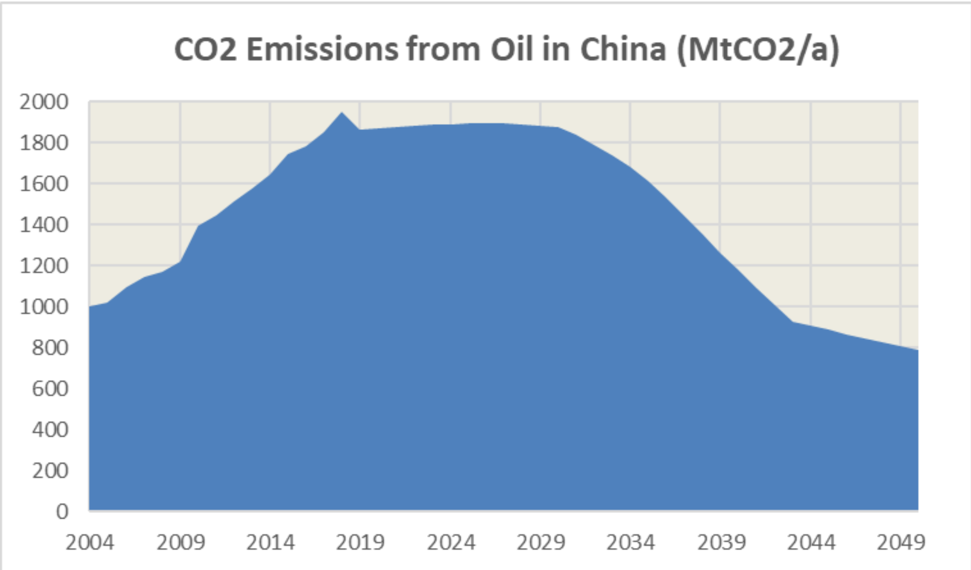


Figure 14.3.7 CO2 emissions from oil in China.

CO_2 emissions

Total CO_2 emissions in China will be peaking at 10,00 million tons by 2025 and will be decreasing to 2900 million tons by 2050 (Figure 14.3.8). This means that emissions will be about 2 tons per capita for 1450 million people and very near the 1.8 t/capita target.

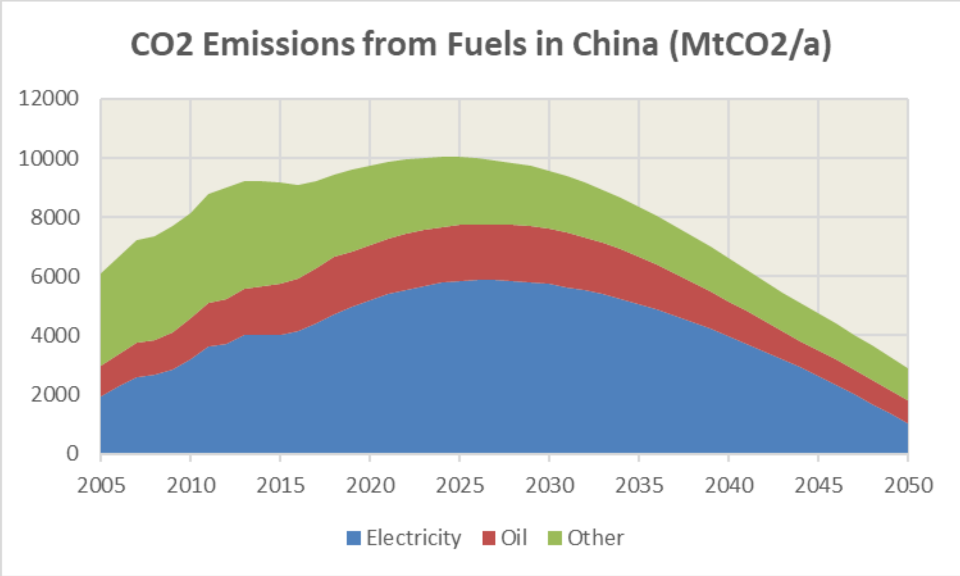


Figure 14.3.8 CO_2 emissions from fuels in China.

14.4 Targets for India

CO2 emissions in India in 2018 were 2480 million tons from fossil fuels. This was about 1.8 tCO2/capita, which will be the target level for India by 2050. However, energy consumption and number of inhabitants are both growing rapidly and carbon free technologies will be needed to reach the goals.

Electricity in India

Electricity generation in India will be growing from 1470 TWh (1080 kWh/capita) to about 3400 TWh (2000 kWh/capita) by 2050.

Consumption is growing so fast and coal will remain as most important fuel until 2050 (Figure 14.4.1). Solar will be increasing fast and will be generation about 33 % of electricity in 2050.

The peak of fossil electricity generation will be achieved by the year 2035. Peak of CO_2 emissions will be at 1800 $MtCO_2$ (Figure 14.4.2). The CO_2 emissions will be decreasing to 1150 $MtCO_2$ by 2050, which was about the same level as in the year 2018 (Figure 14.4.3). The specific emissions from electricity will drop from 760 g/kWh in 2018 to about 340 g/kWh by 2050 (Figure 14.4.4).

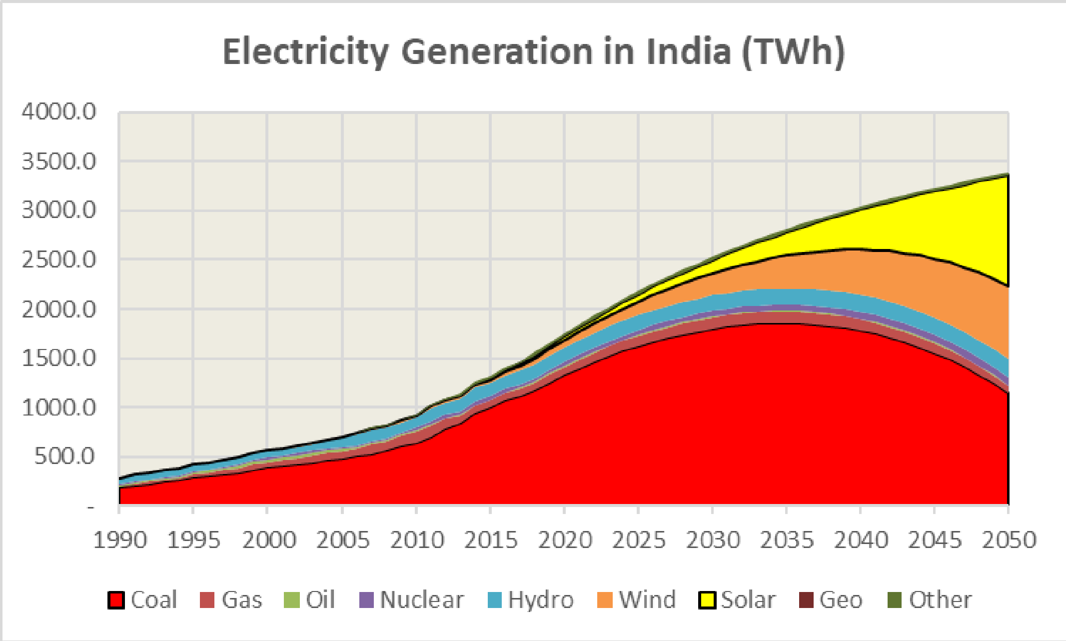


Figure 14.4.1 Electricity generation in India.

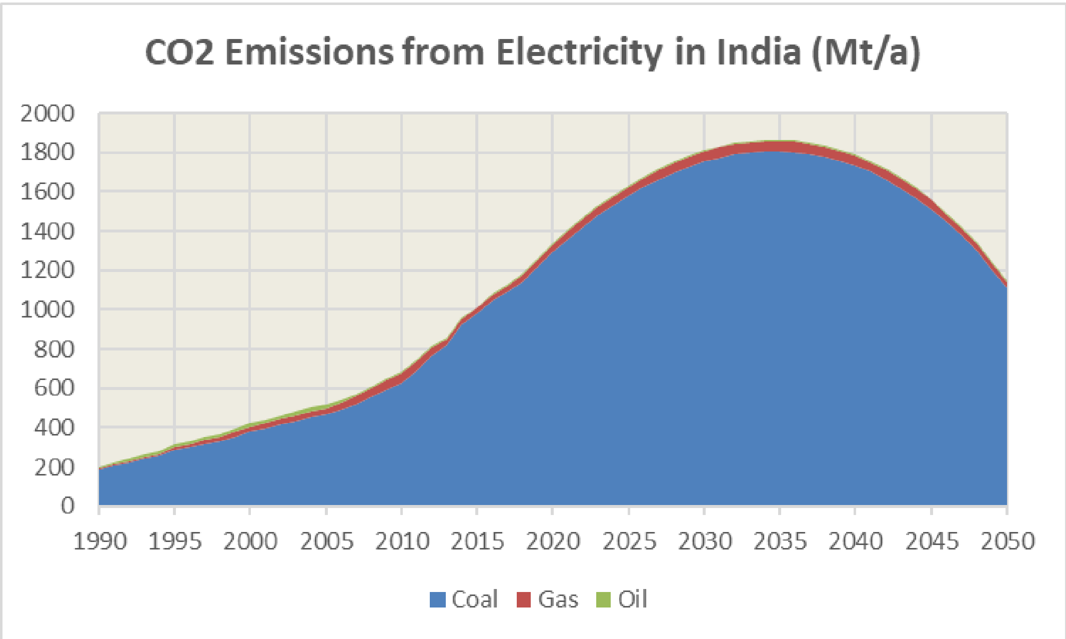


Figure 14.4.2 CO_2 emissions from electricity in India.

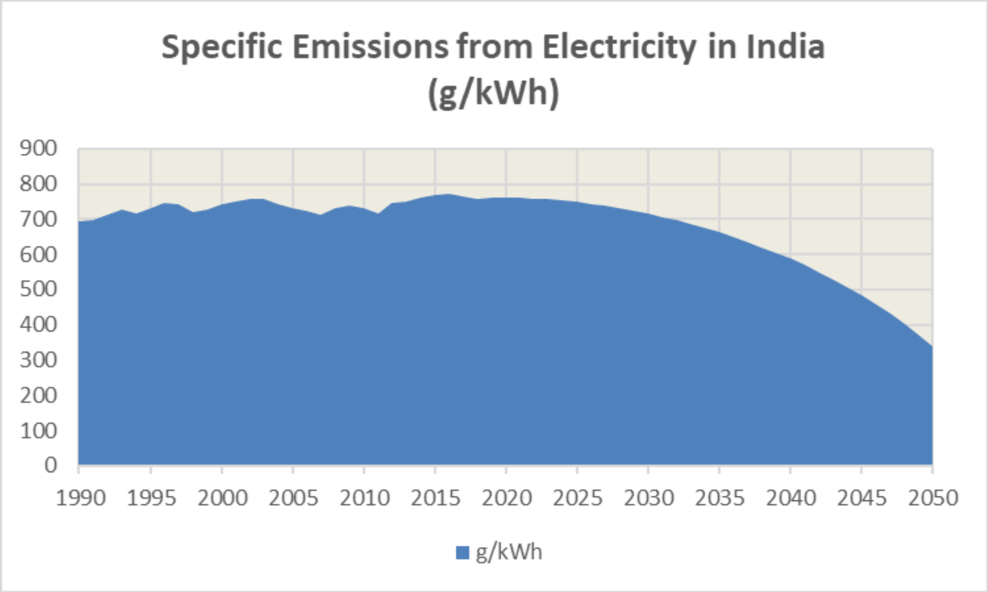


Figure 14.4.3 Specific CO_2 emissions from electricity in India.

Oil consumption

Market share of new cars in India will be changing to 100 % of PEV cars until 2045 (Figure 14.4.4). Market of motor vehicles will grow near 700 million by 2050 and about 63 % of them will be PEVs (Figure 14.4.5).

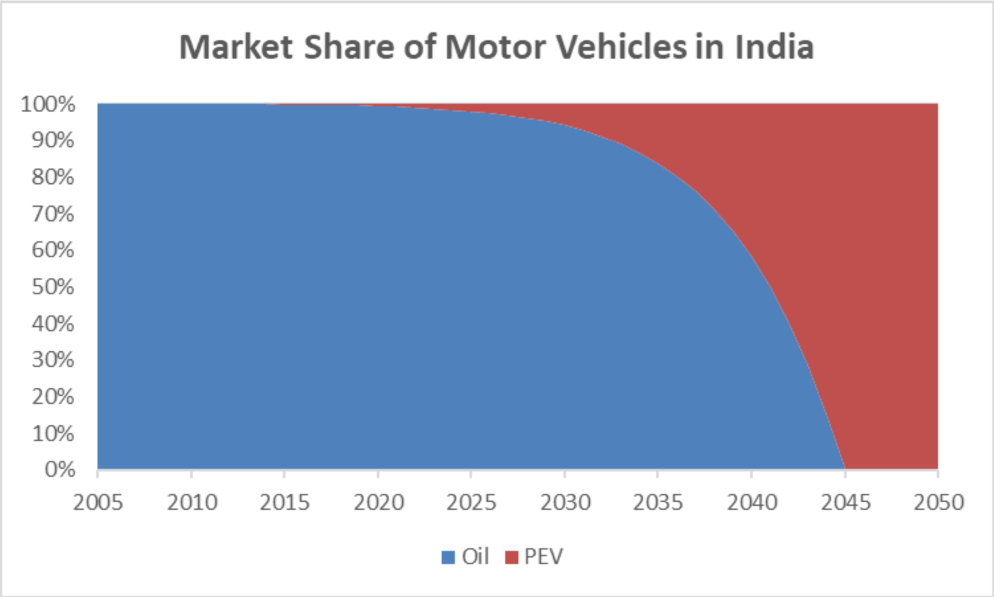


Figure 14.4.4 Market share of motor vehicles in India.

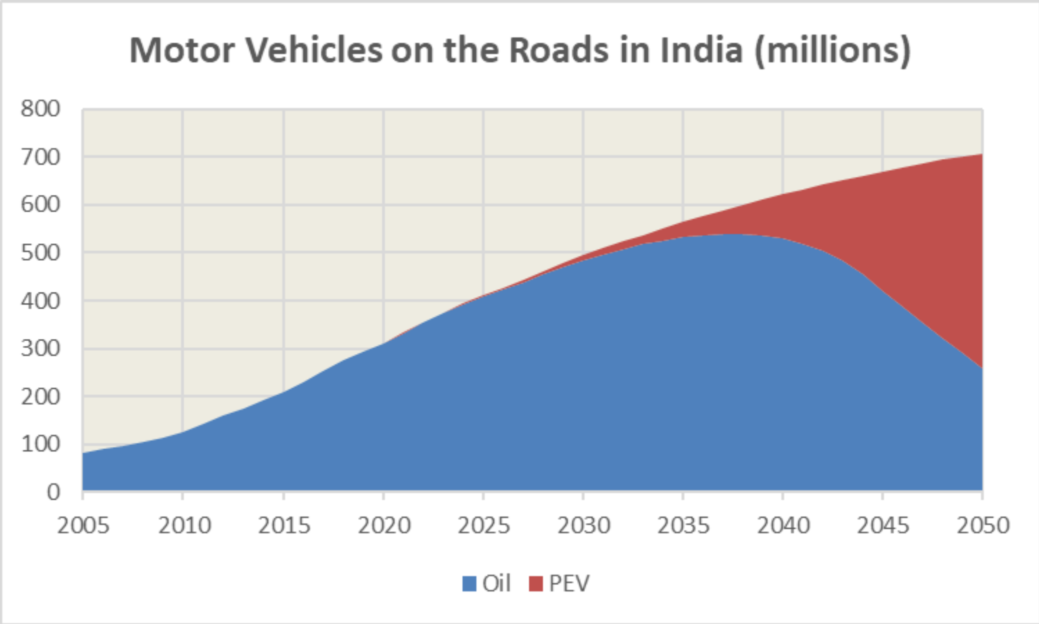


Figure 14.4.5 Motor vehicles on the roads in India.

Oil consumption in India will peak at 500 Mtoe in the year 2035 but will be reduced to 270 Mtoe by 2050 (Figure 14.4.6). The CO_2 emissions from oil will be peaking at 1480 $MtCO_2$ by 2038 (Figure 14.4.7).

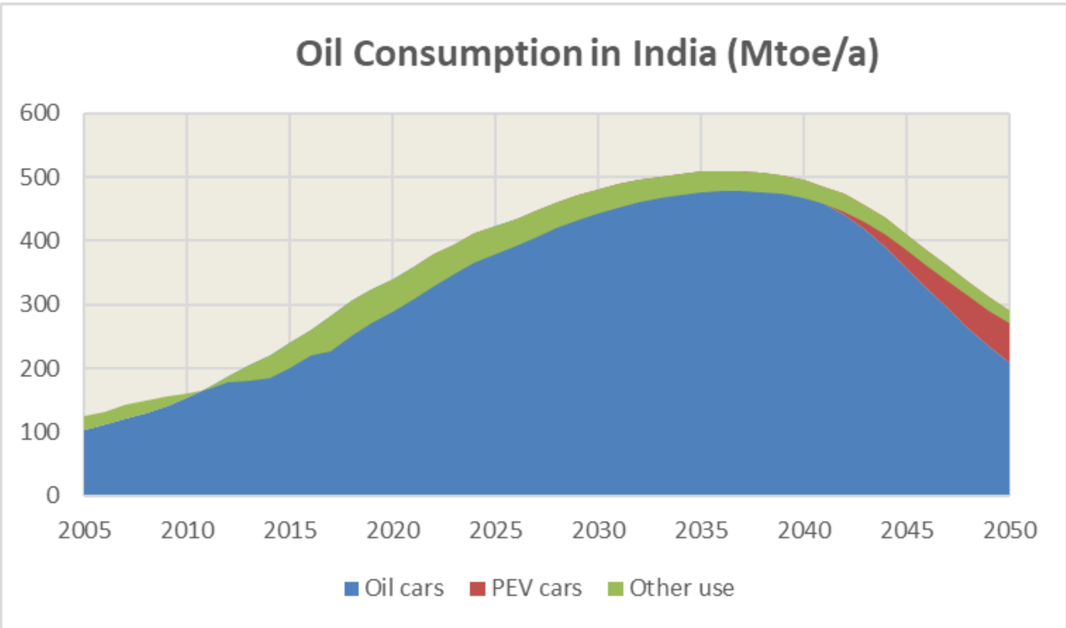


Figure 14.4.6 Oil consumption in India.

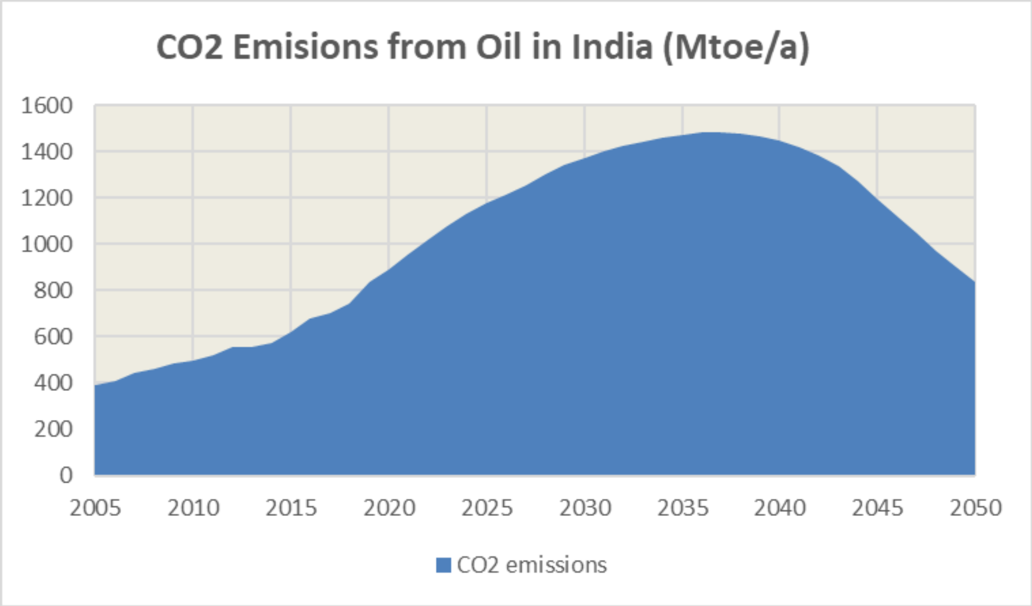


Figure 14.4.7 CO_2 emissions from oil in India.

CO_2 emissions in India

Peak CO_2 emissions will be in India at 3700 $MtCO_2$ by the year 2035 (Figure 14.4.8). In 2050 the CO_2 emissions will be about 2200 million tons, which will be about 1.5 tons/capita for 1500 million people and lower that target level of 1.8 t/capita.

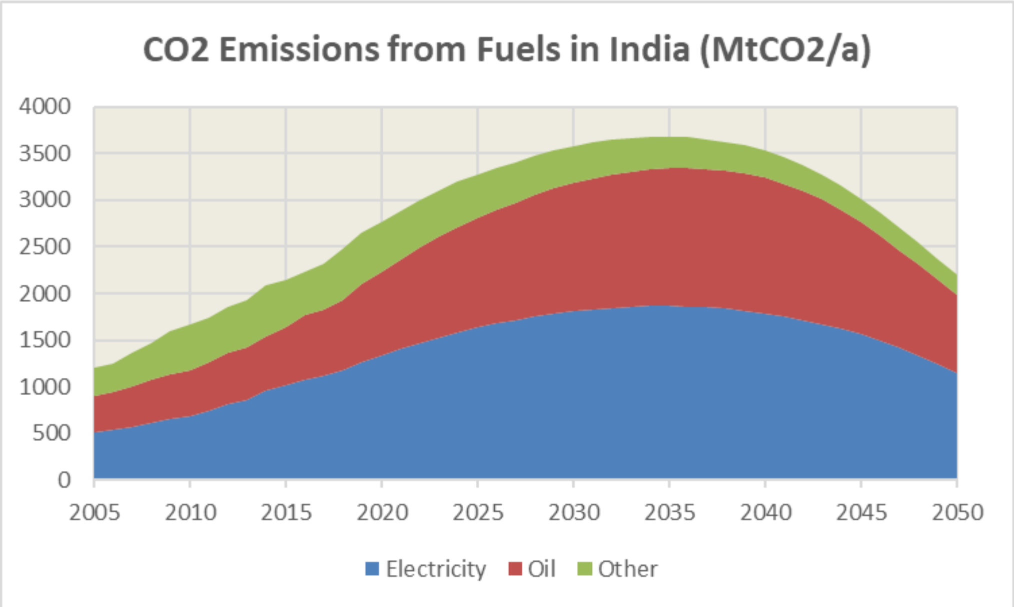


Figure 14.4.8 CO_2 emissions from fuels in India.

14.5 Targets for Middle East

Electricity generation

Electricity generation in Middle East has been using oil and gas, but the new nuclear and solar plants will turn this by 2050 to less than 30 % fossil (Figure 14.5.1). The peak of fossil electricity will be achieved by the year 2030.

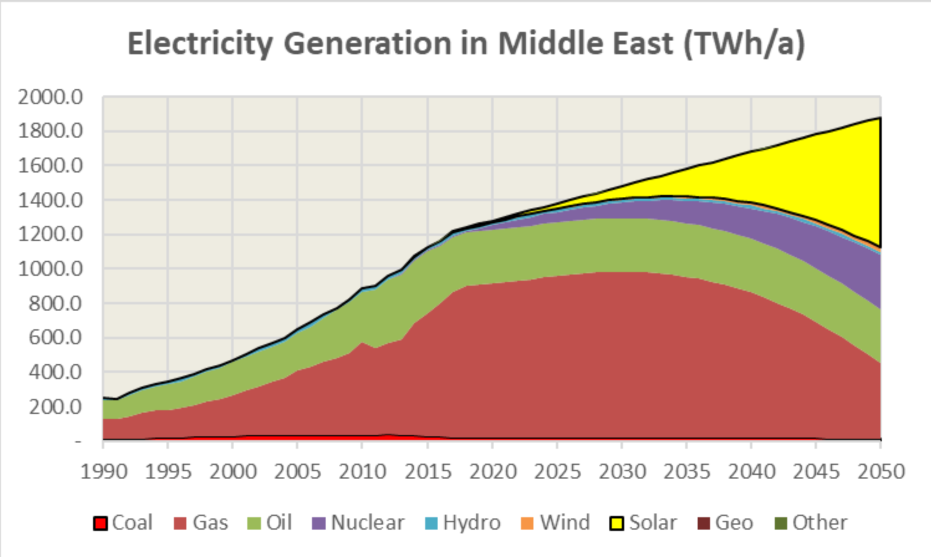


Figure 14.5.1 Electricity generation in the Middle East (TWh).

CO_2 emissions from electricity generation in the Middle East will be peaking at 660 $MtCO_2$ in the year 2030 (Figure 14.5.2). Specific CO_2 emissions from electricity will drop from 500 g/kWh to 220 g/kWh by 2050 (Figure 14.5.3).

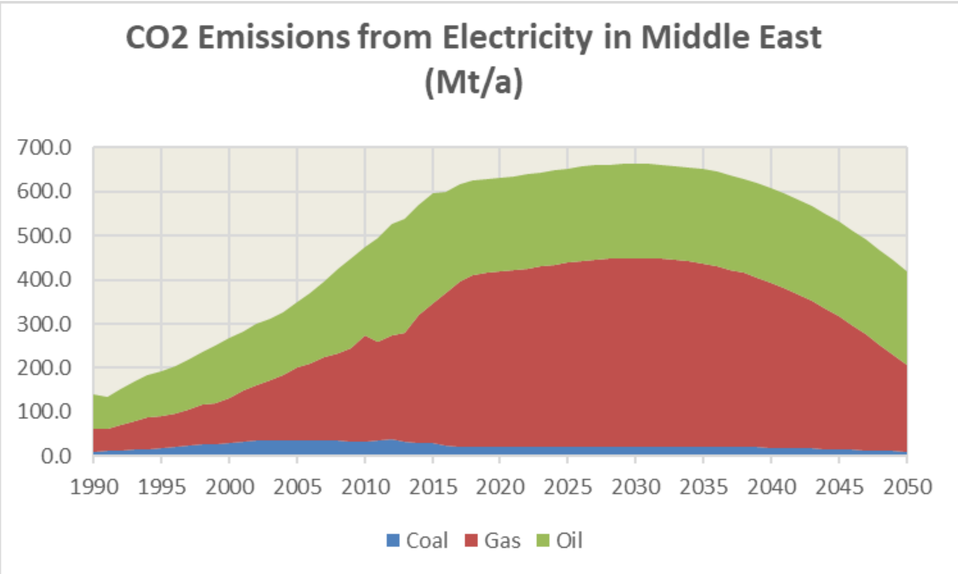


Figure 14.5.2 CO_2 emissions from electricity generation in the Middle East.

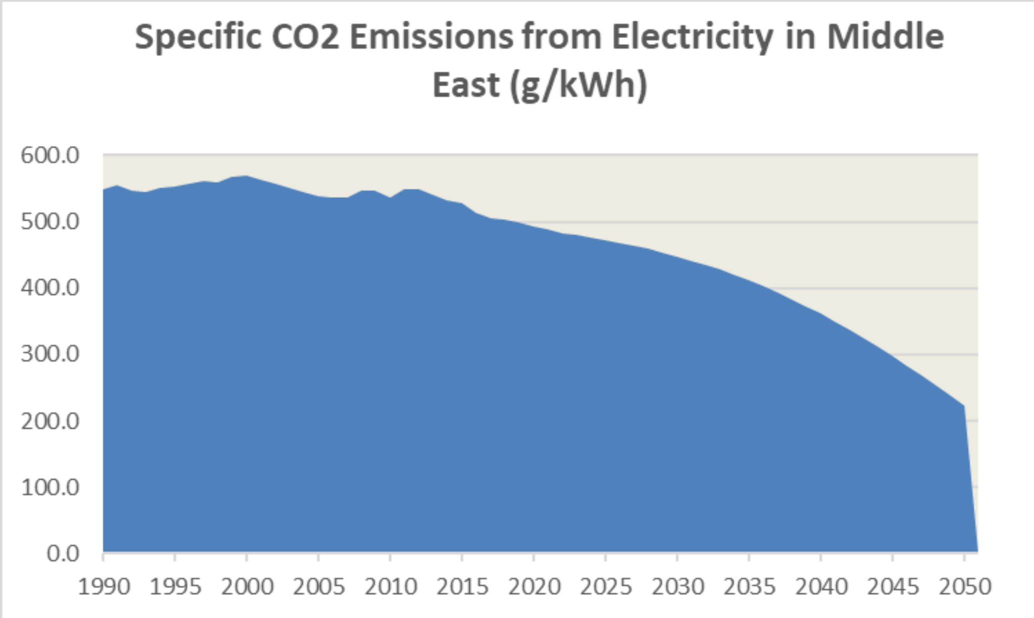


Figure 14.5.3 Specific CO_2 emissions from electricity generation in the Middle East.

Oil in the Middle East

Market share of new motor vehicles is changing to 100 % of PEVs by 2038 (Figure 14.5.4).

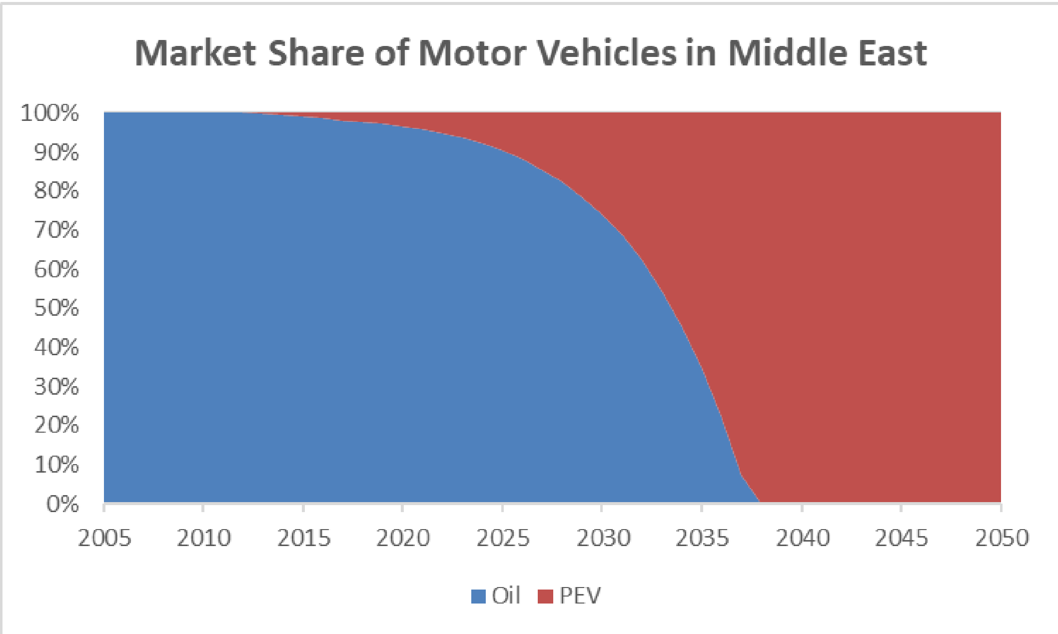


Figure 14.5.4 Market share of new motor vehicles in the Middle East.

Number of motor vehicles on the roads in the Middle East will rise to 120 million by 2050 (Figure 14.5.5).

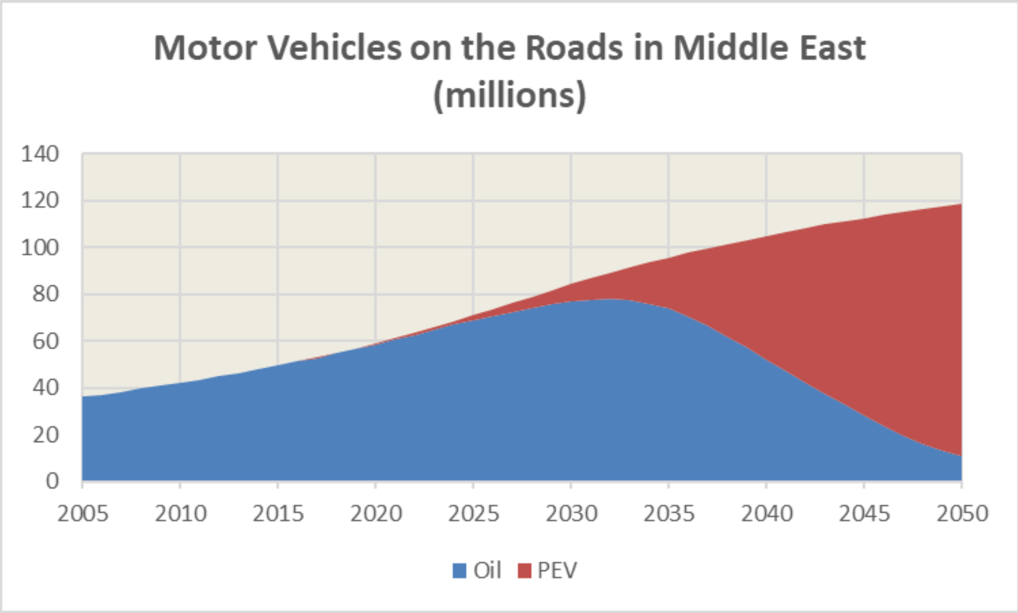


Figure 14.5.5 Number of motor vehicles on the roads in the Middle East.

Oil consumption in the Middle East has peaked at 400 Mtoe in 2015 and will be reducing to about 200 Mtoe by 2050 (Figure 14.5 6). CO_2 emissions of oil will be reduced to 600 $MtCO_2$ by 2050 (Figure 14.5.7).

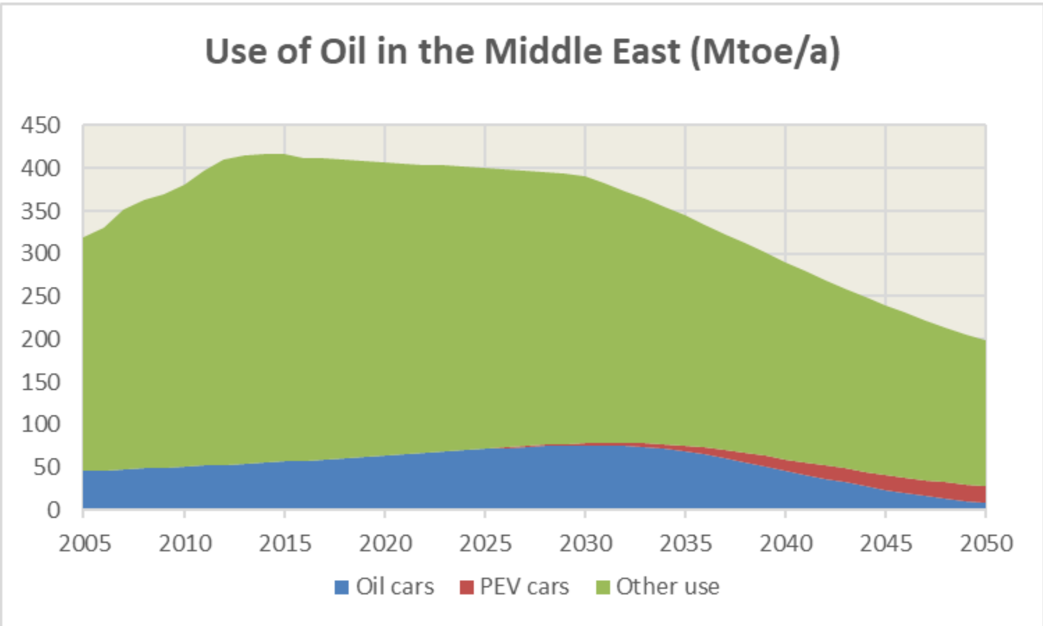


Figure 14.5.6 Use of oil in the Middle East.

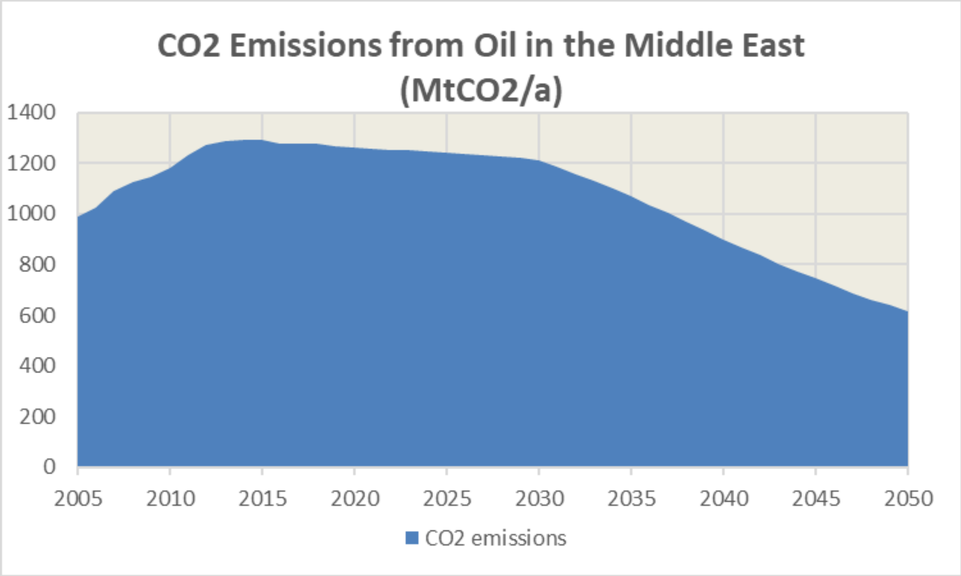


Figure 14.5.7 CO_2 emissions from oil in the Middle East.

CO_2 emissions in the Middle East

The population in the Middle East is today about 555 million and the CO_2 emissions about 2100 $MtCO_2$ or 3.8 tCO_2/capita. The total CO_2 emissions from fossil fuels in the Middle East will be reducing to about 1150 $MtCO_2$ by the year 2050 (Figure 14.5.8). There will be about 700 million in 2050 in the Middle East and the CO_2 emissions about 1.7 tons/capita, which is less than the target 1.8 t/capita.

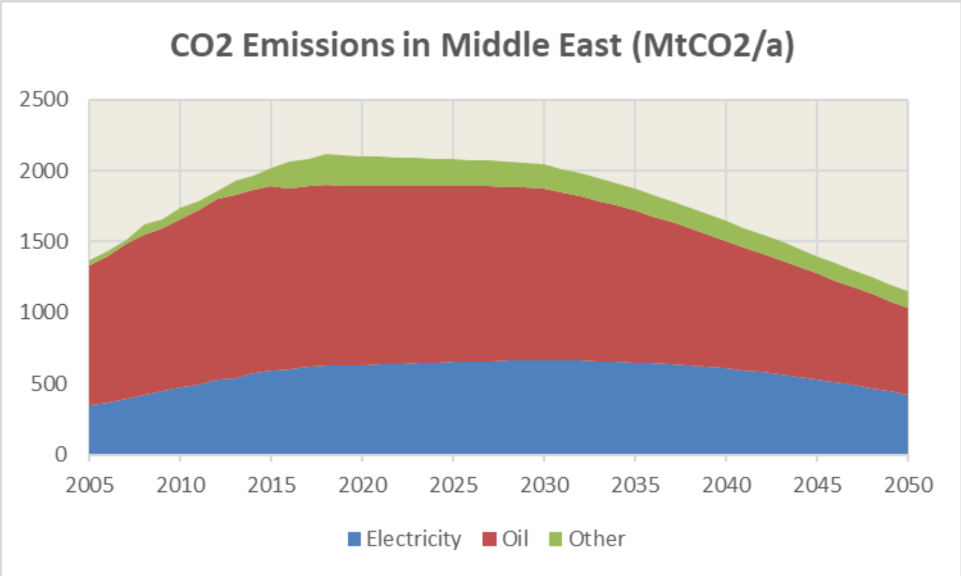


Figure 14.5.8 CO_2 emissions from fossil fuels in the Middle East.

14.6 Targets for Africa

Target emissions

CO_2 emissions in Africa were 1235 $MtCO_2$ in the year 2018. This was about 0.92 tCO_2/capita for 1350 million inhabitants. However, the population is growing fast and emissions at the same time, but the target is to keep the emissions below 1.8 tCO_2/capita by 2050. There will be about 2000 million people in Africa in 2050. The target emissions will be then 3600 $MtCO_2$.

Electricity in Africa

Electricity consumption in Africa will grow from 800 TWh in 2018 to about 2000 TWh in 2050 (Figure 14.6.1). This will be still less than 1000 kWh per capita. Solar and wind will be the main producers of electricity with 38 % and 32 % respectively. Fossil sources will be peaking at 1000 TWh by 2030.

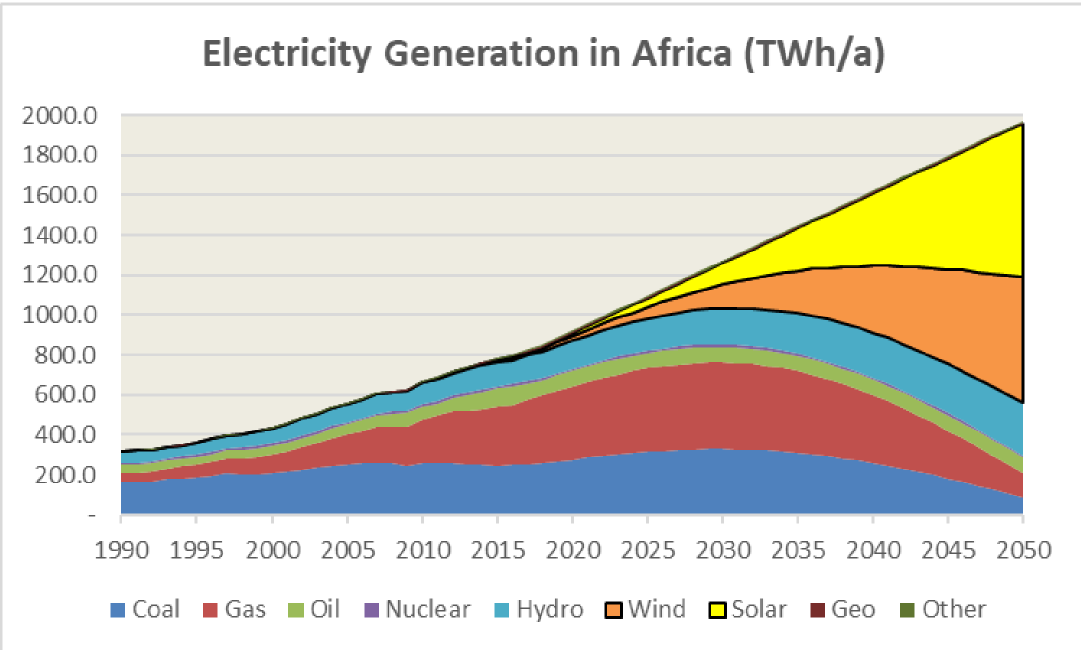


Figure 14.6.1 Electricity generation in Africa.

CO_2 emissions of electricity generation in Africa will pe peaking at 564 $MtCO_2$ in the year 2030 (Figure 14.6.2). However, the emissions will be reduced to 200 $MtCO_2$ by 2050. The specific CO_2 emissions from electricity will drop from 530 g/kWh in 2018 to 100 g/kWh by 2050 (Figure 14.6.3).

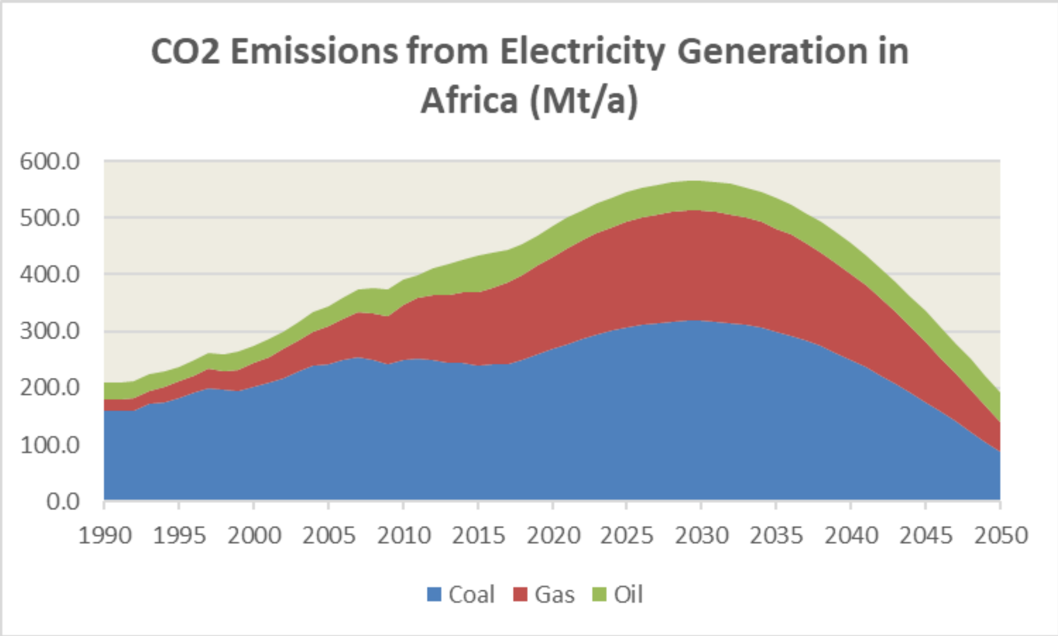


Figure 14.6.2 CO_2 emissions from electricity in Africa.

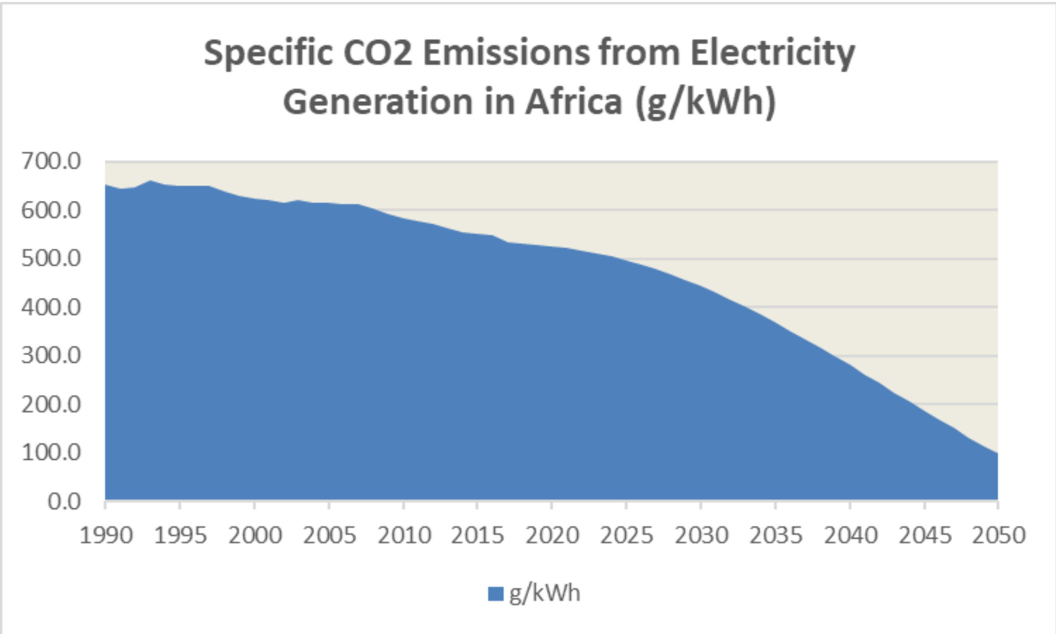


Figure 14.6.3 Specific CO_2 emissions from electricity in Africa.

Oil in Africa

Sales of new motor vehicles in Africa is increasing to about 6.5 million annually (Figure 14.6.4). All new vehicles will be PEVs by 2047. Half of the vehicles will be PEVs by 2050 (Figure 14.6.5).

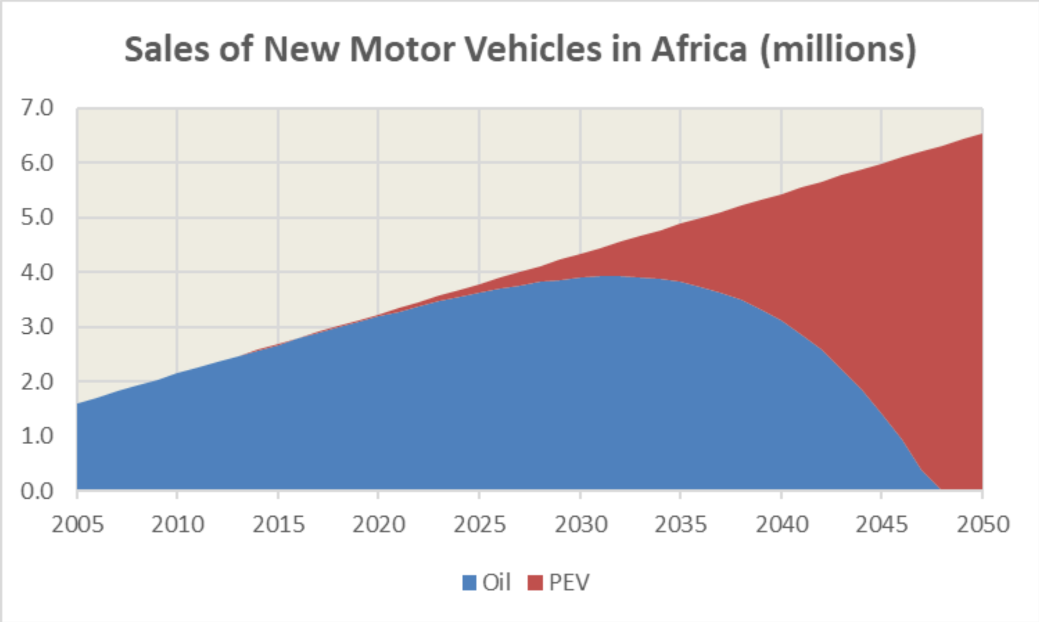


Figure 14.6.4 Sales of new motor vehicles in Africa.

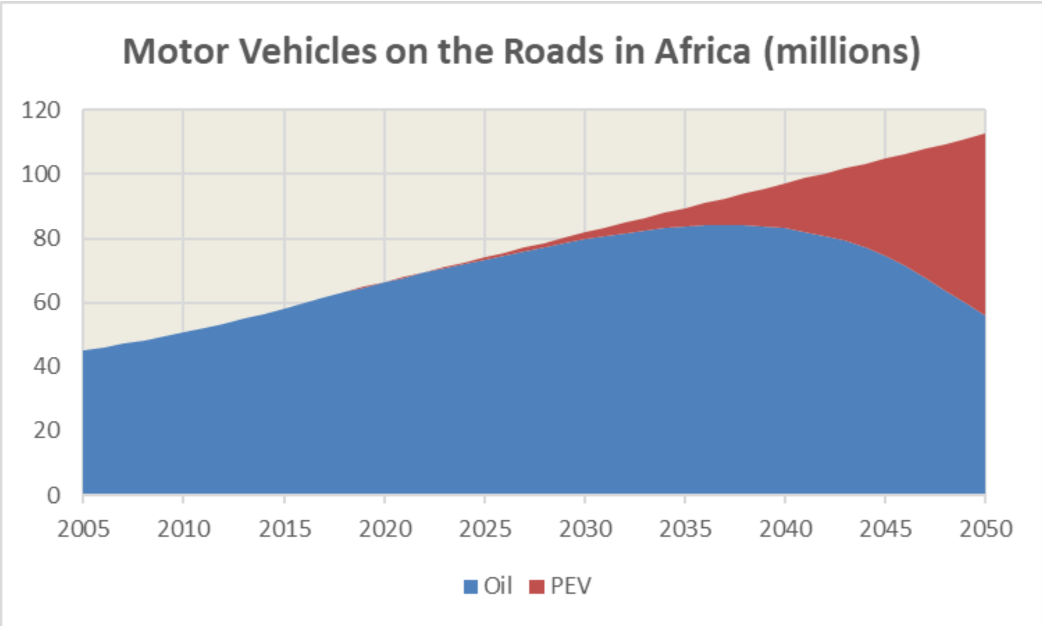


Figure 14.6.5 Motor vehicles on the roads in Africa.

Use of oil will be peaking in Africa at 180 Mtoe in the year 2030 (Figure 14.6.6). The peak of CO_2 emissions from oil will be at 560 MtCO2 at the same time (Figure 14.6.7).

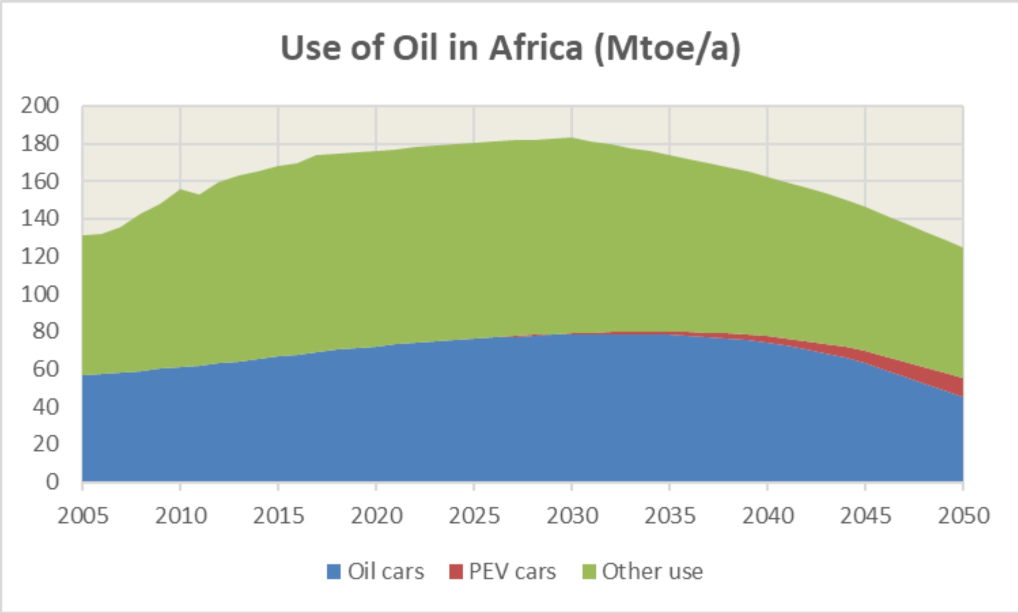


Figure 14.6 6 Consumption of oil in Africa.

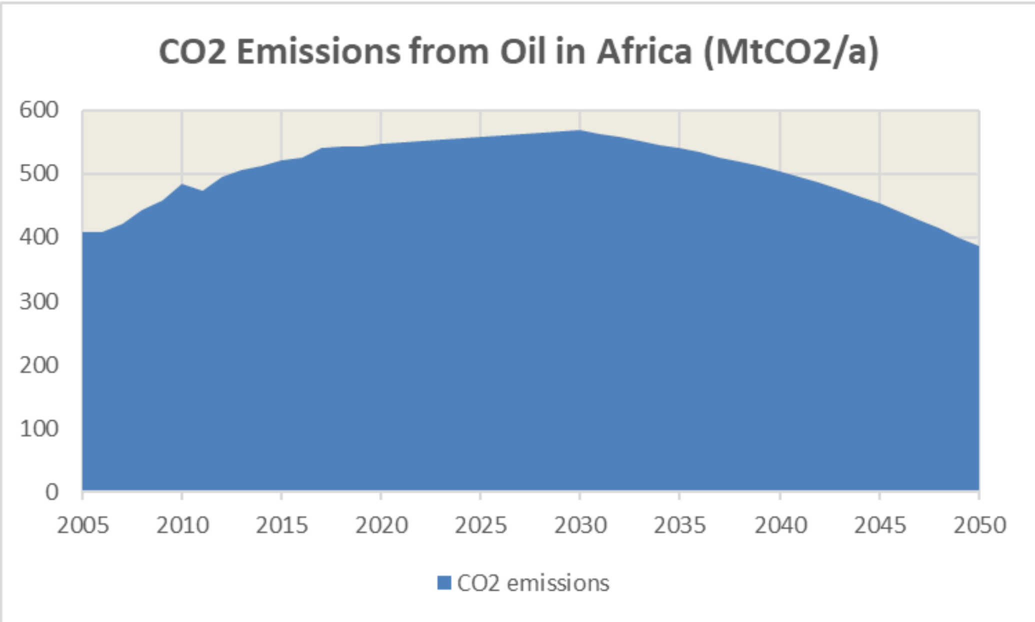


Figure 14.6.7 CO_2 emissions from oil in Africa.

CO_2 emissions from fossil fuels in Africa will be peaking at 1350 $MtCO_2$ in the year 2030 (Figure 14.6.8). In the year 2050 the emissions will be about 900 $MtCO_2$ or about 0.45 t/capita, which is clearly below the global target of 1,8 t/capita.

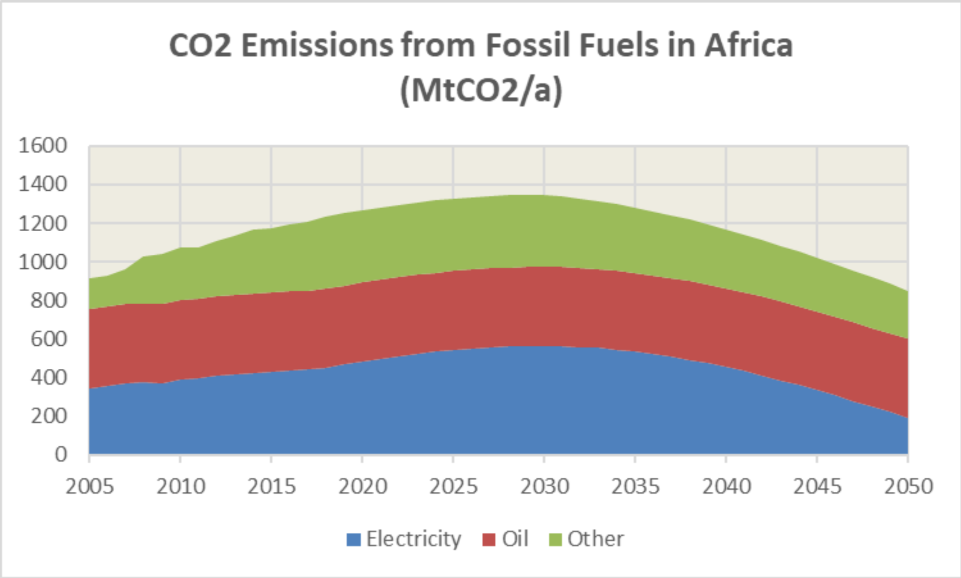


Figure 14.6.8 CO_2 emissions from fossil fuels in Africa.

14.7 Targets for other countries

Electricity generation in the rest of the world is increasing to about 13,000 TWh by 2050 (Figure 14.7.1). However, fossil fuels will peak at 5030 TWh by the year 2025.

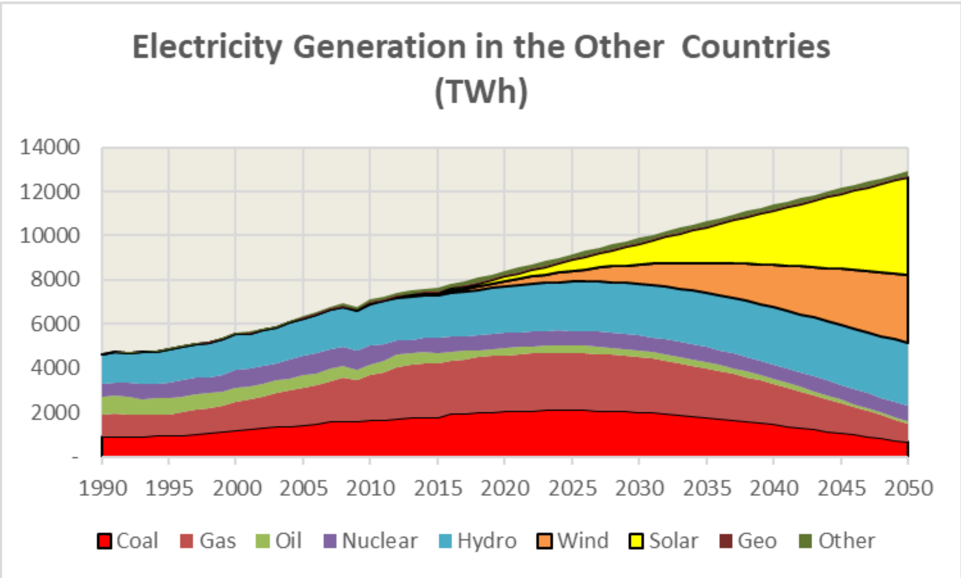


Figure 14.7.1 Electricity generation in the other countries.

CO_2 emissions from electricity generation in the other countries will be peaking at 3500 $MtCO_2$ in the year 2025 (Figure 14.7.2).

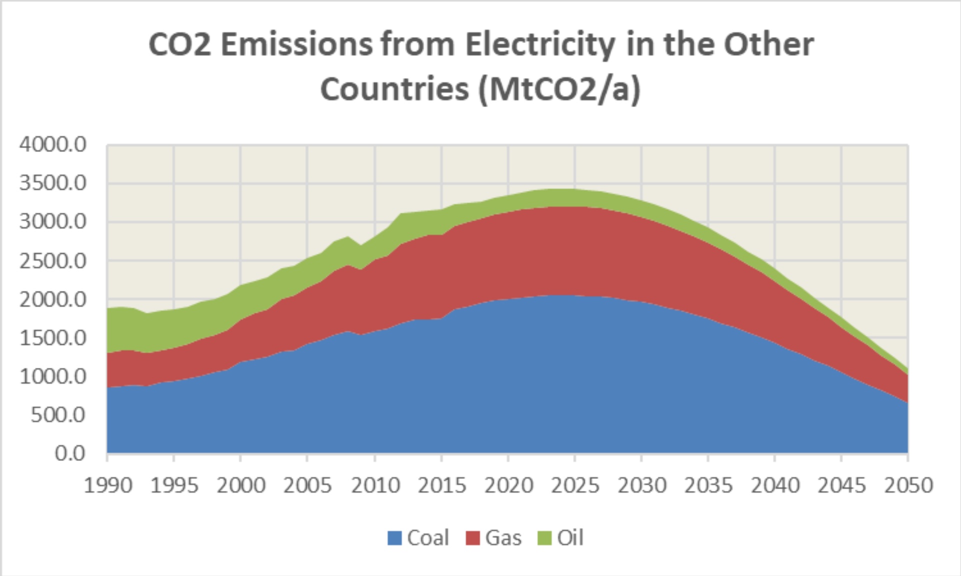


Figure 14.7.2 CO_2 emissions from electricity in the other countries.

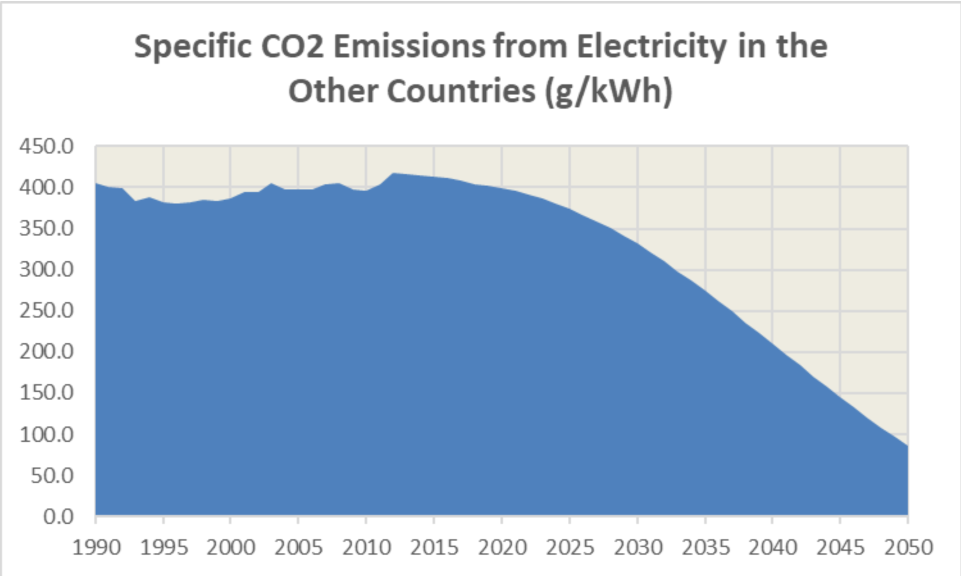


Figure 14.7.3 Specific CO_2 emissions from electricity in the other countries.

Oil in the other countries

The development in the other countries in traffic is estimated to be slower. All ne vehicles will be PEVs by 2050 (Figure 14.7.4). Only 30 % of the vehicles on the roads will be PEVs (Figure 14.7.5).

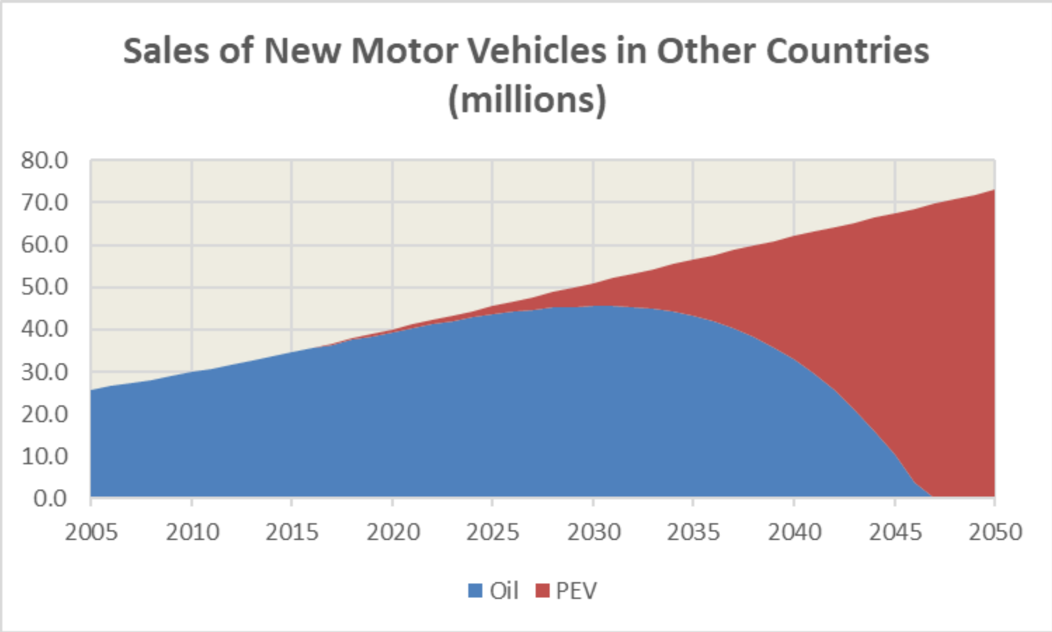


Figure 14.7.4 Sales of new vehicles in the other countries.

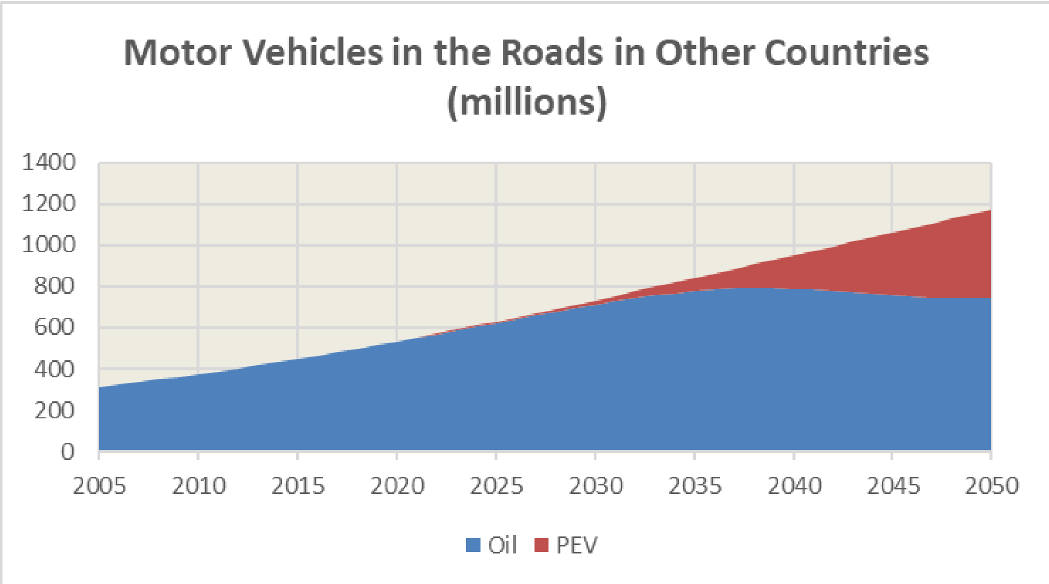


Figure 14.7.5 Vehicles on the roads in the other countries.

Consumption of oil in the other countries will be peaking at 5600 Mtoe in the year 2030 (Figure 14.7.6). The CO_2 emissions from oil will be peaking at 5600 $MtCO_2$ in the same year (Figure 14.7.7).

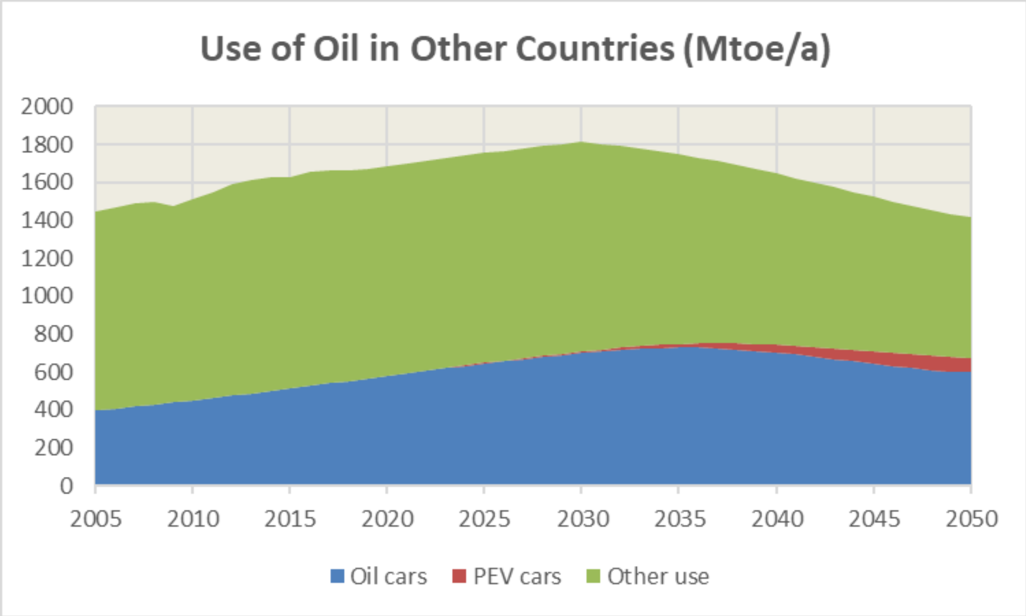


Figure 14.7.6 Consumption of oil in the other countries.

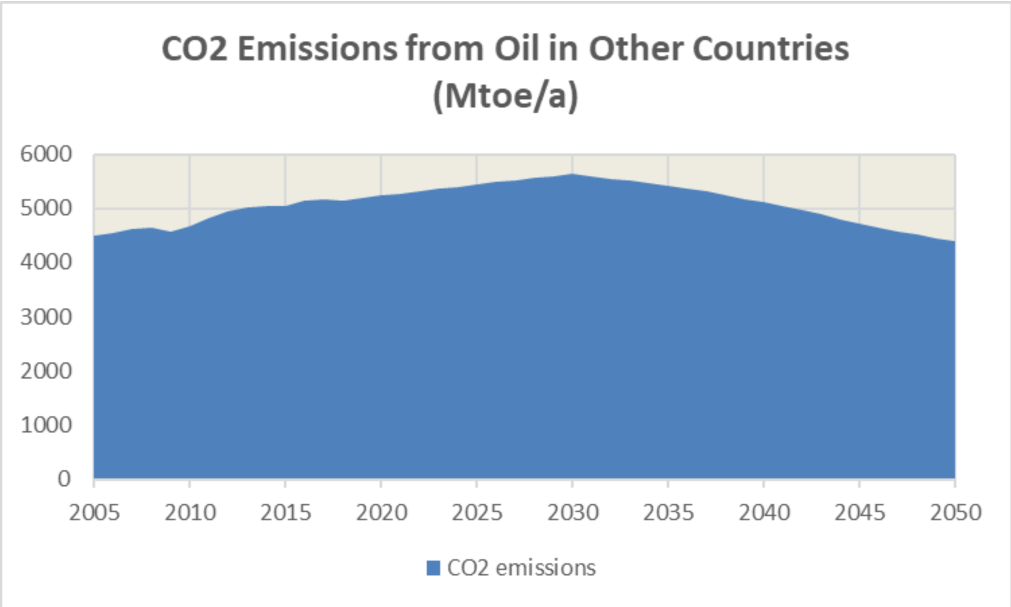


Figure 14.7.7 CO_2 emissions from oil in the other countries.

CO_2 emissions

CO_2 emissions in the other countries will be peaking at 10 Gt in the year 2030 (Figure 14.7.8). Emissions were 4.5 tCO_2/capita for 2240 million people. The emissions will be about 6500 $MtCO_2$ or 2.2 tCO_2/capita for 3000 million people in the year 2050.

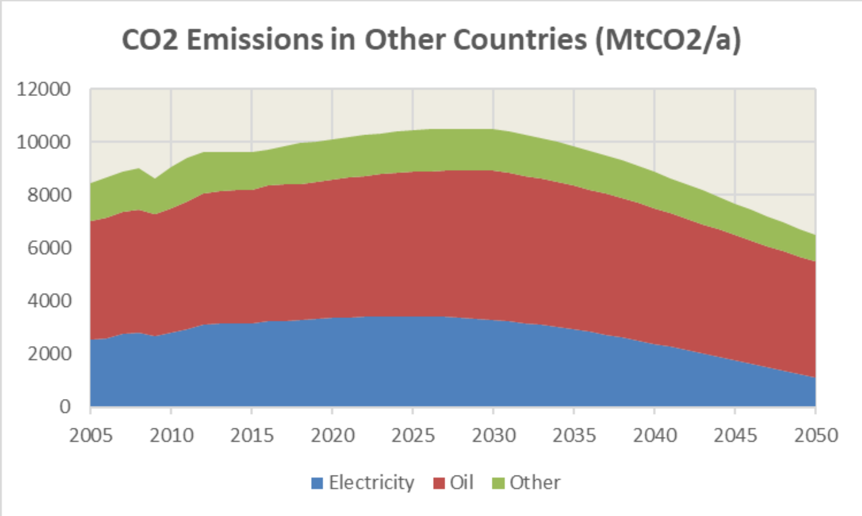


Figure 14.7.8 CO_2 emissions in the other countries.

14.8 Targets for Finland

Targets

Finland has set the coal to be carbon neutral in the year 2035. The CO_2 emissions and carbon sinks should be in balance by then. The CO_2 emissions were 46 $MtCO_2$ in 2018 and the carbons sinks were about 25 $MtCO_2$. The emissions should be reduced to less than 25 $MtCO_2$, if the carbon sinks will remain the same. This means that annual reduction should be 21$MtCO_2$ in 17 years or 1.2 $MtCO_2$ per year.

However, if Finland will follow global goal to reach 1.8 tCO_2/capita, the emissions should be reduced to 10 $MtCO_2$ by 2050. This can be achieved if emissions will be reduced 36 Mt in 32 years or 1.1 $MtCO_2$ annually.

Electricity generation

Finland is a country with 5.6 million inhabitants and about 87 TWh electricity consumption. The specific electricity consumption is then about 15.5 MWh/capita, which is the second highest figure in EU after Sweden.

The electricity generation will be increasing to about 82 TWh by 2021, when the new 1600 MW Olkiluoto 3 nuclear plant will be commissioned in 2020 (Figure 14.8.1). Then the nuclear generation will be about 35 TWh or 6 MWh/capita, which be higher than in Sweden, which has had produced more nuclear power per capita than any other country.

It is useful to note that Finland all coal plant will be decommissioned until the year 2030. However, there will be small amount of gas, oil and peat plants remaining for cogeneration and regulation services.

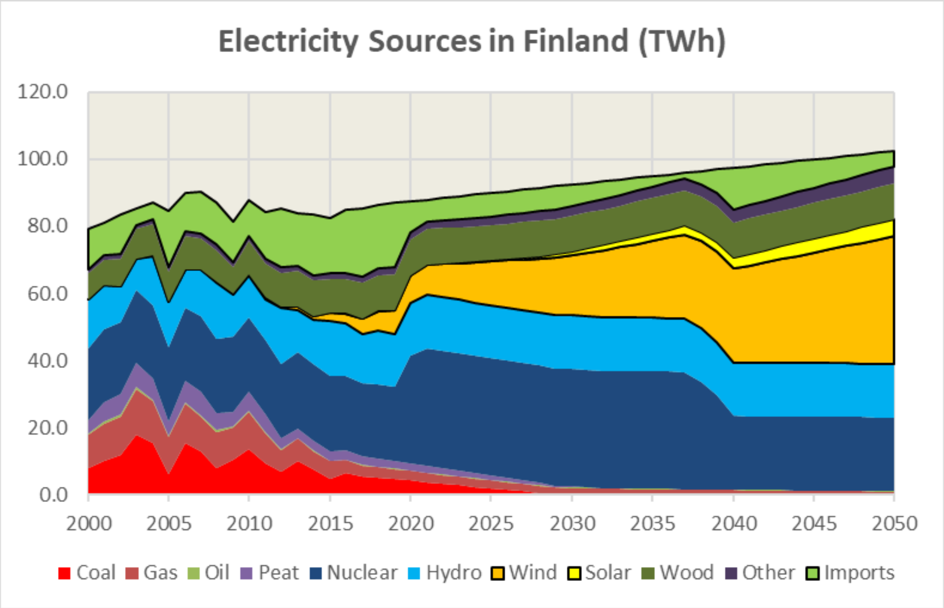


Figure 14.8.1 Electricity generation in Finland.

Another growing sector has been wind power, which will be about 8 TWh by 2020. Renewable electricity will be 35 TWh by 2020 or about the same as nuclear. The electricity generation mix in 2020 will be 44 % nuclear, 44 % renewables and 12 % fossil fired power stations.

The CO_2 emissions from electricity has been evaluated assuming that 30 % imported energy will be generated with natural gas and 70 % will be carbon free because it is coming mainly from Sweden. The emissions will be dropping from 7 $MtCO_2$ in 2018 to near zero by 2030, when coal use in electricity generation will be stopped (Figure 14.8.2).

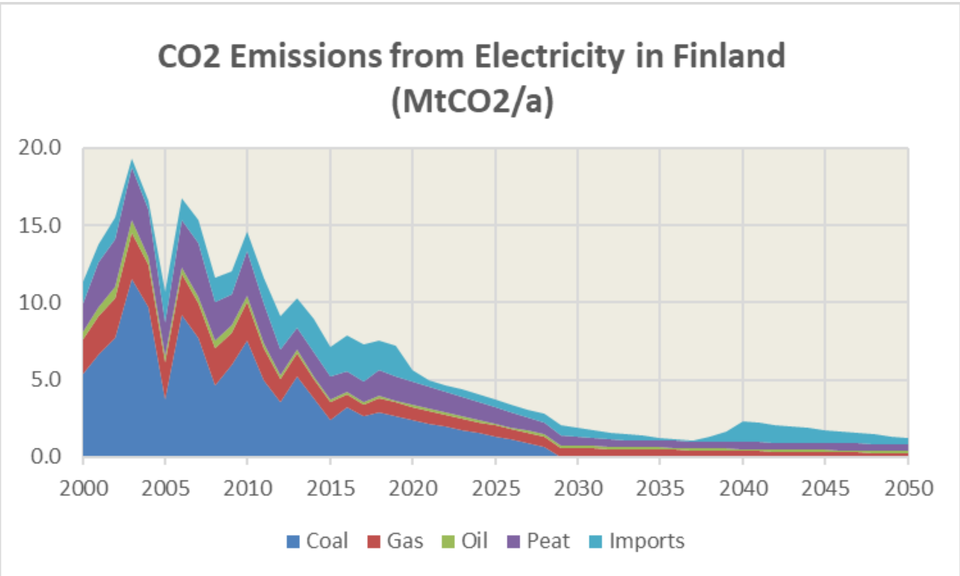


Figure 14.8.2. Emissions from electricity in Finland.

The specific emissions drop from 80 g/kWh today to about 50 g/kWh by 2021, when the new nuclear plant will be in commercial operation (Figure 14.8.3). By the year 230 electricity will be practically CO_2 free.

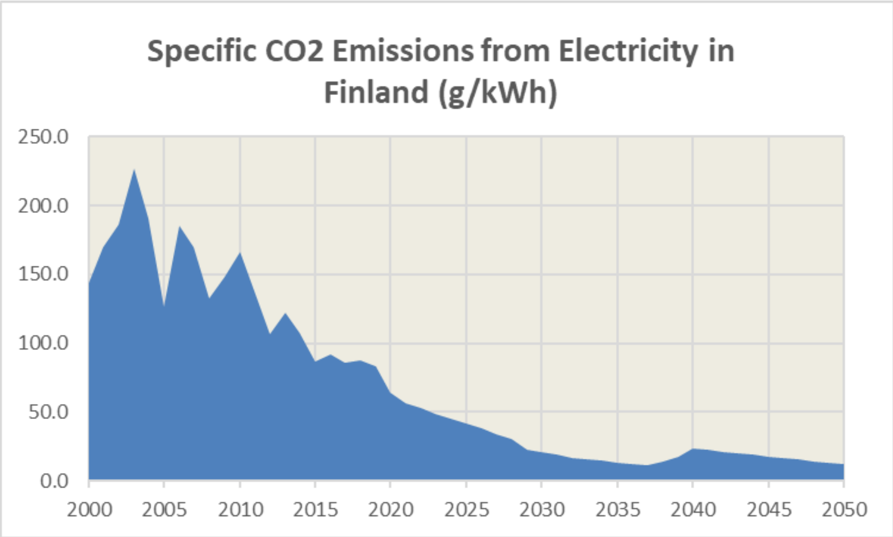


Figure 14.8.3 Specific CO_2 emissions of electricity in Finland.

Oil

Traffic, industry and heating sectors have been the highest consumer of oil in Finland. The consumption of oil in the traffic will be decreasing, because the new cars will be increasingly plug-in battery or hybrid vehicles or plug-in vehicles (PEV). In 2019 the market share is already 6 % of new cars. By 2030 PEV cars will reach 100 % market share because it has been assumed that selling of petrol or diesel cars will be banned by 2030 (Figure 14.7.4). The cars on the roads in Finland will change from oil to PEVs much slowly. By 2050 all vehicles will be PEVs (Figure 14.8.5).

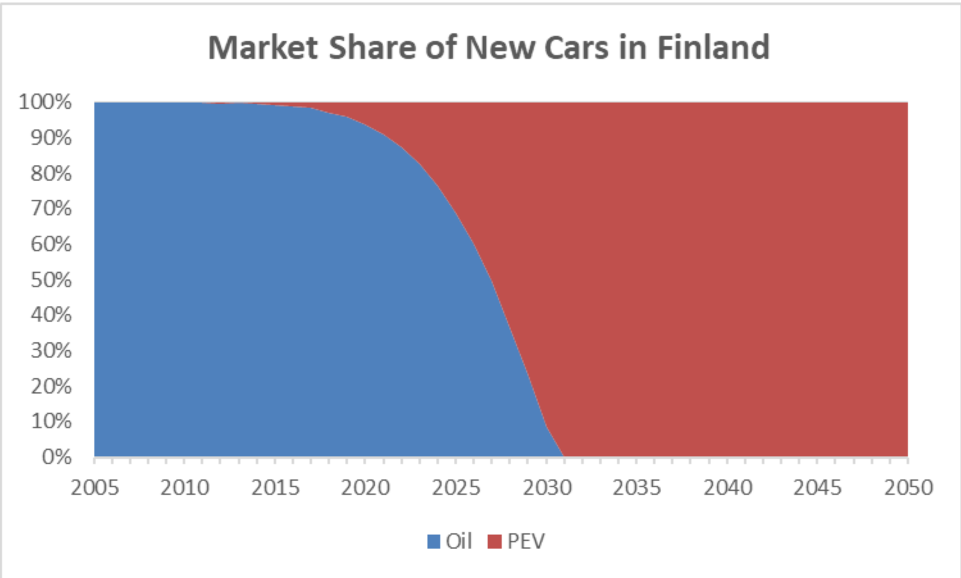


Figure 14.8.4 Market share of new cars in Finland.

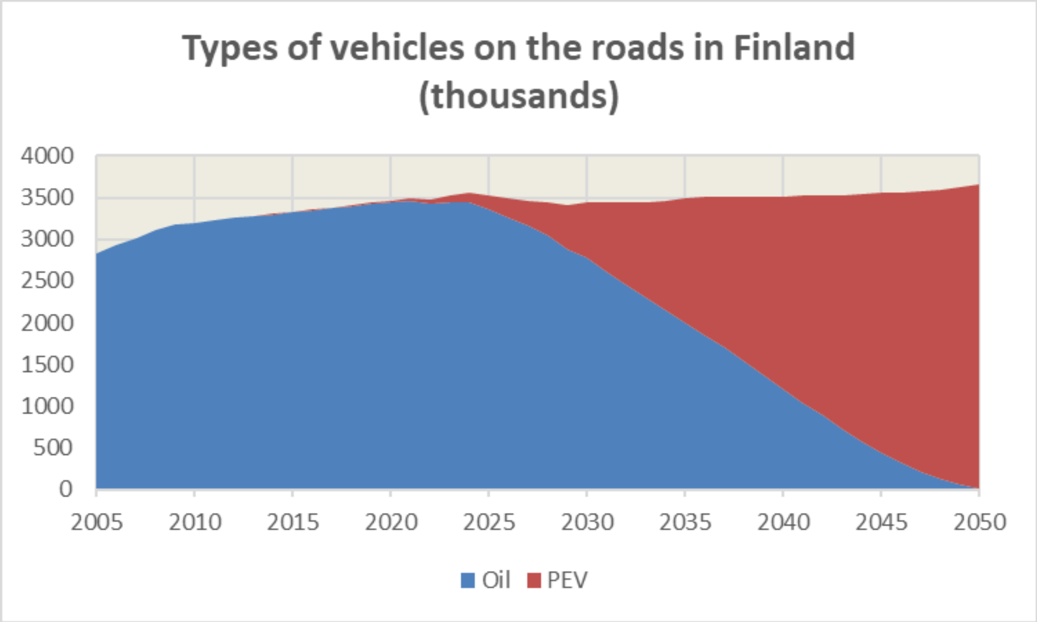


Figure 14.8.5 Market share or vehicles on the roads in Finland.

Oil consumption in Finland will decrease from 11 Mt in 2005 to 1.2 Mt by 2050 or with 88 % or 6 % annually (Figure 14.8.6). Oil consumption by vehicles will decrease from 3.5 Mt in 2005 to 0.7 Mt by 2050 or with 80 %. Oil heating will be stopped by 2030.

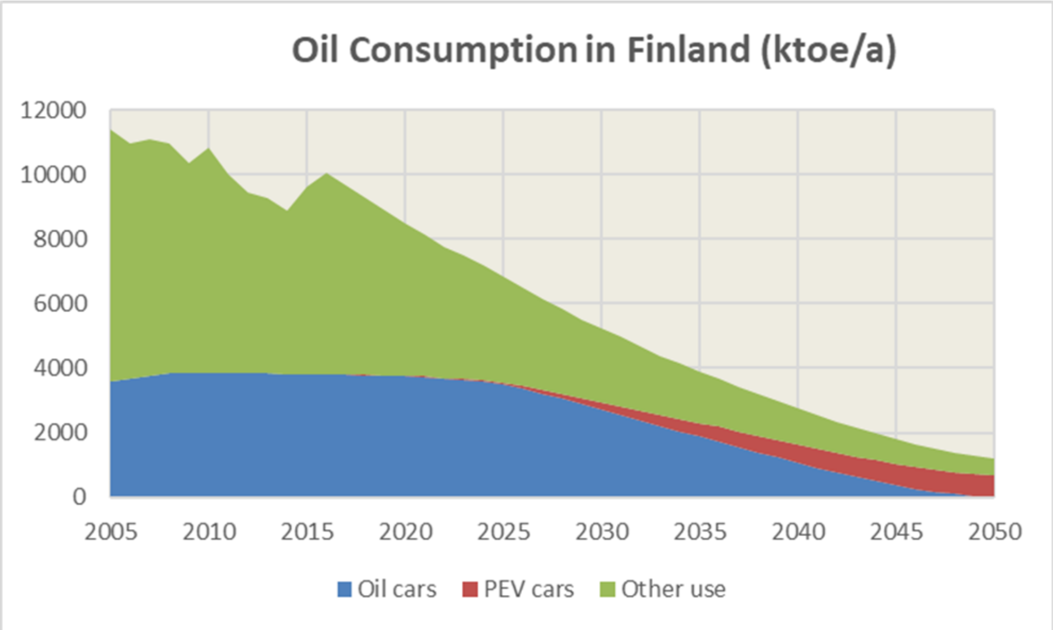


Figure 14.8.6 Oil consumption in Finland.

CO_2 emissions

CO_2 emissions in Finland have decrease from 55 Mt in 1990 to 40 Mt I 2018 (Figure 14.8.7). About 8 Mt in 2050, which is about 1.4 t/capita. Oil has caused about 65 % of CO_2 emissions in Finland and immediate actions will be needed to decrease oil consumption

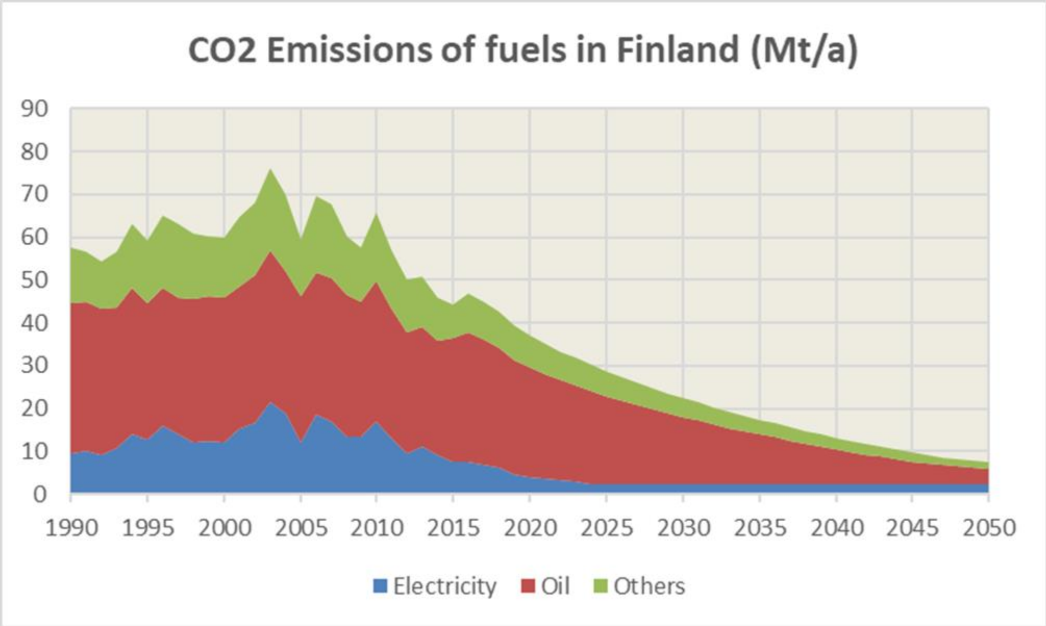


Figure 14.8.7 CO_2 emissions in Finland.

15 ECOLOGICAL LIVING

15.1 CO_2 emissions in a family

The countries can proceed only slowly in emission reductions with about 2 – 3 % reductions annually or 20 – 30 % reductions in decade. However, individual persons can make choices and start ecological emission living right away by building zero emission houses and driving zero emission cars.

One would need to start to evaluate his emissions. CO_2 emissions in our family in the year 2018 have been about 4600 kgCO_2 (Table 15.1.1). About 50 % of emissions are coming from our home, which has 82 square meters and it is connected to district heating network. The heat consumption of the 7-store building was 422 MWh. The living area was 3184 m^2 and then the specific consumption was 133 kWh/m^2.

Table 15.1.1 CO_2 emissions of a single family with two persons in the year 2018.

Year	**2018**	**Specific consumption**		**Emissions**	**kgCO2**	**Percent**
Primary house		Area	82 m2			
	Heat energy	133 kWh/m2	10906 kWh	200 g/kWh	2181	
	Electricity	25	2050 kWh	80 g/kWh	164	
	Total		12956		2345	50%
Summer cottage		Area	100 m2			
	Heat energy	10 kWh/m2	1000 kWh	0 g/kWh	0	
	Electricity	100	10000 kWh	80 g/kWh	800	
	Total		11000 kWh		800	17%
Car		Driving with engine	8000 km			
		Driving with electr.	6000 km			
	Fuel	0.08 l/km	640 l	2200 g/l	1408	
	Electricity	0.2 kWh/km	1200 kWh	80 g/kWh	96	
	Total				1504	32%
Flying		Distance	0 km			
	Fuel	0.05 l/km	0 liter	2200 g/l	0	0%
Total emissions					**4649**	100%
	Emissions per person				**2325**	

We have also a summer cottage, which is heated by wood and electricity. Because the electricity in Finland has specific emissions of 80 g/kWh, the CO_2 emissions are 17 % of our all emissions.

We have a plug-in electric vehicle and we drive about 14,000 km annually. About 60 % of the driving comes from driving with internal combustion engine and 40 % from electrical motor. Thus, the CO_2 emissions are about 1500 kg, which is about 32 % of all emissions.

We have not been flying after year 2011, which might be about the same size emitter of CO_2 as a car. We have made some trips with metro to Helsinki city, but this has caused so much emissions, because the electricity is so clean.

Our district heating company has promised to stop its coal plant by 2025 and district heat will become much cleaner. In 2025 the emissions of our heat will be about 100 g/kWh or 1000 kg less than today. In 2021 the electricity will be almost carbon free because the new 1600 MW nuclear plant will be in commercial operation a several coal plants will be decommissioned by 2025.

Then after 2025 our car is the main emitter of CO_2. However, within the year 2025 battery electric vehicles (BEV) will be much more economical and we might change the PHEV to BEV by then. The CO_2 emissions from driving will be then 1250 kg less than today. Thus by 2025 our emission will be about 1500 kfCO_2 or less than 1 ton/capita (Table 15.1.2).

Table 15.1.2 CO_2 emissions of a single family 2025.

Year	**2025**	**Specific consumption**				**Emissions**		**kgCO2**	**Percent**
Primary house			Area	82	m2				
Heat energy		133	kWh/m2	10906	kWh	100	g/kWh	1091	
Electricity		25		2050	kWh	25	g/kWh	51	
Total				12956				1142	78%
Summer cottage			Area	100	m2				
Heat energy		10	kWh/m2	1000	kWh	0	g/kWh	0	
Electricity		100		10000	kWh	25	g/kWh	250	
Total				11000	kWh			250	17%
Car		Driving with engine		0	km				
		Driving with electr.		14000	km				
Fuel		0.08	l/km	0	l	2200	g/l	0	
Electricity		0.2	kWh/km	2800	kWh	25	g/kWh	70	
Total								70	5%
Flying			Distance	0	km				
Fuel		0.05	l/km	0	liter	2200	g/l	0	0%
Total emissions								**1462**	100%
Emissions per person								**731**	

If a family will build a log house using 270 mm logs, it can have a 60 tCO_2 carbon sink (see Table 12.2.1). Using Finnish electricity (25 gCO_2/kWh) and a heat pump in the year 2025 the CO_2 emissions of a log house for heating and electricity are only 225 kg per year (Table 15.1.3). If the family has a summer cottage and a BEV-car, the total emissions will be only about 0.5 tCO_2 annually. The log house has a carbon storage of 60 tons CO_2 in its logs. This means that the household will be CO_2 free during the first 120 years.

Table 15.1.3 CO_2 emissions of a family living in a log house in Finland.

Year 2025		**Log House**	**Specific consumption**	**Emissions**	**kgCO2**	**Percent**
Primary house		Area	120 m2			
	Heat energy	125 kWh/m2	15000 kWh	10 g/kWh	150	
	Electricity	25	3000 kWh	25 g/kWh	75	
	Total		18000		225	41%
Summer cottage		Area	100 m2			
	Heat energy	10 kWh/m2	1000 kWh	0 g/kWh	0	
	Electricity	100	10000 kWh	25 g/kWh	250	
	Total		11000 kWh		250	46%
Car		Driving with engine	0 km			
		Driving with electr.	14000 km			
	Fuel	0.08 l/km	0 l	2200 g/l	0	
	Electricity	0.2 kWh/km	2800 kWh	25 g/kWh	70	
	Total				70	13%
Flying		Distance	0 km			
	Fuel	0.05 l/km	0 liter	2200 g/l	0	0%
Total emissions					**545**	100%
	Emissions per person				**273**	

15.2 Ecological eating

Food contains also greenhouse gases but has been very difficult to evaluate how much of emission they are causing. However, the average statistics of a Finn are available (15.2.1). The shops are gathering information about our food and in a near future each person can get evaluation of all food he or she has been shopping annually.

Table 15.2.1 Annual $CO_{2\text{-}eq}$ emissions of a Finn eating 940 kg of food annually.

Food per person				
- beef	18 kg/person	10 kgCO2/kg	180	kg
- pork	36 kg/person	5 kgCO2/kg	180	kg
- chicken	20 kg/person	4 kgCO2/kg	80	kg
- eggs	12 kg/person	3 kgCO2/kg	36	kg
- fish	15 kg/person	1.5 kgCO2/kg	23	kg
- milk	240 kg/person	1 kgCO2/kg	240	kg
- cereals	80 kg/person	0.7 kgCO2/kg	56	kg
- fruits	100 kg/person	0.7 kgCO2/kg	70	kg
- vegetables	116 kg/person	0.7 kgCO2/kg	81	kg
- other	300 kg/person	1 kgCO2/kg	300	kg
Total	**937** kg/person	**1.3** kgCO2/kg	**1,246**	**kg**

It is possible to reduce emission by 40 – 50 % to stop eating of beef, pork, chicken, eggs and milk. The emissions could be about 600 kgCO_{2eq}

15.3 CO_2 emissions of a family

The CO_2 emissions in our present home are today about 2.6 tCO_2 (Table 15.1.1). The total emissions are 4.6 tCO2 or 2.3 t/capita. If we are eating as an average Finn, we are producing greenhouse gas emissions 2.5 tCO_2eq today (Table 15.2.1). Thus, the total emissions would be about 7 tCO2 eq or 3.5 t/capita.

However, because the CO_2 emissions from heat and electricity could decrease by 2025, the emissions from living will drop to 1.5 tCO_2. Together with eating (2.5 tCO_{2eq}) our emissions will be 4 tCO2 or 2 t/capita. I think that we are on the track to reach the global goal to have less than 1.8 tCO_2 emissions by 2050.

16 SUMMARY AND CONCLUSIONS

Global warming

It has been found that global warming of atmosphere after years 1901 – 1930 has been about 1.0 deg. C. The 11-year average temperature has increased by 0.96 deg. C and 30-year average temperature by 0.80 deg. C. The 30-year average temperatures have been considered to measure a permanent change in climate.

It has been found in this book that the global warming has been mainly caused by the changes of solar irradiance until 1990. The total solar irradiance (TSI) has been changing +/- 0.2 W/m^2 and the irradiance has caused variation in global temperature with the formula dT = 1.23 x dTSI. Solar irradiance caused warming has been +/- 0.25 deg. C during the years 1950-1990 and has been negative since 2010.

During the last 11-years solar irradiance had caused about 0.1 deg. C global cooling. If the solar irradiance is eliminated, global warming has been increasing at rate of 0.34 deg. C per decade since 1990. The main reason for warming has been the greenhouse gases.

Model for global warming

The model for global warming developed in this book is following (See Chapter 5.2):

(5.2.2)	**dT = 1.23 x dTSI + 4.61 x ln (C/292) – 0.30 x ln (E/22.57)**

TSI is total solar Irradiance, C=CO_2 concentration in the atmosphere and E= SO_2 emissions. The formula forecasts warming during years 1901 – 2018 with 0.071 dg. C standard deviation.

Radiative forcing of CO_2 has been increasing with logarithmic relation to CO_2 concentration: Rf = 3.75 x ln(C/Co), where C = concentration of CO_2 in the atmosphere. Global temperature has been increasing with the linear relation to radiative forcing same way as solar irradiance (dT = 1.23 x dRf). Thus, the coefficient of global warming by CO_2 is 1.23 x 3.75 = 4.61. The warming has been about 1.6 deg. C (4.61 x ln (408/292= from the years 1901 – 1930 to years 2008-2018.

The concentration of CO_2 in the atmosphere will be changing with the mass balance model of CO_2, where global CO_2 emissions will be equal to change of mass of CO_2 in the atmosphere plus the change of mass of CO_2 in carbon sinks. This equation means that the carbon sinks will be absorbing CO_2 independently of emissions and can decrease mass of CO_2 in the atmosphere, if emissions will be decreasing below level of 18 $GtCO_2$/a.

Emissions of Sulphur dioxide (SO_2, E in formula) have caused global cooling with formula Rf = -0.30 x ln (E/22.57). The cooling has been about 0.5 deg. C in years 2008 – 2018 compared with the bas years 1901 – 1930.

Finally, total solar irradiance (TSI) has been cooling the earth during the years 2008 – 2018 about 0.1 deg. C. The net influence of CO_2 (+1.6), SO_2 (- 0.5) and TSI (- 0.1) has been +1.0 deg. C from the years 1901 -1930 until 2008 – 2018.

Forecasting future warming

These new evaluations will indicate that we will need to reduce the CO_2 emissions with 50 % by 2050 to limit global warming to 2.0 deg. C, which was set as a limit in Paris in 2016. This can be achieved in all countries will limit their emissions to 1.8 t/capita by 2050. Then the global emissions will be 18 Gt, which is about 50 % from the present level.

Only with 4 % annual decrease in CO_2 emissions the warming will be limited to 1.5 deg. C. This is impossible because countries like China and India are still increasing their emissions. Thus, the world needs to adapt itself to live in a 2-degree warmer world than during the years 1901-1930. This will mean changes in weather, smelting of ice in Greenland and Antarctic, which will cause about 50 – 80 cm rise in seawater level by 2100.

In the very long-range influence of CO_2 will be decreasing as fossil fuel period will end by the year 2200 and most of the CO_2 will be absorbed by the seas. However, there is a risk that absorption will be slowing down.

In the long run the changes in climate will be caused by changes in eccentricity of earth´s orbit, which will be warming the world until the year 30,000 AD, when the orbit is approaching a form of a circle. After year 110,000 AD global cooling will start, because the orbit will be starting to approach oval form. In about 250,000 AD the cooling will be more that 1.0 deg. C and a new ice age may be coming.

Actions needed

We will need global and individual actions to limit warming to less than 2 degrees. The promises given in Paris 2016 are not enough. Individuals can start to make actions at once and ask, what action his or her representative in the parliament will do. You should ask also what you can do for your country to save the world.

To limit global warming to 2 degrees Celsius all nations should have a same coal to reduce CO2 emissions by 2050 to less than 1.8 tCO2/capita