# Solving of the climate change problem


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The article is based on the book *Energiankäyttäjän käsikirja 2013* (in Finnish).


## Summary

***The climate change problem is how to limit global temperature rise to less than 2 $^{o}$C. This can be done by first to understand the mathematics of temperature increase, which is caused by the increase of $CO_2$-emissions. The theory of temperature increase was invented by Swedish Nobel Laureate Svante Arrhenius, who wrote in Philosophical Magazine in 1896 that temperature ($\Delta T$) is increasing according to content of $CO_2$ in the atmosphere by formula:***

$$\Delta T = K \times \log (C/280)$$

***where***

***K = constant, which is 6.8 $^{o}$C by this evaluation***

***C= concentration of $CO_2$ in the atmosphere (ppm) = 280 ppm in 1700***

***Then the action plan should be developed, which will limit the CO2-concentration to 550 ppm. This will mean that cumulative emissions should not exceed 3700 Gt. Because 1400 Gt has been already emitted, the plan should be developed so that the total emissions from energy industries will be less than 2300 Gt in the future.***

***The plan is following:***

1) ***The emissions should be stabilized to present level of 36 Gt/year until 2040. Every country should have less than 4.2 t/capita by 2040.***
2) ***After 2040 each country should decrease its emissions 2 % annually. The emissions in 2100 will be then 10 Gt annually.***


## 1 Temperature increase

According to the measurements made by the Finnish Meteorological institute the temperature has increased from the beginning of 1900–century until today with about 1 $^{o}$C. This can be calculated using 30 year average temperature measurements from 1900-1930 and 1980-2010, which show that the average temperature in Finland has increased with about 0.77 $^{o}$C within 80 years (Figure 1.1).

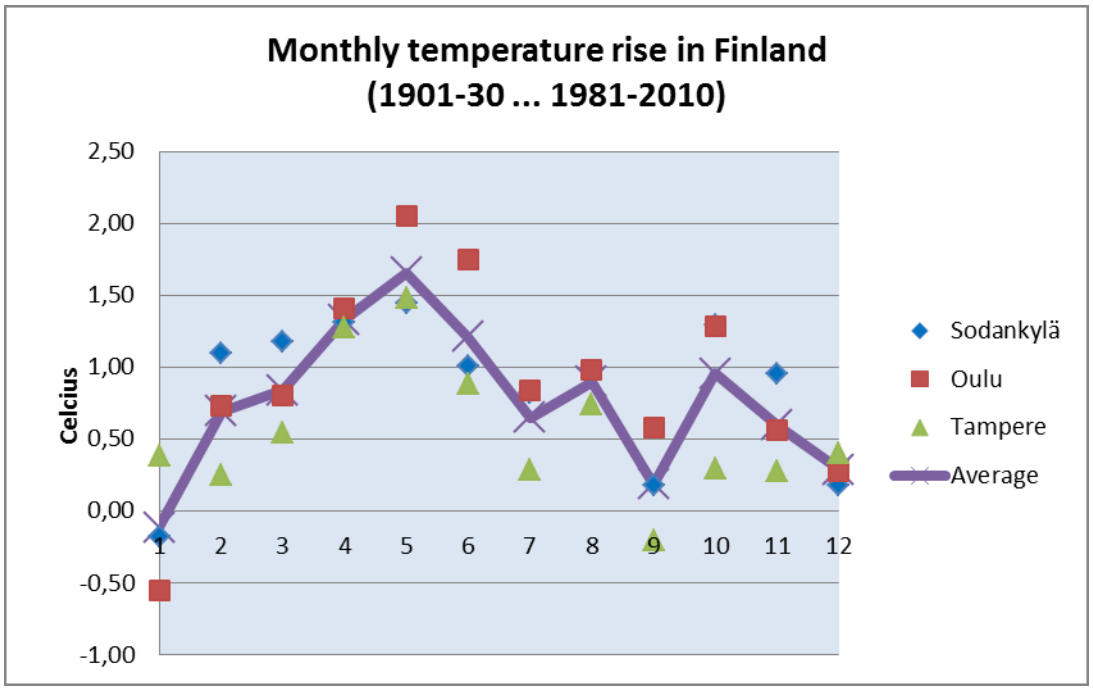


*Figure 1.1 Monthly temperature rise in Finland has been 7.7 $^{o}$C.*

The $CO_2$-emissions are quite well known cumulative from 1965, which is the starting year of emissions data in British Petroleum (PB) energy statistics. The data shows that until 1995 the cumulative emissions were about 980 Gt. In 1995 the $CO_2$-concentration was 361 ppm. Using the formula:

(1) $$T = 6.8 \times \log(361/280) = 0{,}75\ ^{o}C$$

We can found that the temperature increase should have been 0.75 $^{o}$C.

**The future temperature increase should be limited to two degrees of Celsius. Using the formula (1) we can evaluate that the $CO_2$-concentration should be less than 550 ppm**

The ten year averages in temperature increase have been fluctuating because of the aerosols and solar radiations (Figure 1.2). The measurements in Sodankylä in North Finland, are one of the most reliable measurements, because they are far from coast and major cities.

The same kind of fluctuation has been noticed in the average temperatures of the world (Figure 1.3). The study points out that about 2/3 of the temperature increase has been caused by the mankind (anthropogenic). Thus the forecast of the future temperature increases can be considered to be the maximum estimates. Minimum estimates are about 2/3 about the maximum estimates.

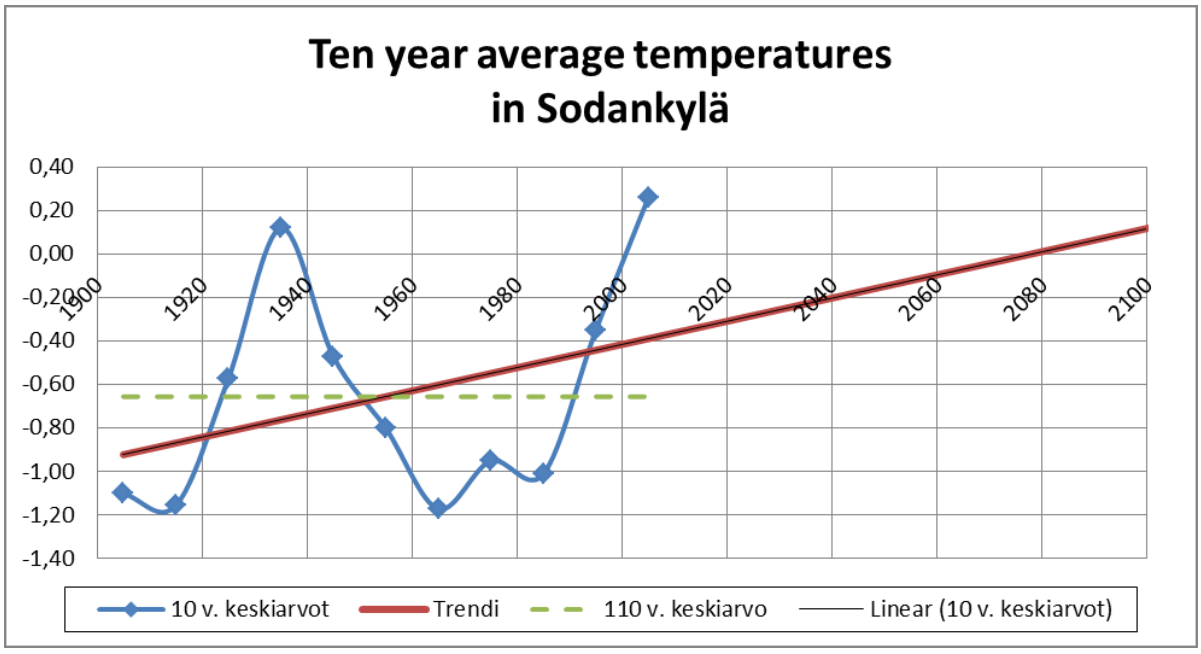


*Figure 1.2 The temperature increase in Sodankylä.*

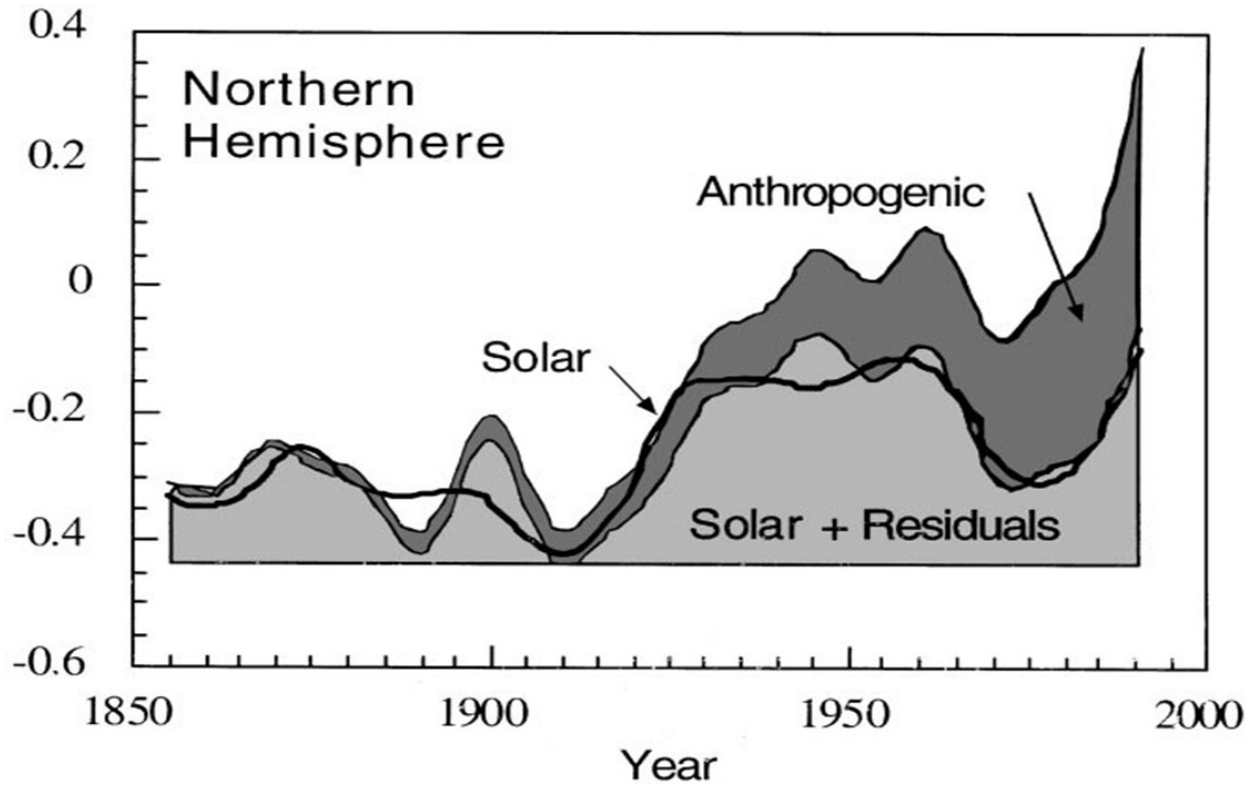


*Figure 1.3 Analysis of temperature increases in the Northern Hemisphere (Beers et al.).*

## 2. Concentration and emissions

The cumulative emissions have been increasing according to the Figure 2.1 and the $CO_2$ concentration according to the Figure 2. If we present the $CO_2$-concentration and cumulative $CO_2$-emissions in the same Figure 3, we can find that the $CO_2$-concentration has increased by 76 ppm from 1960, when the emissions have been 1110 Gt after 1960.

We can continue the line in Figure 2.4 to estimate future cumulative emissions and concentration development in Figure 3.1. From the figure one can see that the critical value of 550 ppm can be reached, if the cumulative emissions will be 3700 Gt.

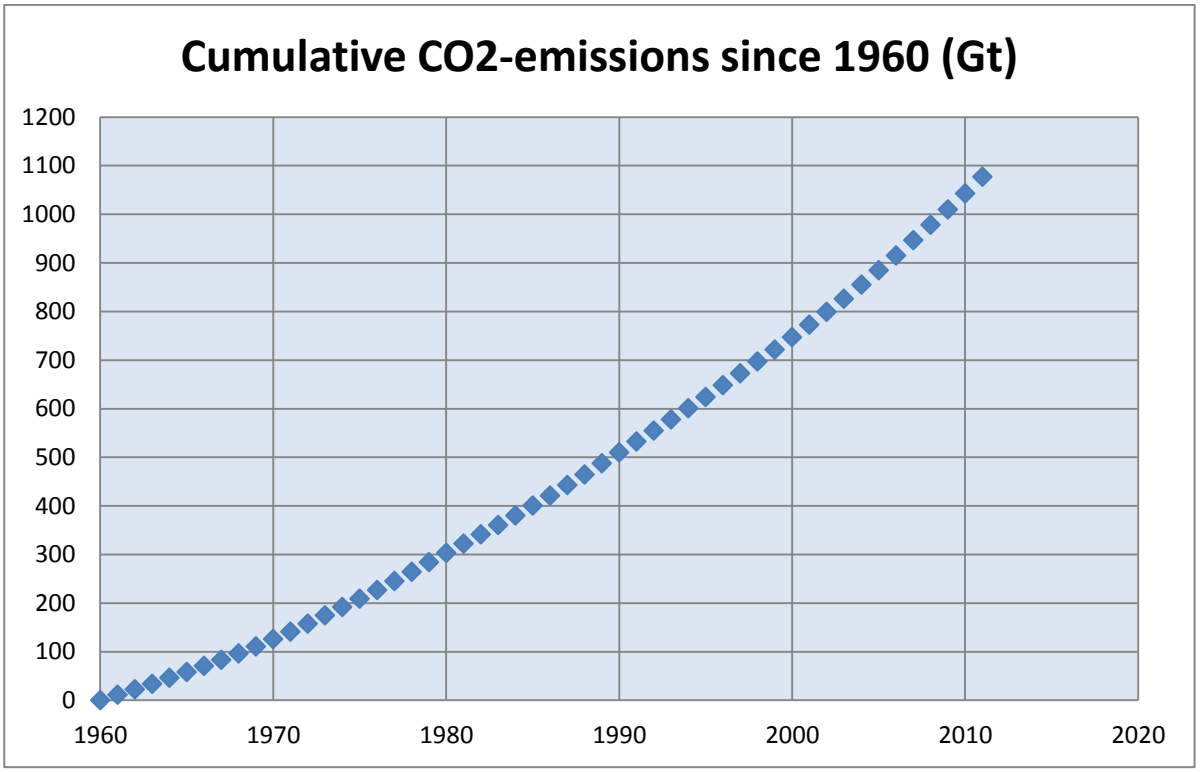


*Figure 2.1 Cumulative emissions since 1960.*

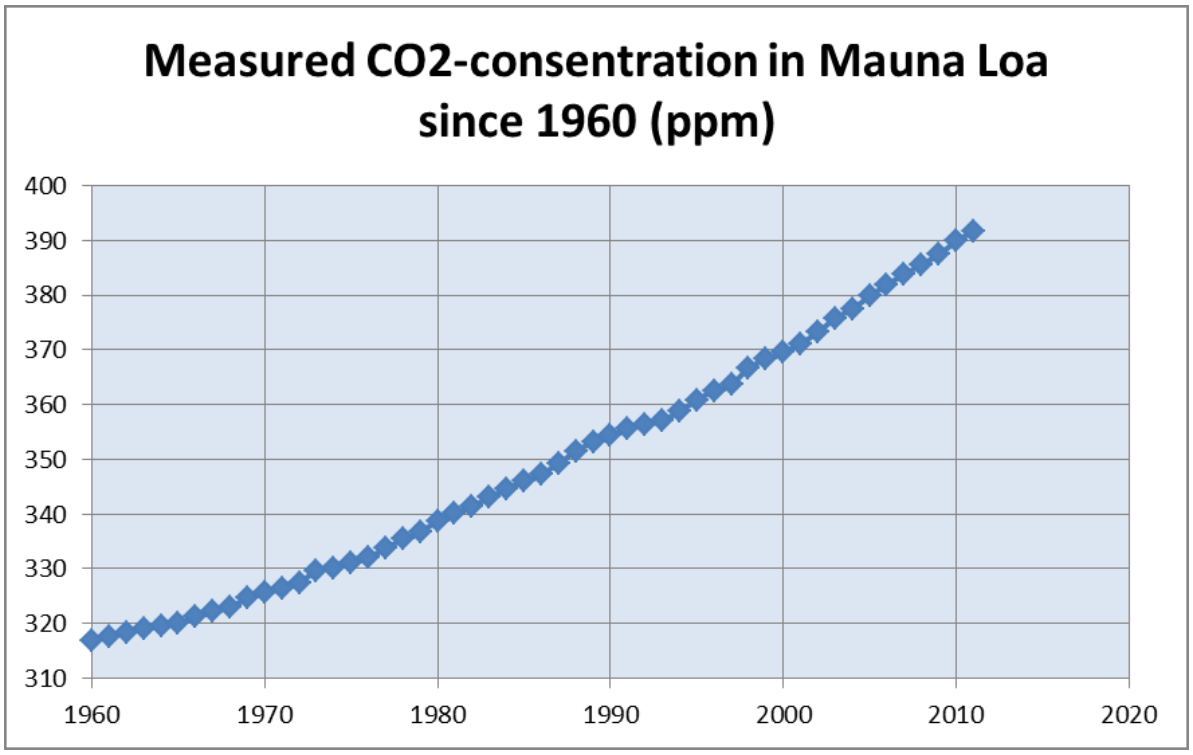


*Figure 2.2 Measured CO2-concentration in Mauna Loa.*

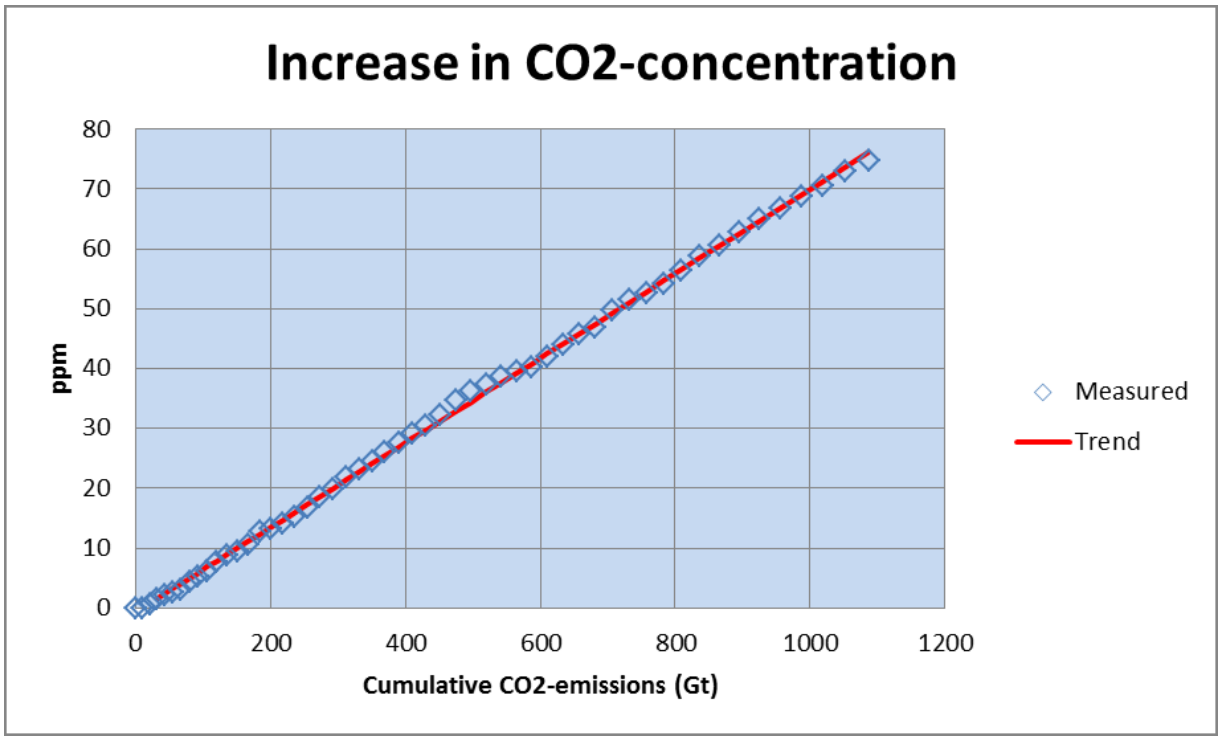


*Figure 2.3 Concentration has increased with 76 ppm at 1110 Gt emissions.*

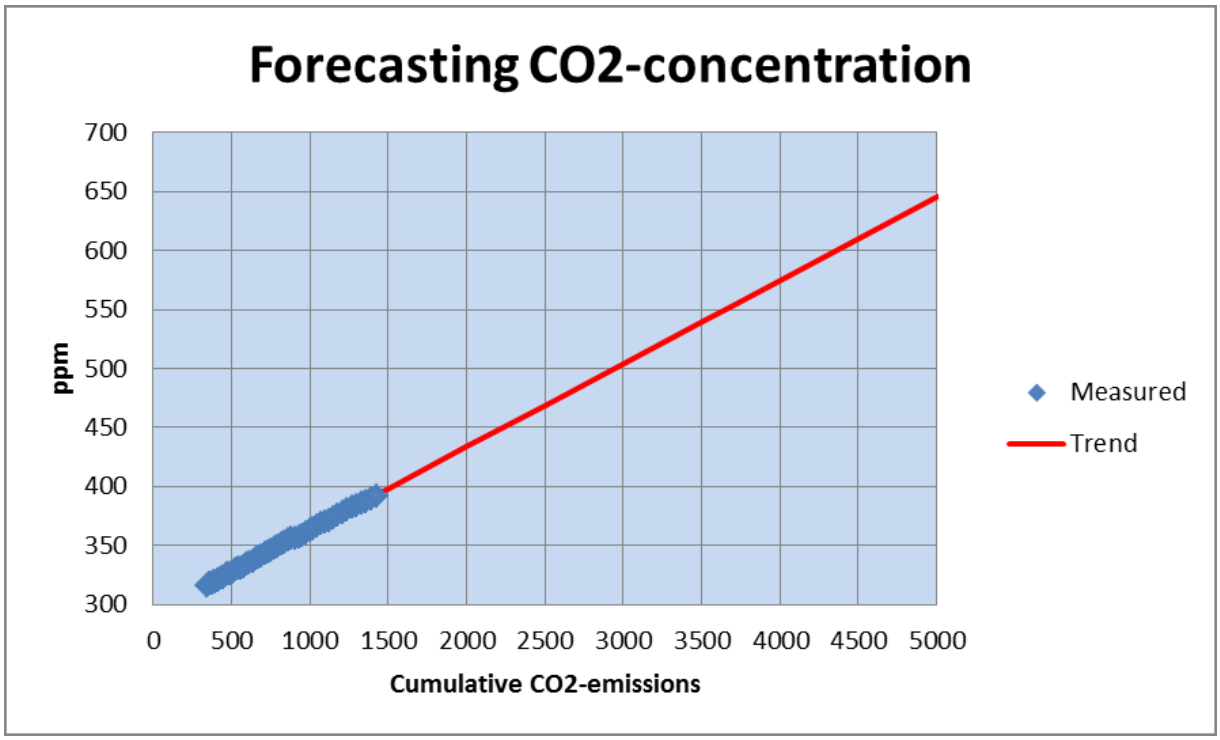


*Figure 2.4 Concentration of 550 ppm will be reached at 3700 Gt emissions.*

## 3 Reduction of $CO_2$-emissions

There are many ways to limit the cumulative emissions to 3700 Gt. One plan is to reduce emissions 1 % each year starting today. This will mean that the cumulative emissions will be about 3420 Gt until the year 2100 (Figure 5). The $CO_2$-concentration will be 526 ppm in 2100 (Figure 3.1).

However, it is not possible to reduce emissions starting today, because of the long construction time of the power plants. It is probable that the emissions are increasing for a while. If the present trend of increasing of emissions is continuing, the cumulative emissions will reach 7500 Gt and the concentration will increase to 800 ppm. This will mean that the temperature will increase with 3.2 $^{o}$C according to the formula (1). Thus better plan should be developed.

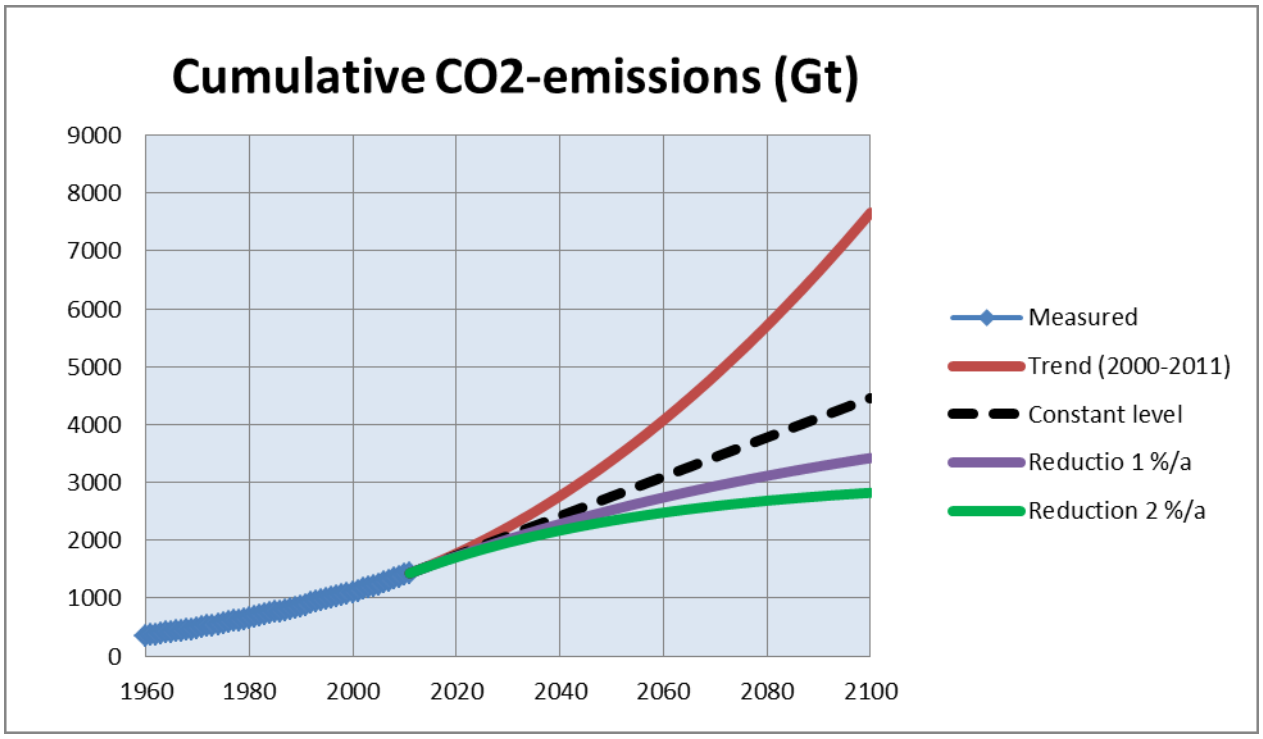


*Figure 3.1 Cumulative emissions until 2100.*

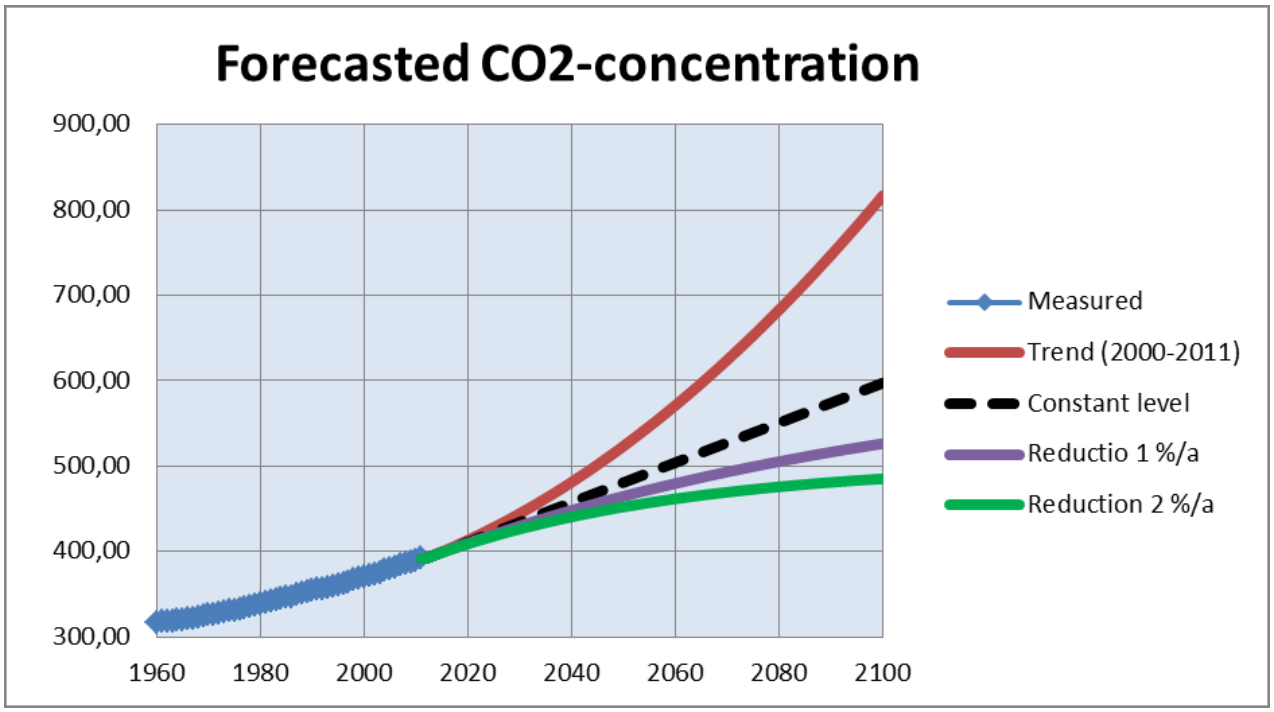


*Figure 3.2 Forecasted CO2-concentration.*

# 4 Reduction plan

The reduction plan of emissions has been given in Table 4.1. Until 2040 the CO2-emissions will be kept at today's level of 36 Gt annually. At 2040 each country has the same emission limit 4.2 t/capita.

*Table 4.1 Reduction plan*

| Year | World Population milj. | Emissions Mt | Reduction % | Emissions t/capita | Cumulative emissions Mt |
|---|---|---|---|---|---|
| 2010 | 7,0 | 36,0 | 0 % | 5,1 | **1364** |
| 2020 | 7,5 | 36,0 | 0 % | 4,8 | **1724** |
| 2030 | 8,0 | 36,0 | 0 % | 4,5 | **2084** |
| 2040 | 8,5 | 36,0 | 0 % | 4,2 | **2444** |
| 2050 | 9,0 | 29,4 | -18 % | 3,3 | **2771** |
| 2060 | 9,2 | 24,0 | -33 % | 2,6 | **3038** |
| 2070 | 9,4 | 19,6 | -45 % | 2,1 | **3257** |
| 2080 | 9,6 | 16,0 | -55 % | 1,7 | **3435** |
| 2090 | 9,8 | 13,1 | -64 % | 1,3 | **3581** |
| 2100 | 10,0 | 10,7 | -70 % | 1,1 | **3700** |

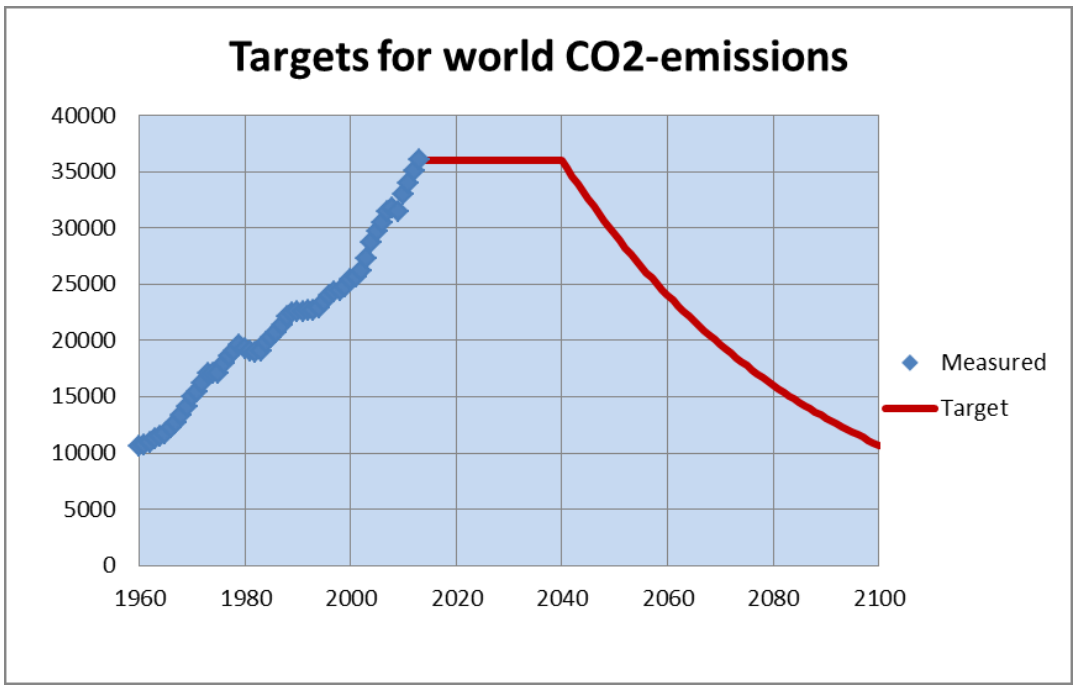


*Figure 4.1 Reduction plan of world CO2-emissiions.*

After 2040 all countries should reduce their emissions 2 % annually so that world emissions will be 10 Gt in 2100. The cumulative emissions will be 3700 Gt, which was the goal. The target will be much harder to developed countries like Finland, which should start reduction today with 2.6 % annually to reach the 4,2 t/capita coal by 2040 (Table 4.2).

*Table 4.2 Emission targets for Finland.*

| Year | Finland Population milj. | Emissions Mt | Reduction % | Emissions t/capita |
|---|---|---|---|---|
| 2010 | 5,4 | 56,0 | 0 % | 10,4 |
| 2020 | 5,6 | 43,0 | -23 % | 7,7 |
| 2030 | 5,8 | 33,1 | -41 % | 5,7 |
| 2040 | 6,0 | 25,4 | -55 % | 4,2 |
| 2050 | 6,2 | 20,8 | -63 % | 3,3 |
| 2060 | 6,4 | 17,0 | -70 % | 2,7 |
| 2070 | 6,6 | 13,9 | -75 % | 2,1 |
| 2080 | 6,8 | 11,3 | -80 % | 1,7 |
| 2090 | 7,0 | 9,3 | -83 % | 1,3 |
| 2100 | 7,2 | 7,6 | -87 % | 1,0 |

However, the developed countries like Finland can build nuclear power plants to reduce the emissions. The developed countries have also enough money to build capital intensive power plants like solar and wind. They can also put large efforts in insulating their homes. Also China should start reduction to achieve 4.2 t/capita target.

**References**

Asko Vuorinen "*Energiankäyttäjän käsikirja 2013*" (in Finnish)

J. Beer, W. Mende, R. Stellmacher. "*The role of the sun in climate forcing"*. Quarterly Science Review. 2000

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