2. FUNDAMENTALS OF EMISSION CONTROL

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AMBIENT AIR STANDARDS

1 Sulfur Oxide (SO2)

2 Nitrogen Oxides (NO2)

3 Particulate matter (PM 10, PM 2,5)

4 Ozone

Ambient Air (WHO)
Sulphur Oxides (SO2)

- 24 h average
  - 125 ug/m3 Target 1
  - 50 ug/m3 Target 2
  - 20 ug/m3 Guideline
- 10 minute average
  - 500 ug/m3 Guideline

Ambient Air (WHO)
Nitrogen Oxides (NO2)

- 1 year average
  - 40 ug/m3 Guideline
- 1 hour average
  - 200 ug/m3 Guideline

Ambient Air (WHO)
Particulate matter PM10

- 1 year average
  - 70 ug/m3 Interim target 1
  - 50 ug/m3 Interim target 2
  - 20 ug/m3 Guideline
- 24 hour average
  - 150 ug/m3 Interim target 1
  - 100 ug/m3 Interim target 2
  - 50 ug/m3 Guideline

Ambient Air (WHO)
Particulate matter PM2,5

- 1 year average
  - 35 ug/m3 Interim target 1
  - 25 ug/m3 Interim target 2
  - 10 ug/m3 Guideline
- 24 hour average
  - 75 ug/m3 Interim target 1
  - 50 ug/m3 Interim target 2
  - 25 ug/m3 Guideline

Emission standards

Sulfur oxides

Nitrogen oxides

Particles

CO2-emissions

Emission standards (EU)
Sulfur Oxides

- Fuel input>300 MWt
  - Solid and liquid fuels 200 mg/m3
  - Natural gas plants 35 mg/m3
- 50 -100 MWt
  - Solid and liquid fuels 850 mg/m3
  - Biomass 200 mg/m3
  - Natural gas 35 mg/m3

Emission standards (EU)
Nitrogen Oxides

- Fuel input>300 MWt
  - Solid and liquid fuels 200 mg/m3
  - Natural gas plants 100 mg/m3
- 50 -100 MWt
  - Solid and liquid fuels 400 mg/m3
  - Biomass 400 mg/m3
  - Natural gas 100 mg/m3

Emission standards
Nitrogen Oxides

- Diesel engines (World Bank)
  - Normal 2000 mg/m3 (15 % O2)
  - Difficult areas 400 mg/m3 (15 % O2)
- Gas Engines (German TA-luft)
  - Normal 500 mg/m3 (5 % O2)
  - Difficult areas 250 mg/m3 (5 % O2)
- Gas turbines (>50 MWt)
  - oil fired 120 mg/m3 (15 % O2)
  - gas fired 50 mg/m3 (15 % O2)

Emission standards
Particles (World Bank)

- Diesel engines (heavy fuel oil)
  - <50 MWt 100-150 mg/m3 (15 % O2)
  - >50 MWt 50 mg/m3 (15 % O2)
- Diesel Engines (light fuel oil)
  - < 100 MWt 30 mg/m3 (15 % O2)

Emission standards
Particles (EU)

- Solid fuels
  - 50-100 MWt 50 mg/m3 (6 % O2)
  - >100 MWt 50 mg/m3 (6 % O2)
- Liquid fuels
  - 50-100 MWt 50 mg/m3 (3 % O2)
  - >100 MWt 50 mg/m3 (3 % O2
- Gaseous fuels
  - > 100 MWt 5 mg/m3 (3 % O2)
  - 50-100 MWt 10 mg/m3 (3 % O2)

CO2-emissions

CDE (g/kWh) = C (g/kWh) / η

Were C = carbon content of fuel

η = efficeincy

CO_2 contents of burning with 100 % efficiency

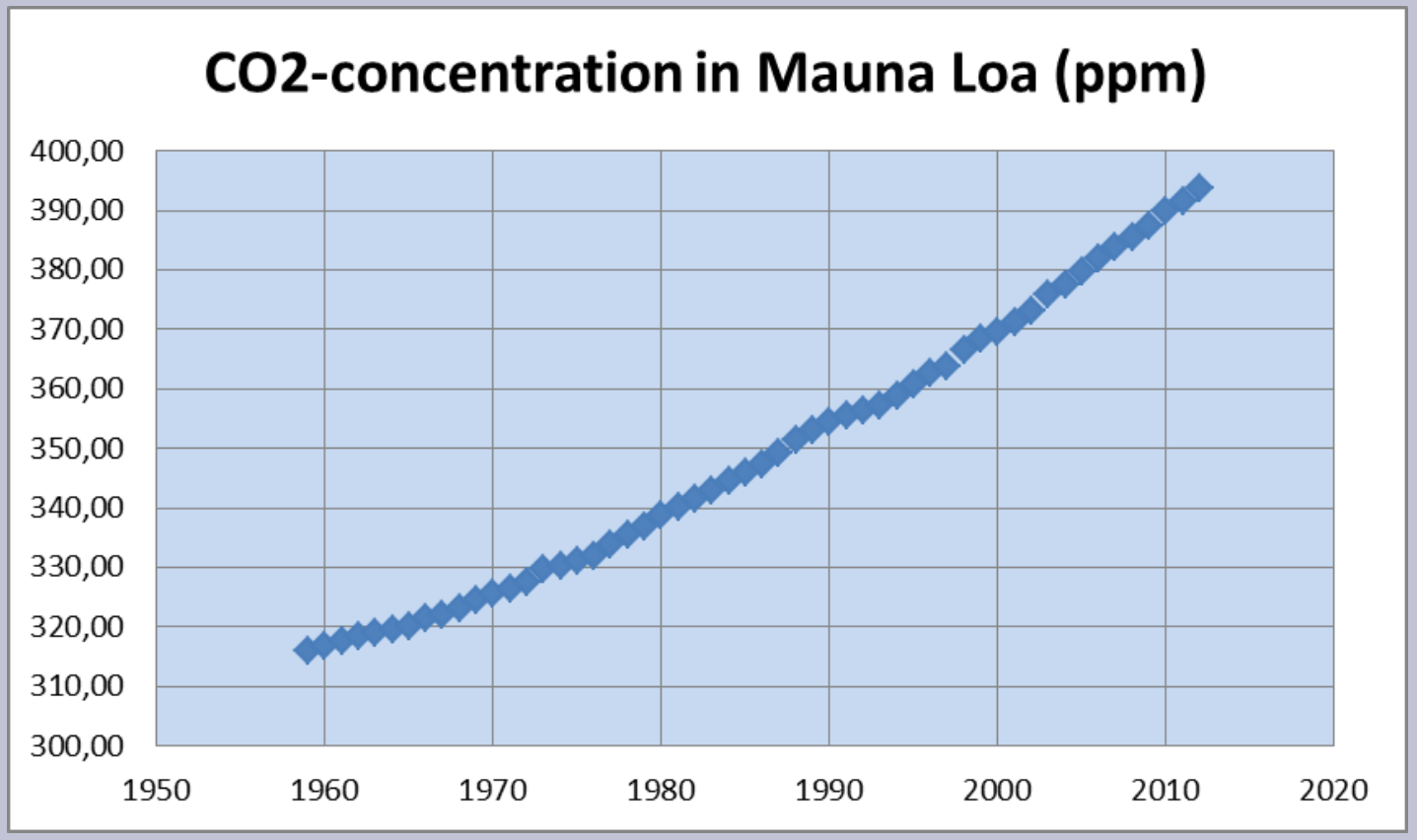
- Natural gas 202 gCO_2/kWh
- Distillate oil 266 ”
- Residual fuel oil 278.2 ”
- Hard coal 340.6 ”
- Lignite (peat) 360-430

CO2-emissions

	g/kWh
Gas fired plants	
CHP 90 % efficiency	224
GTCC 55 % efficiency	367
Gas Engine 45 % efficiency	449
Gas Turbine 33 % efficiency	612
Coal fired plants	
Supercritical 45 % efficiency	757
Subcritical 38 % efficiency	896

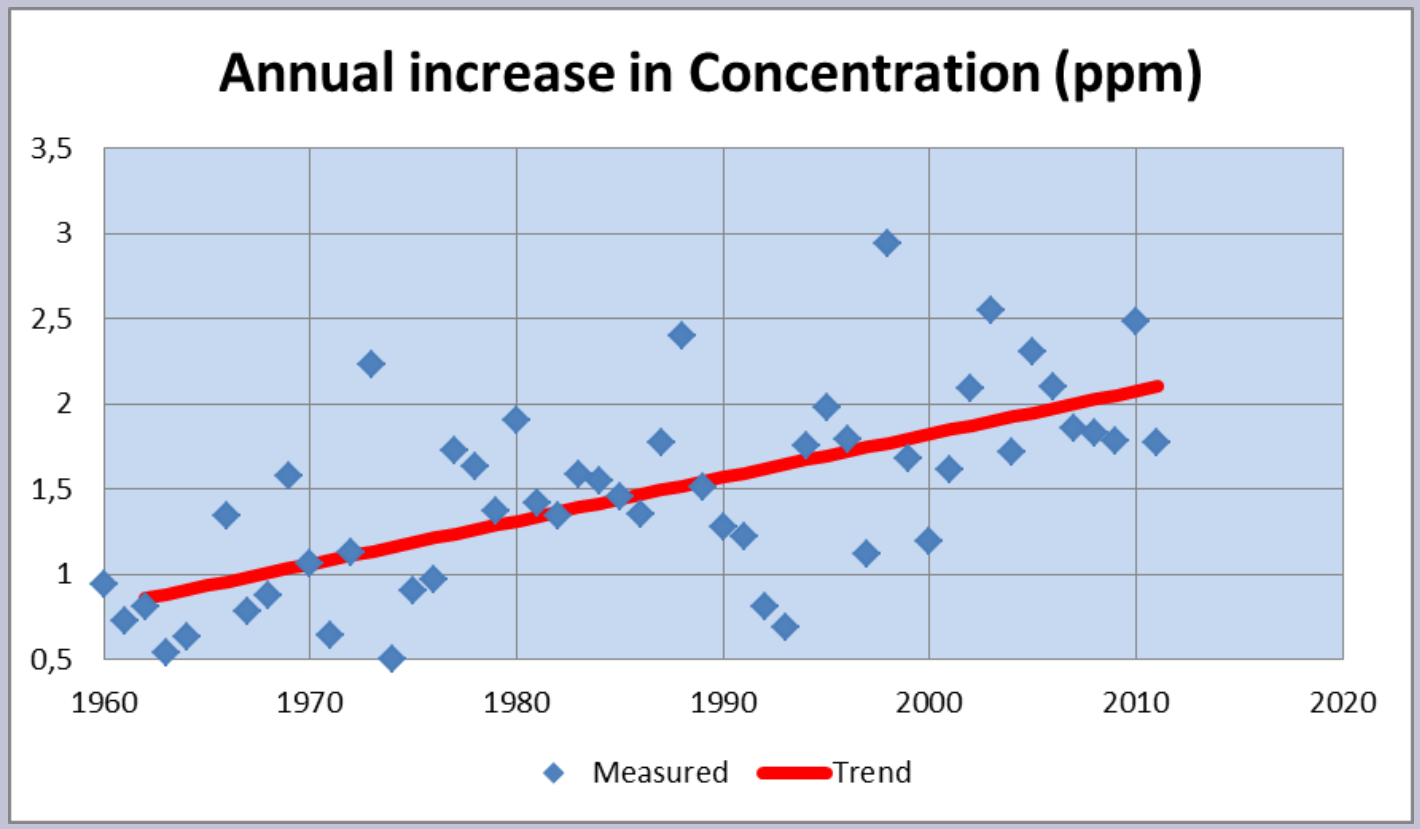
CO2-concentration in atmosphere

Measured CO2-concentration in Mauna Loa (ppm)



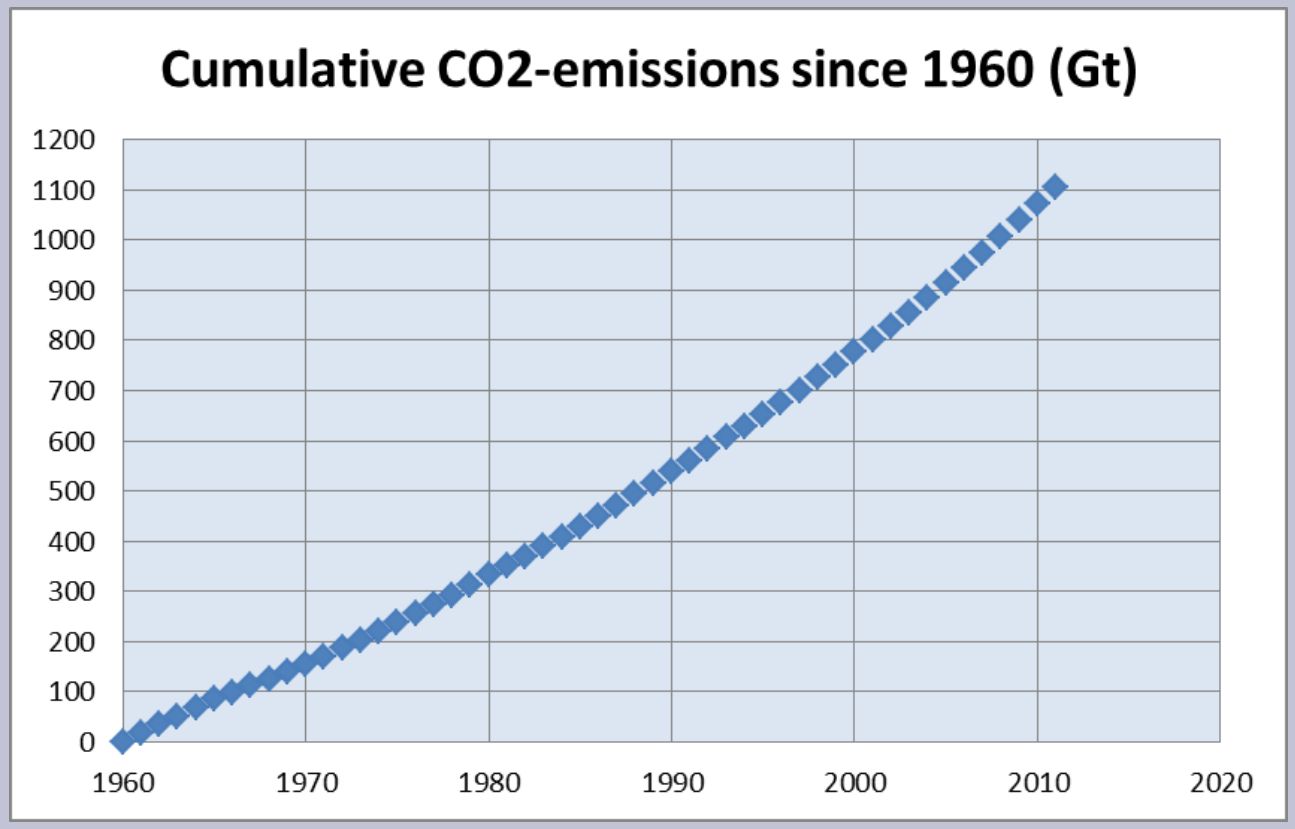
Concentration has increased with 41 % from 280 ppm

Linear trend of increase in CO2-concentration

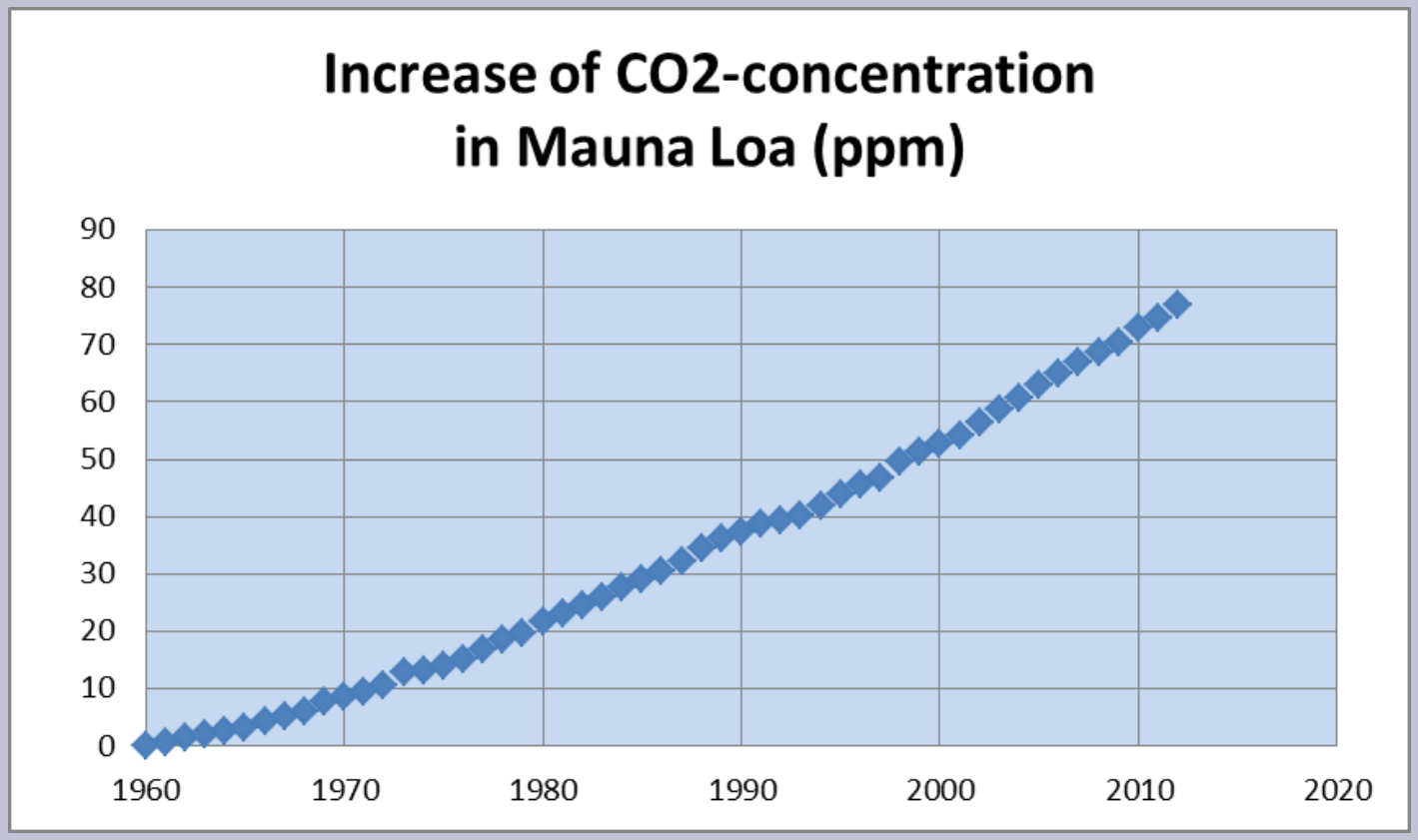


Annual increase is increasing + 1 ppm/50 years

Cumulative CO2-emissions

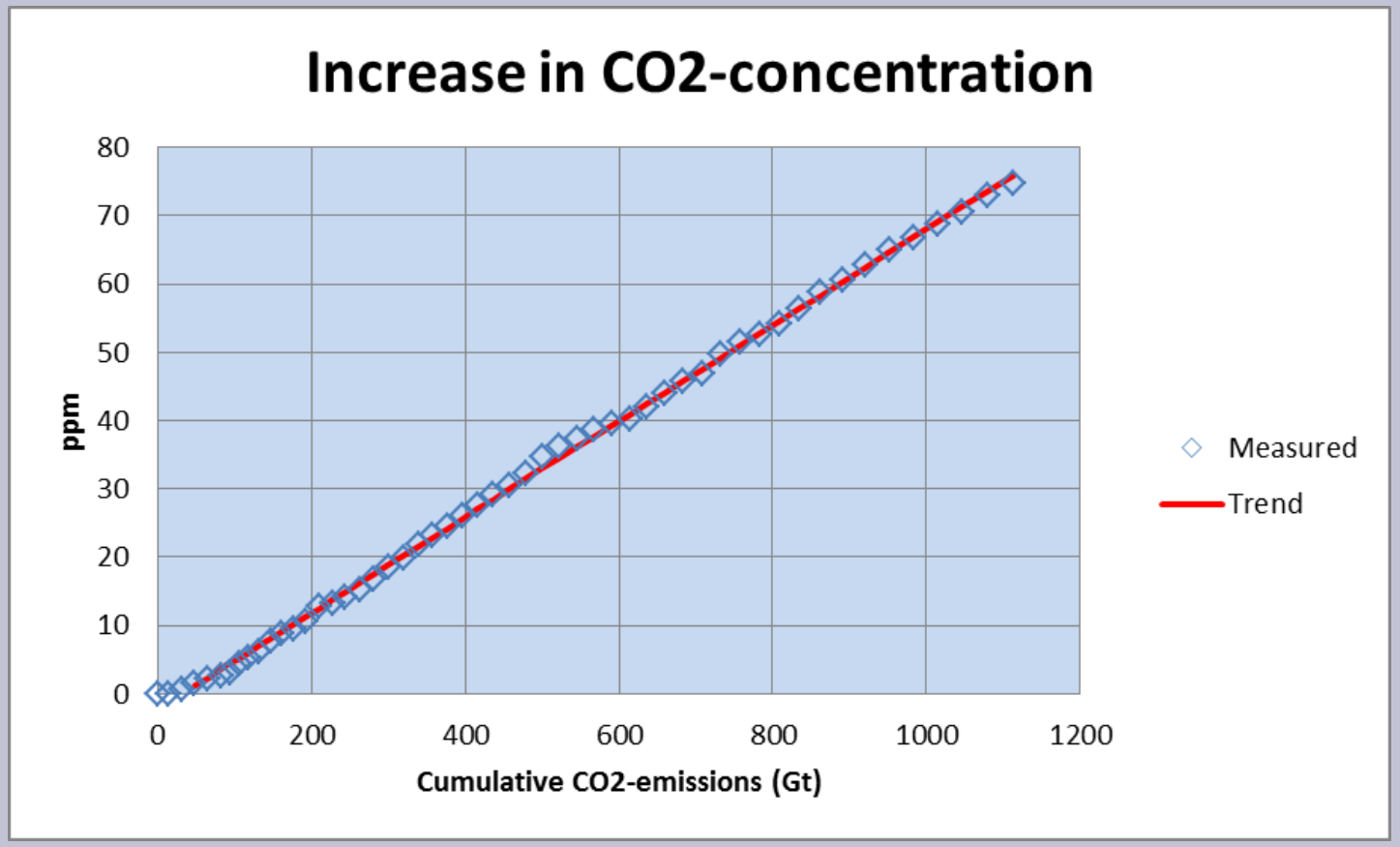


Increase in concentration since 1960



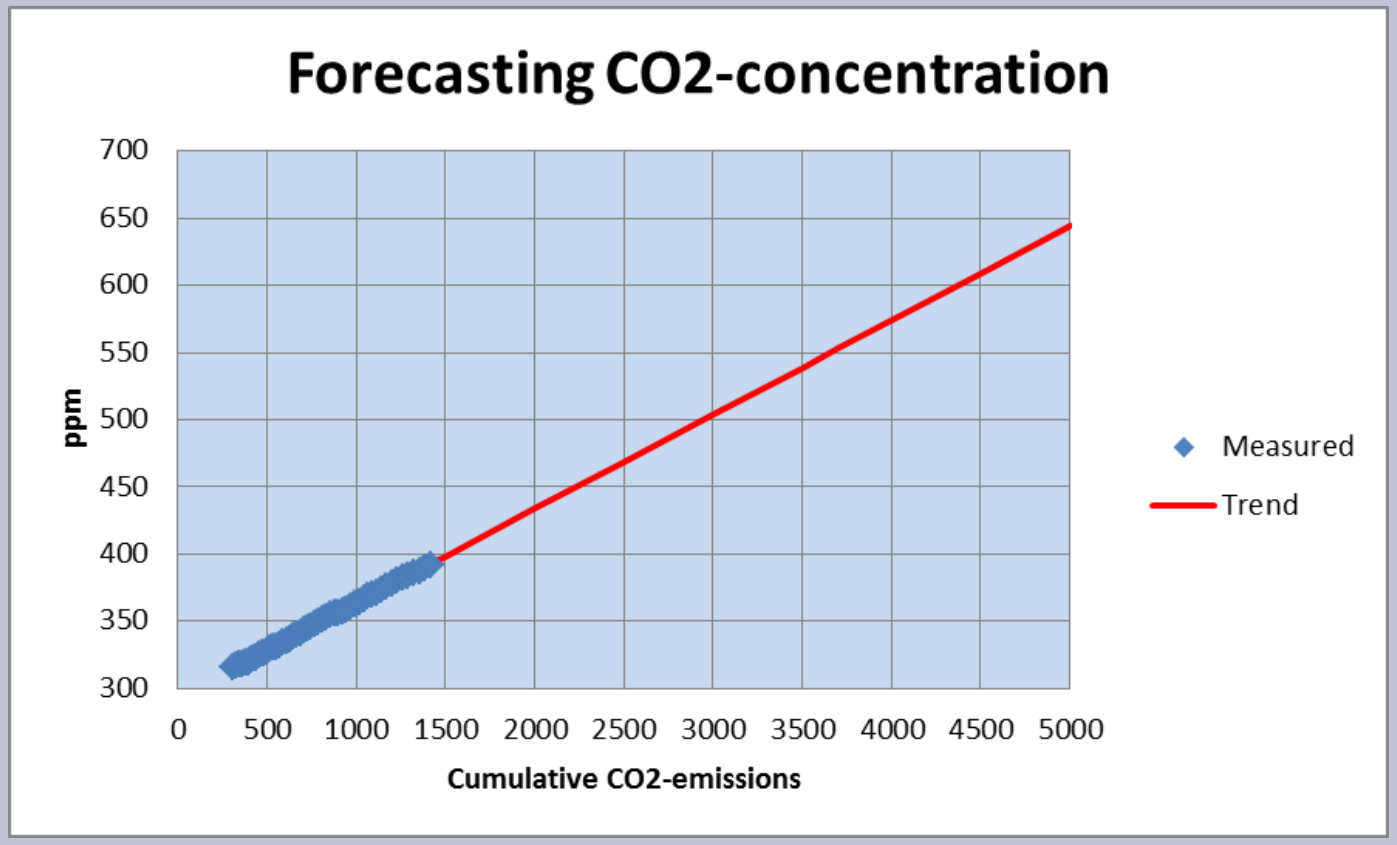
76,9 ppm increase since 1960

Correlation of CO2-concentration and emissions



1110 Gt emissions cause 75 ppm increase in concentration

Forecasting of CO2-concentration using emissions



Concentration will increase to 550 ppm,
if emissions will be 3700 Gt

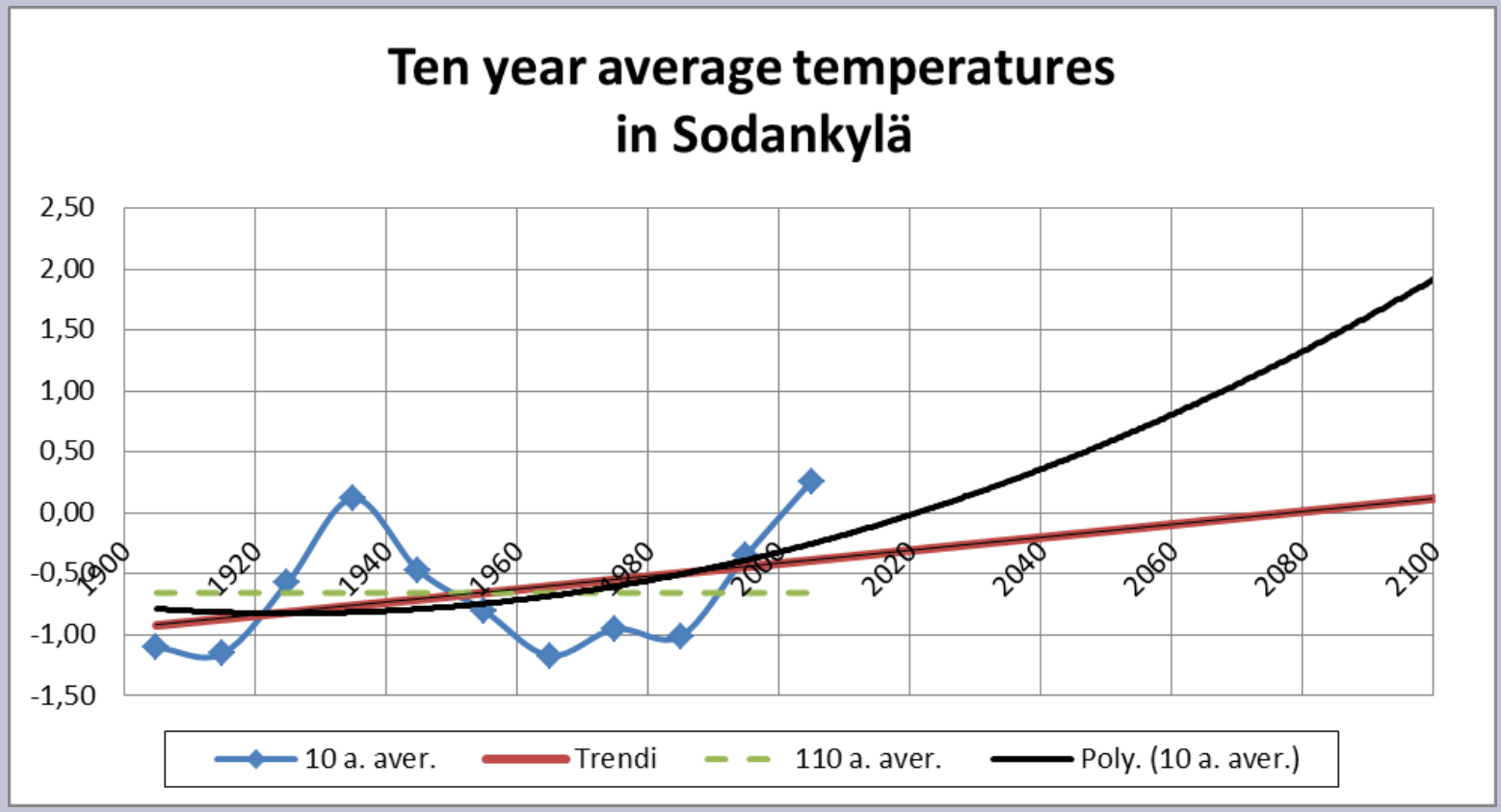
Global warming

CO2 content in air and global temperature

- Samuel Langley made tables of infrared radiation of moon
- Svante Arrhenius* made a formula
  - T = α x log (C/C0), where
  - T = temparture in the atmosphere
  - C0 = CO2 concentration in the beginning
  - C = CO2-concentration in future

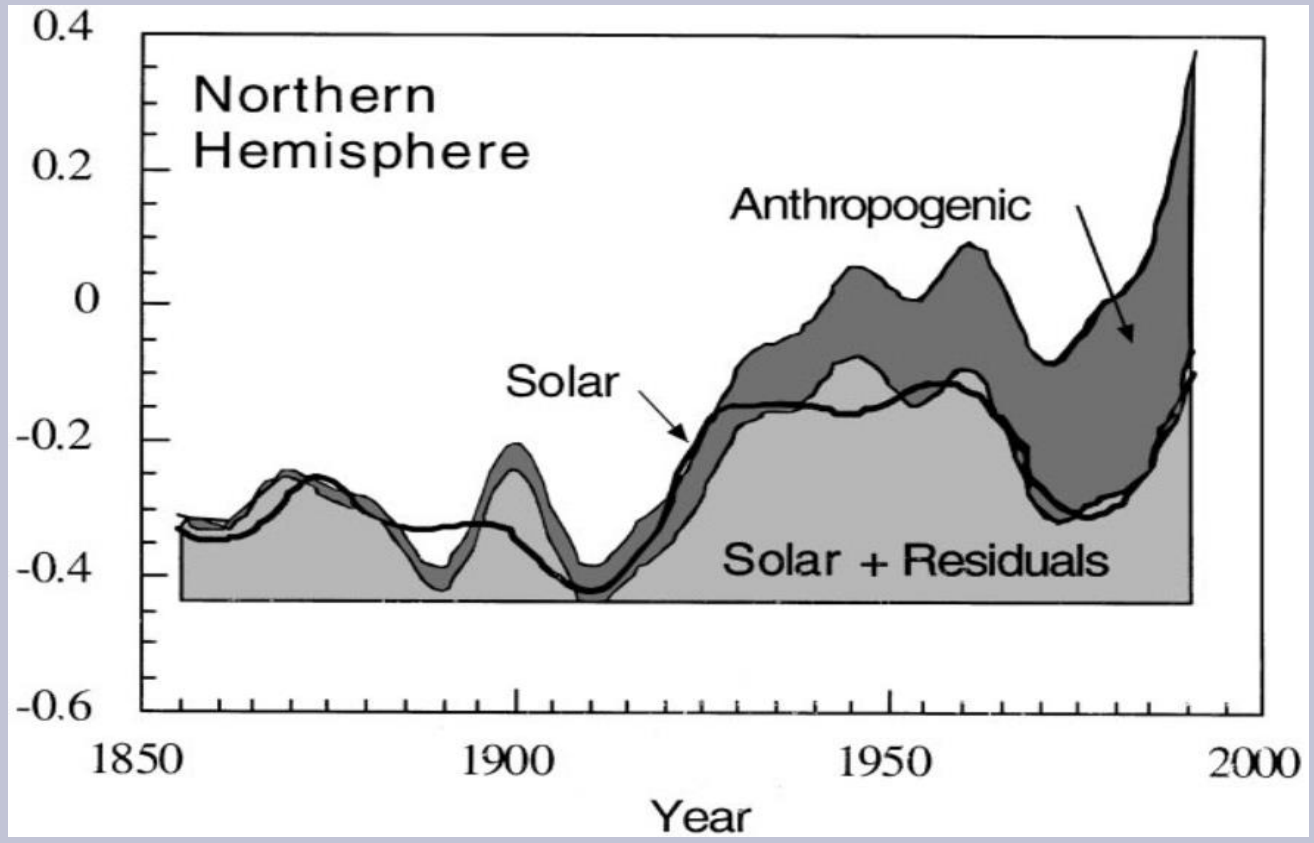
* Philosophical Magazine 1896

Temperature in Sodankylä
at 67 N lattitude inland



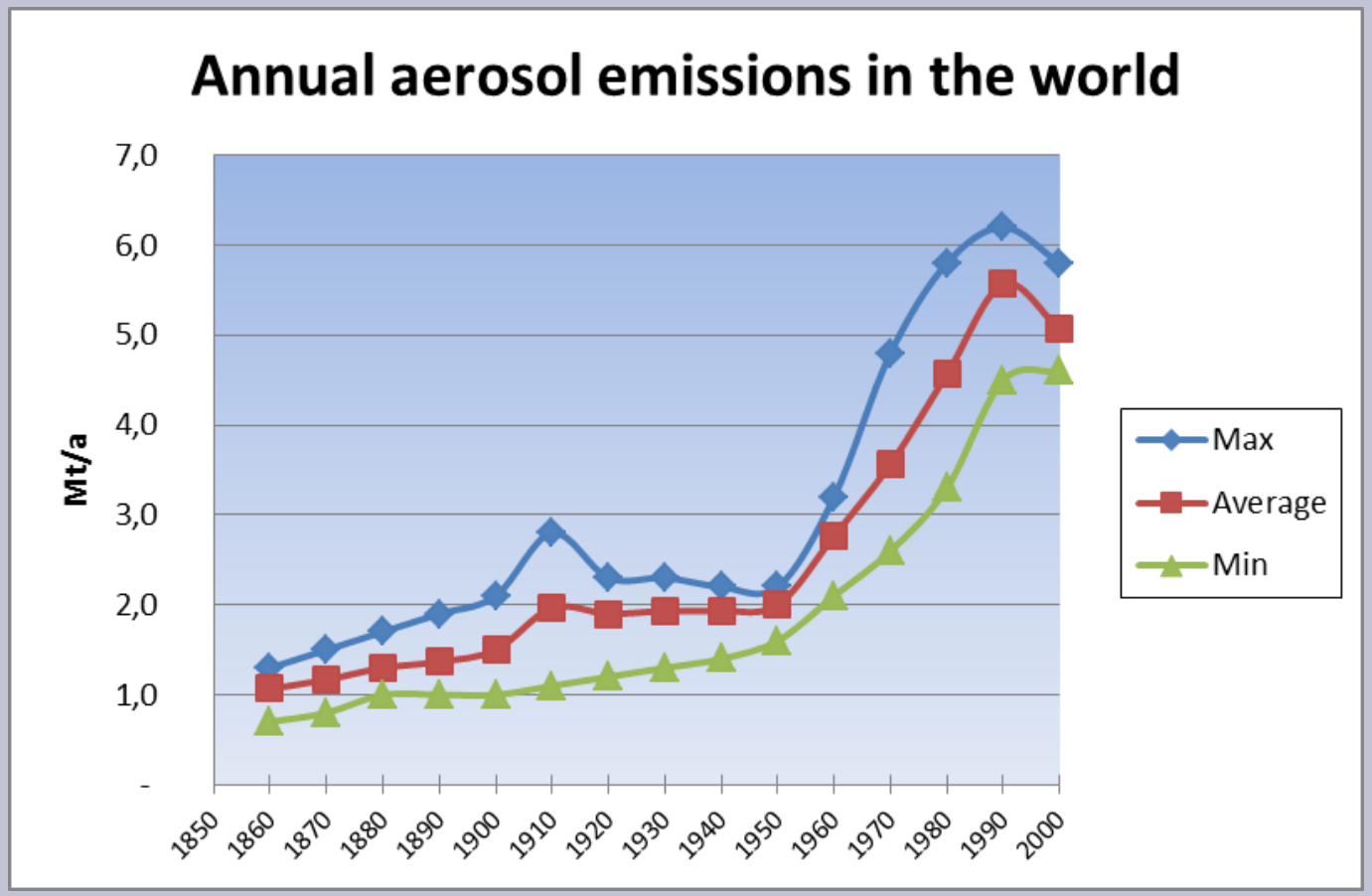
From 1905 to 2005 linear trend of temperatures indicates 1.2 C tempereture rise and polynomial trend 3 C increase

Solar radiation effect 0,2 C by Beer et. al.



Aerosol emissions

one reason for rapid increase after 1950 ?



Temperature increase and CO2-emissions

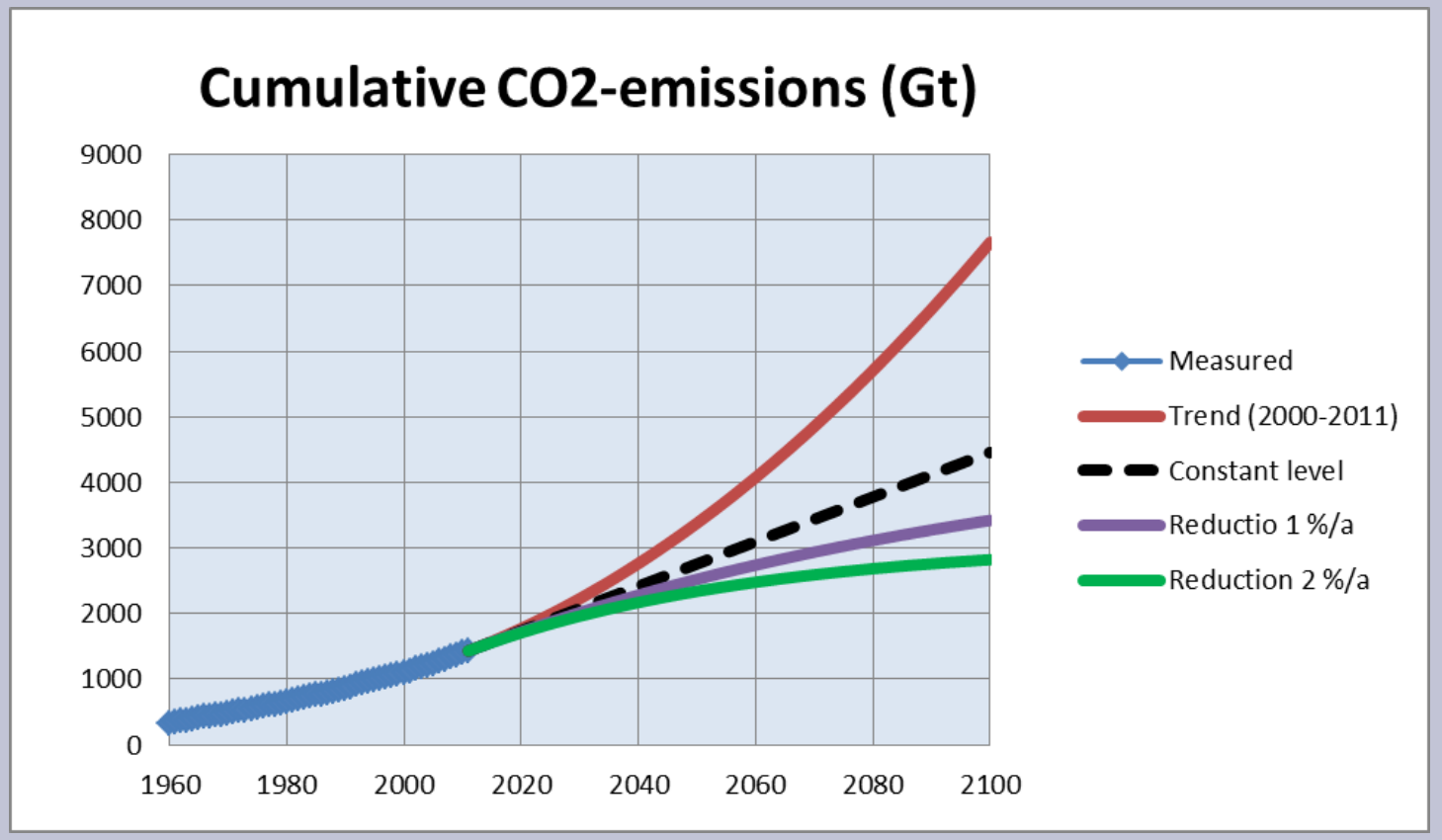
- Finnish correlation*
  - Temperature increase with 1,0 C
  - Concentration increase with 40 %
  - From 280 ppm to 392 ppm

- Formula $T = 6,8 \times \log (CO2/280)$

Temperature increase and CO2-concentration

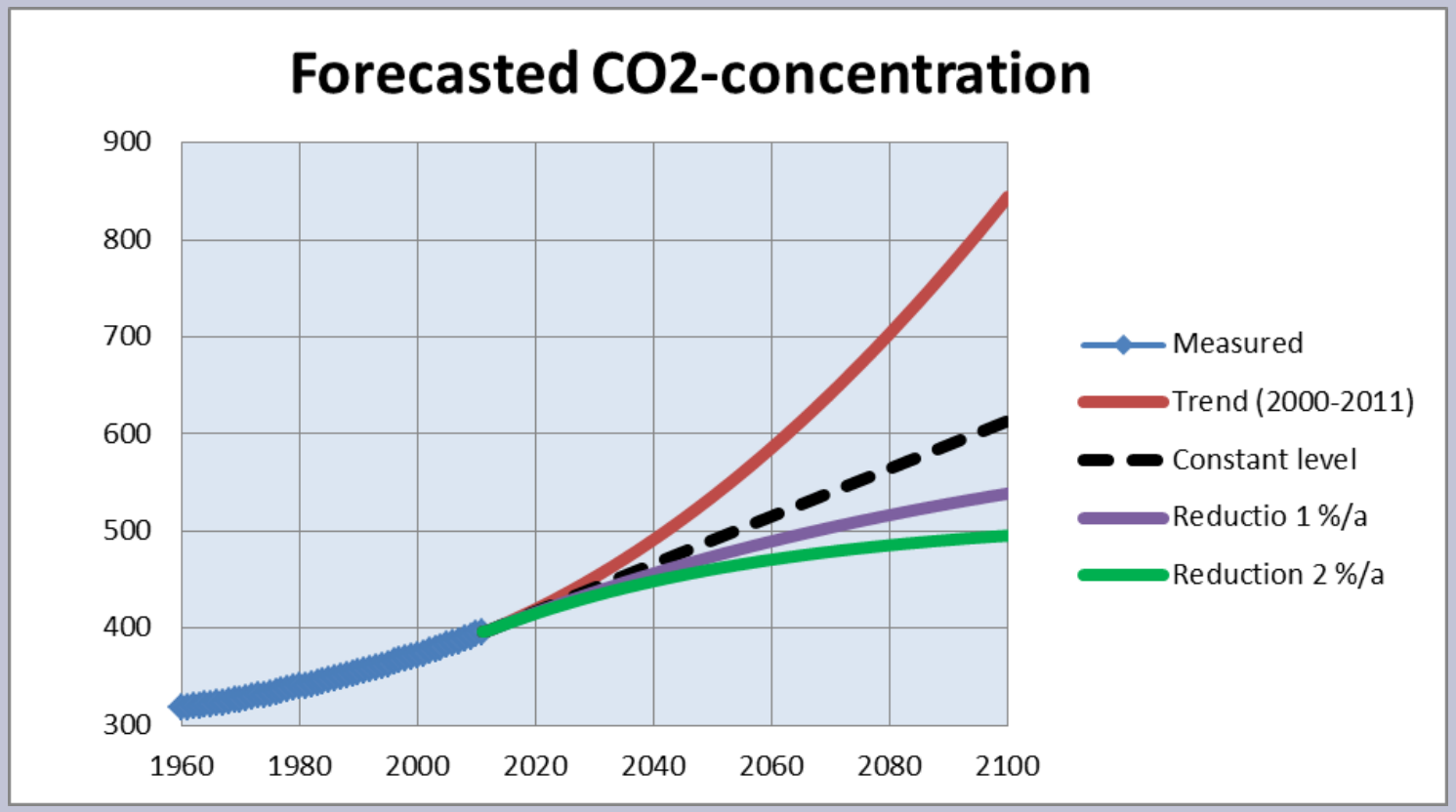
- Formula
  - T = 6,8 x log (550/280) = 2,0 C

Cumulative emissions should remain under 3700 Gt

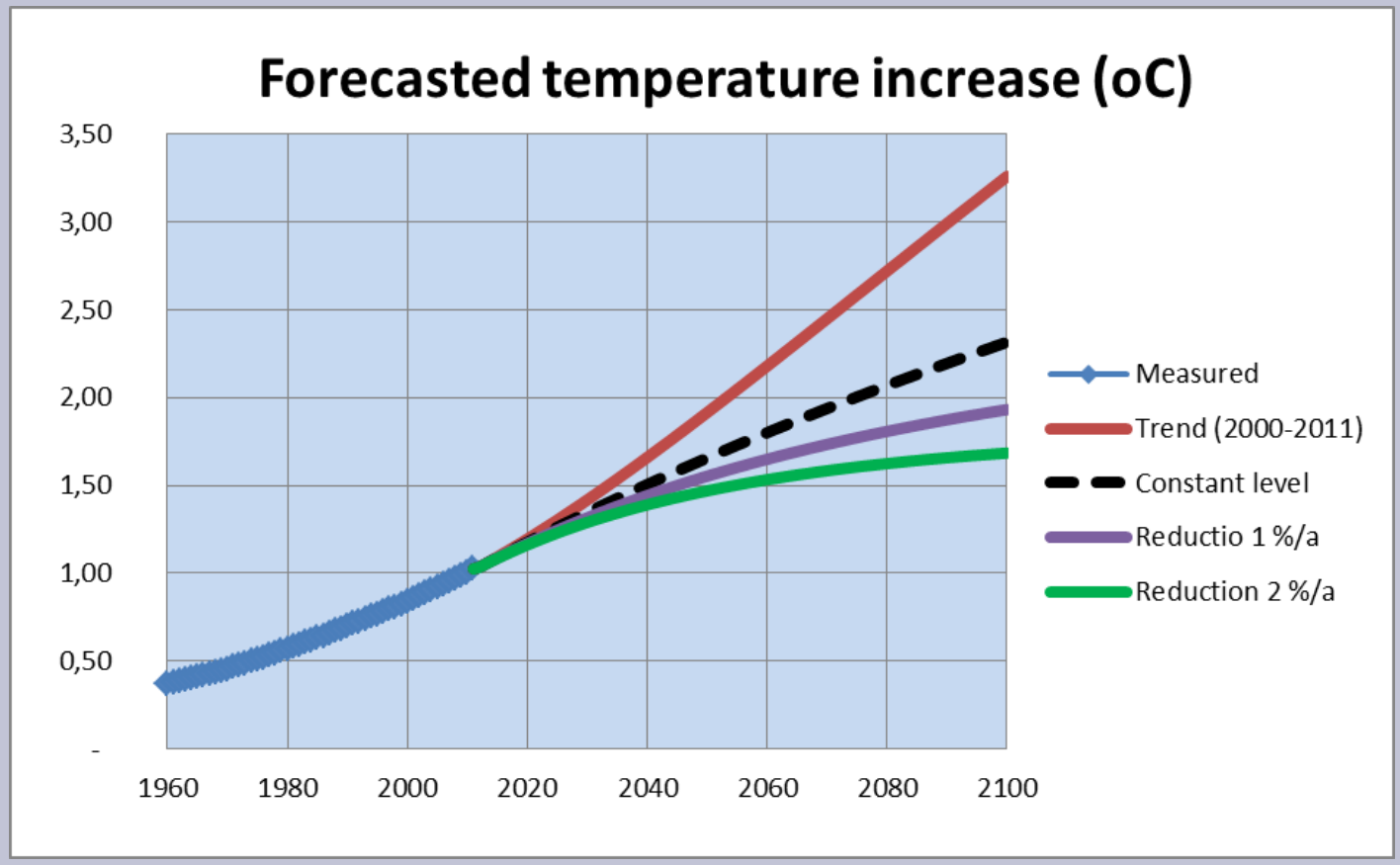


Reduction with 1 %/a is needed

CO2-concentration should be limited below 550 ppm



Temperature increase can be limited to 2 deg. C



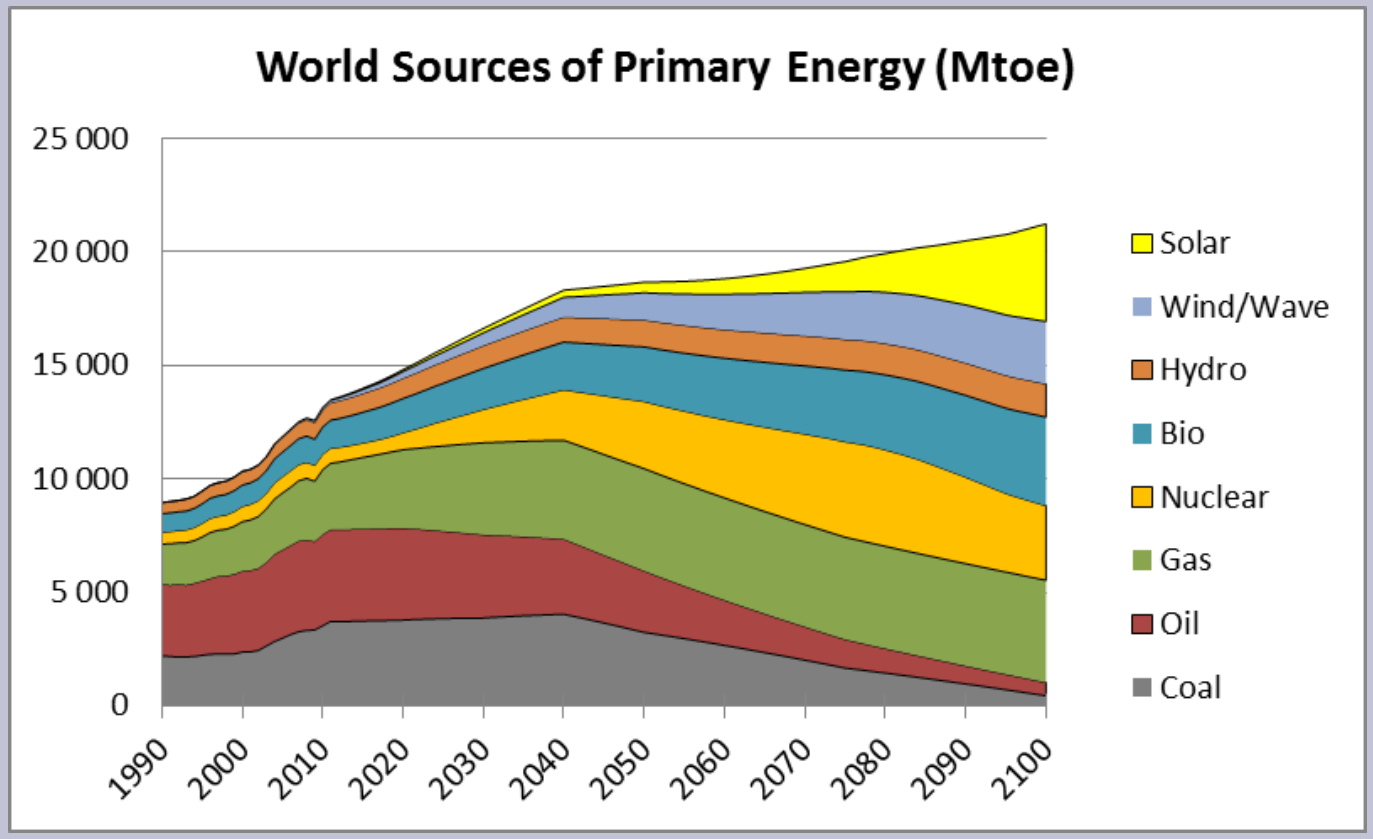
Targets for the world by A. Vuorinen

- Goal for 2100
  - Cumulative emissions < 3700 Gt
- Targets for 2040
  - 2010 to 2040 stabilisation to present level Emissions < 4,2 t/capita in every country
- Target for 2100
  - 2040 to 2100 reduction of emissions 2 % /a
  - 1 t/capita in every country

Targets for the world by A. Vuorinen

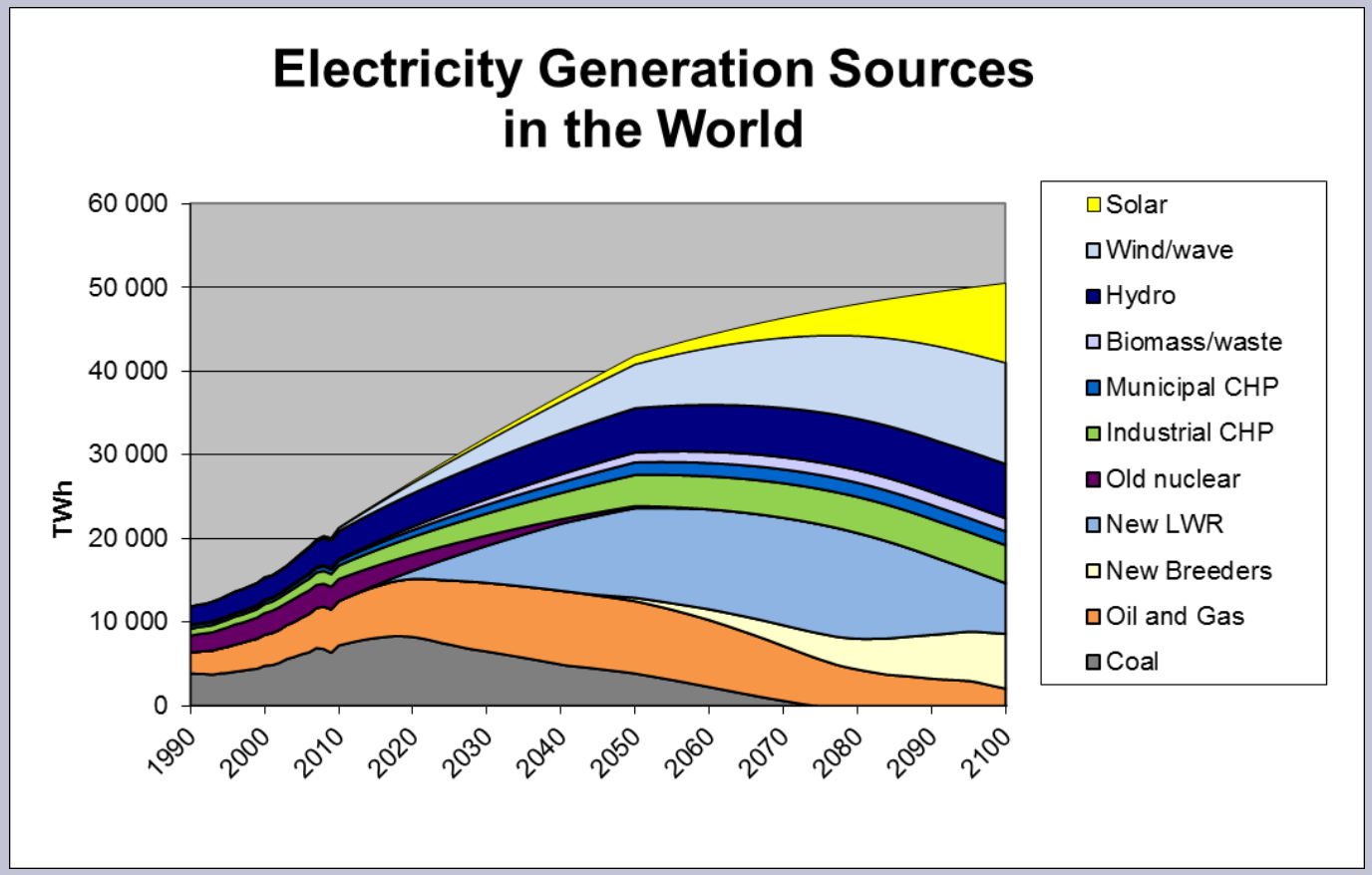
- Emissions from energy industries
  - 2011 34000 Mt 4,9 t/capita
  - 2040 34000 Mt 4,2 t/capita
  - 2100 10000 Mt (-70%) 1,0 t/capita
- Emission from electricy generation
  - 2010 11 000 Mt 1,5 t/capita
  - 2040 11 000 Mt 1,4 t/capita
  - 2100 3 000 Mt (-70%) 0,3 t/capita

World primary energy sources until 2100



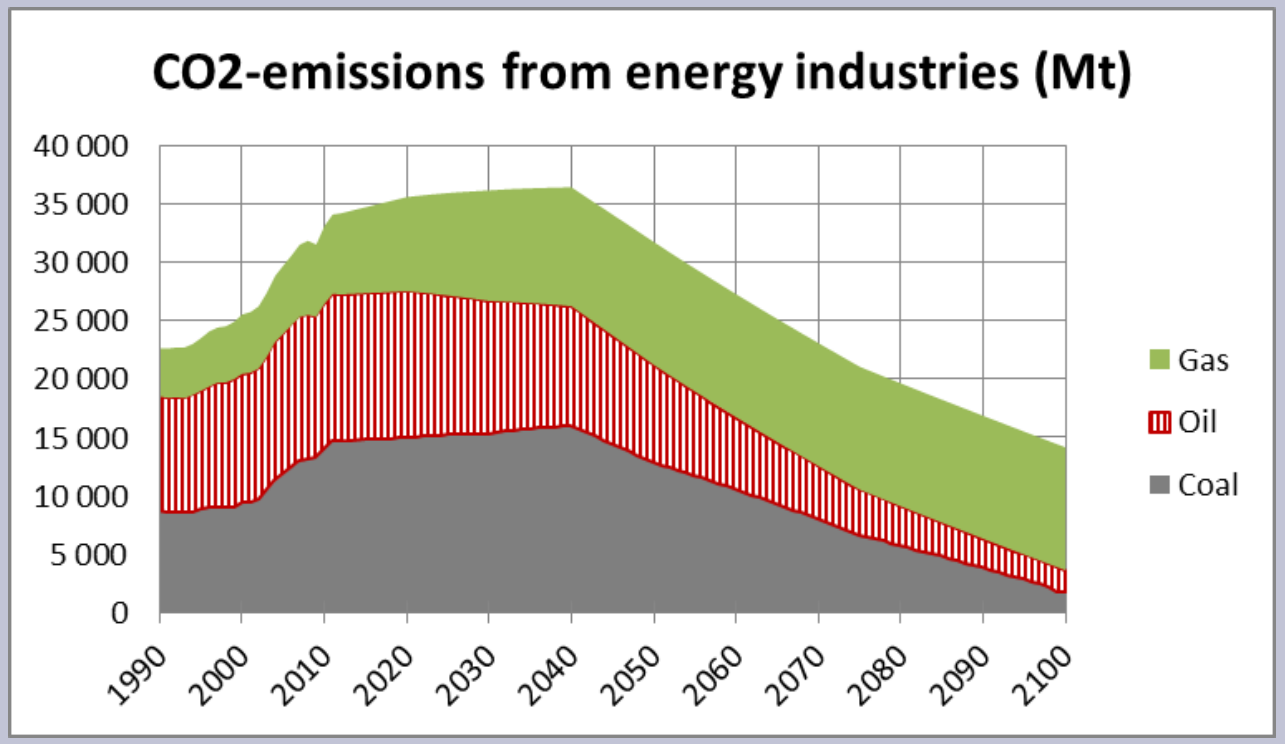
Based on book: Energy User's handbook 2013

Electricity generation by nuclear and renwables



Based on book: Planning of Nuclear Power Systems to Save the Planet

CO2-emissions from energy industries



Based on book: Planning of Nuclear Power Systems to Save the Planet

Some methods

- Stick
  - CO2-tax of 60 eur/t makes gas cheaper than coal in variable costs
  - Emission limit of 500 gCO2/kWh stops coal plants
- Carrot
  - Feed in tariffs for renwables
  - Lissences for nuclear plants

Summary

- CO2-emission reduction targets are very demanding
- They can be reached with renewable and nuclear power systems
- It does not necessarily cost very much, if costs are minimized

For details see reference text book ”Planning of Optimal Power Systems”

Author:
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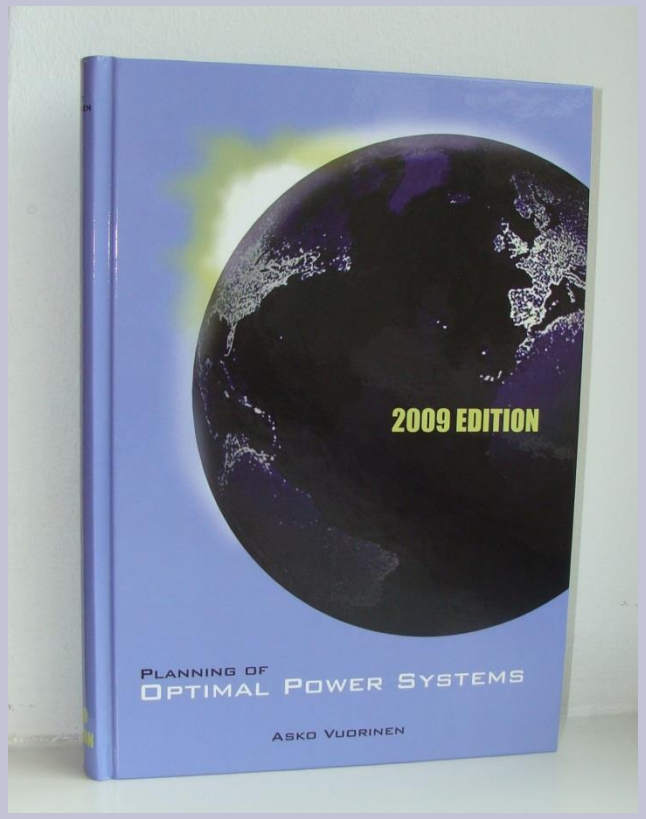

https://www.booky.fi/tuote/vuorinen_asko/planning_of_optimal_power_systems/9789526705712