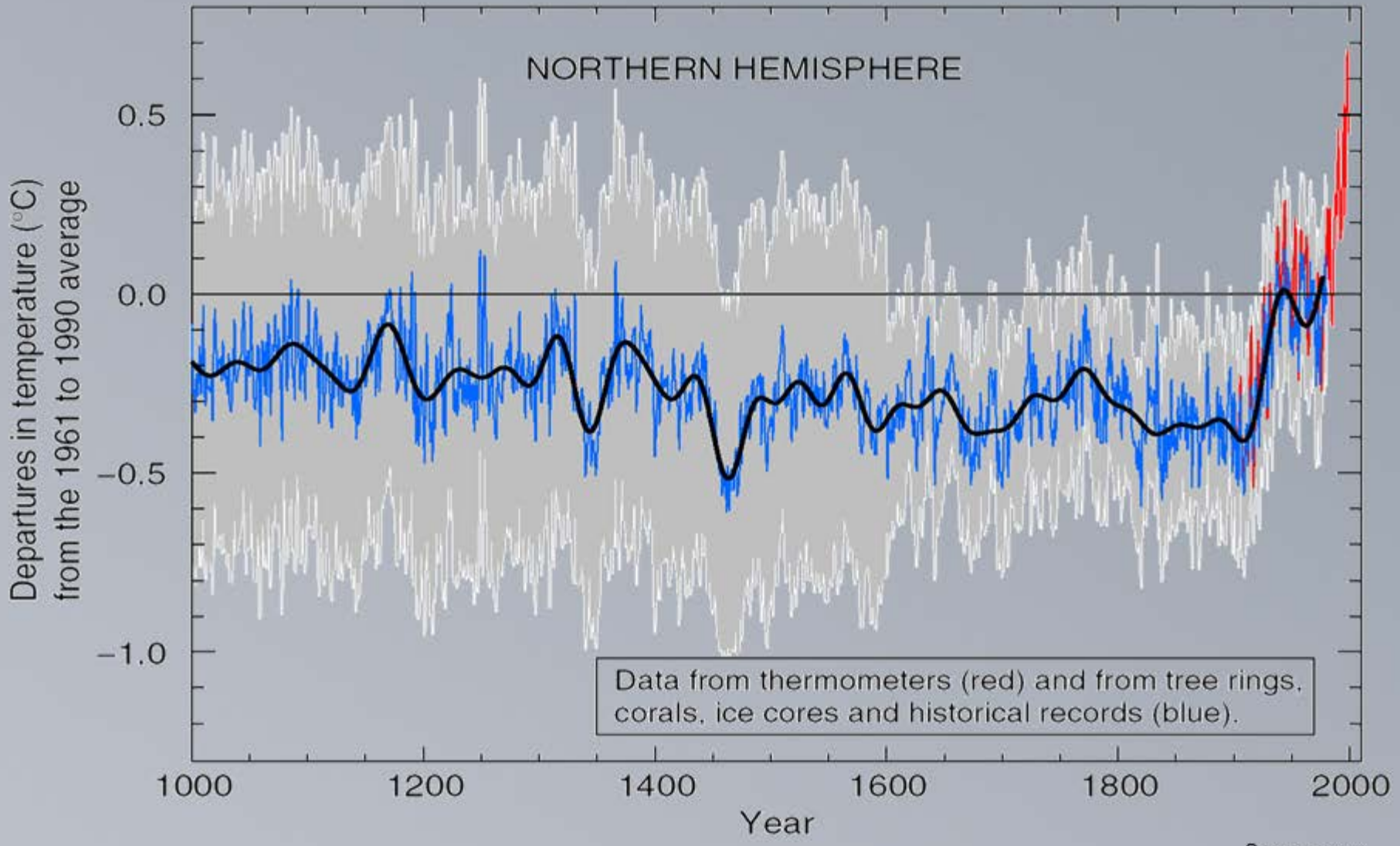
M09. Greenhouse Gas Basics

Source: i-fink.com

Basics of Greenhouse Gases

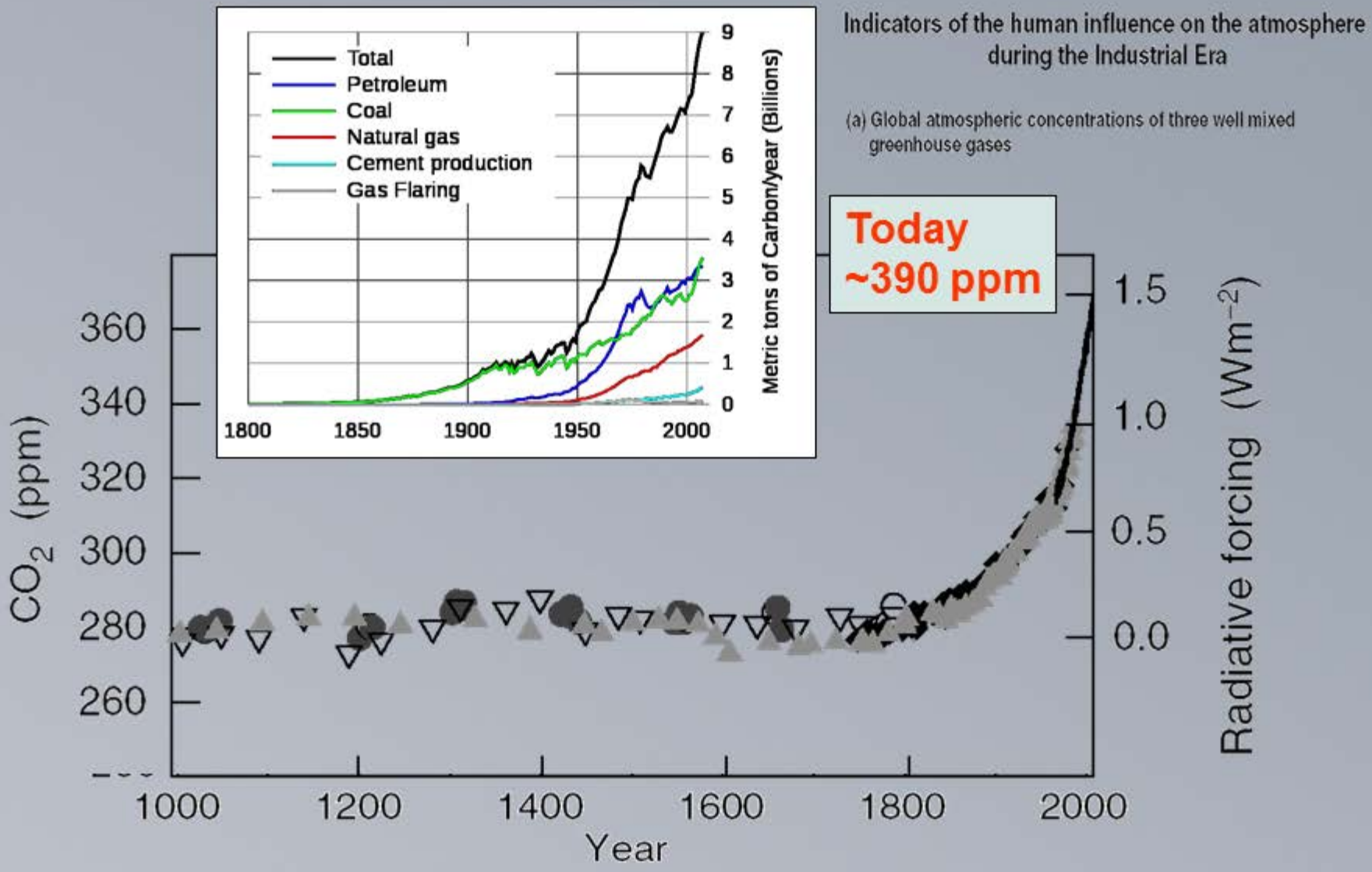
- Evolution of temperature and CO2 in air
- Physical interpretation of global warming
- Prediction and impacts of climate change
- Relevant greenhouse gases (GHGs)
- Calculation and data of CO2 emissions
- Total GHG emissions of fuels and food

Evolution of air temperature
at earth's surface for 1000 years

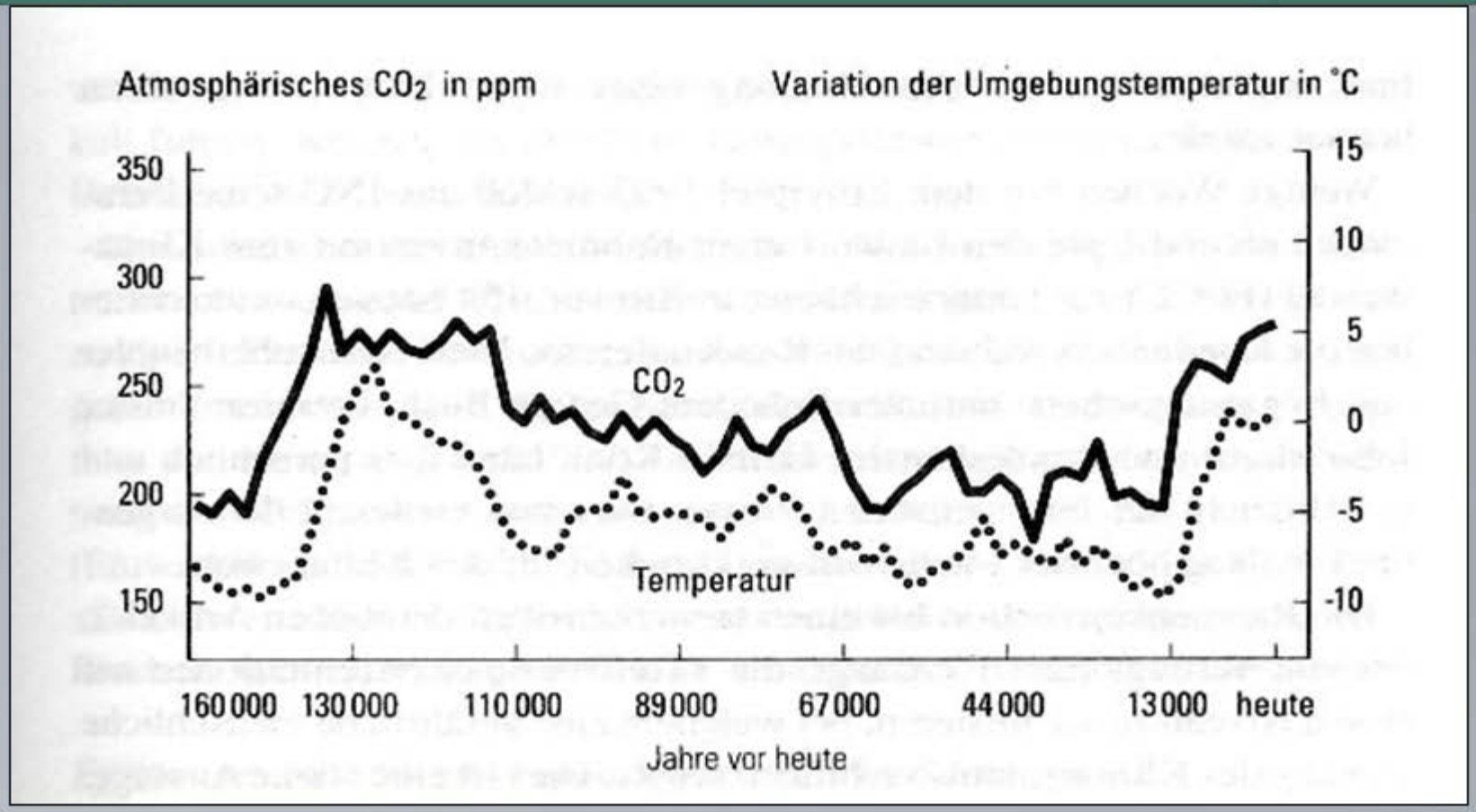


Source: renac

Evolution of CO2 content
in the atmosphere for 1000 years



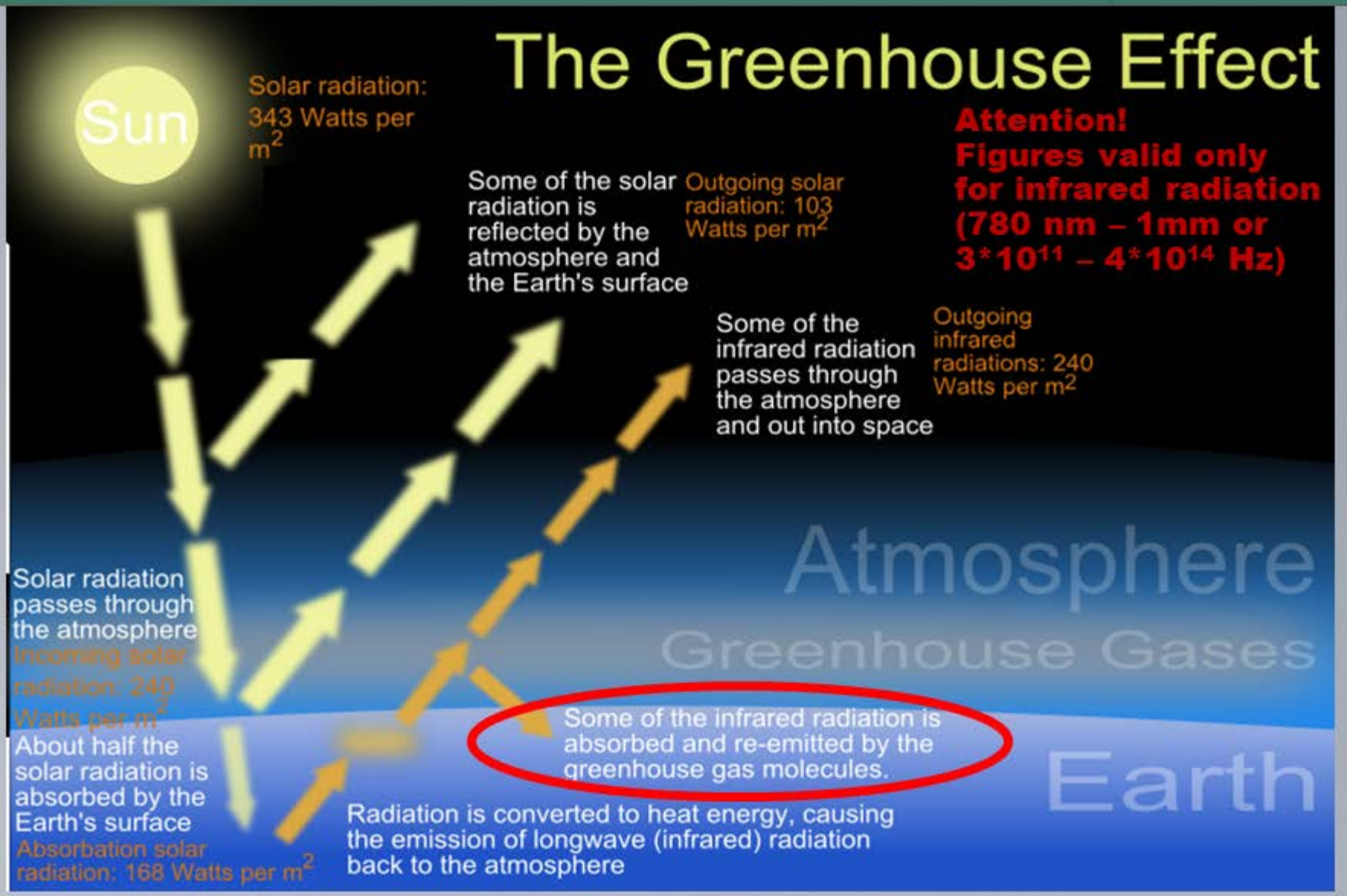
Vostok Sensation:
Correlation between CO2 and air temperature



A strict correlation between CO_2 concentration and air temperature
during the last 160000 years
measured in „fossile“ air bubbles in antarctic ice

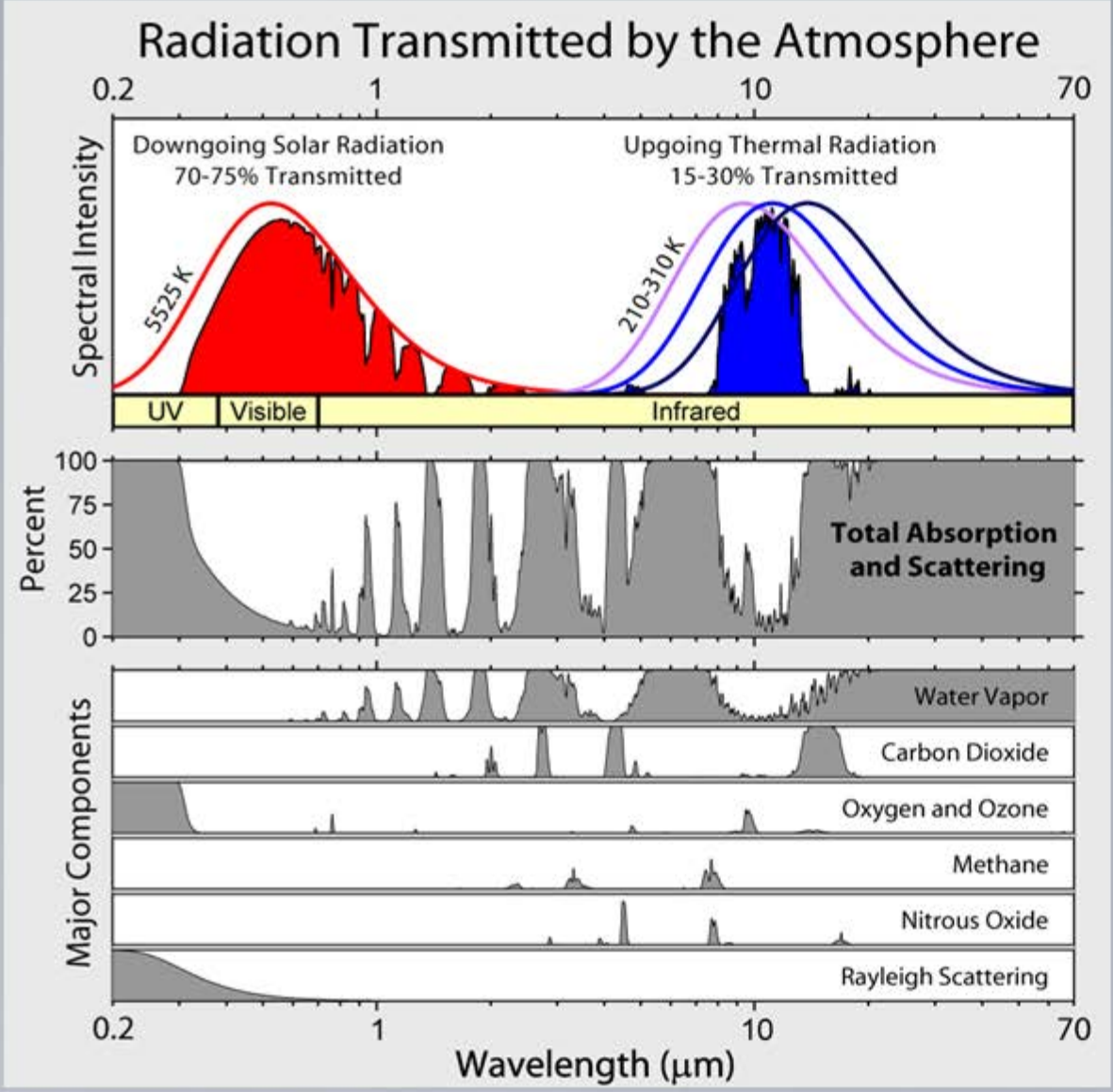
Source: E. U. von Weizsäcker et al.: Faktor vier. München 1997

Greenhouse effect -
The reason of global warming



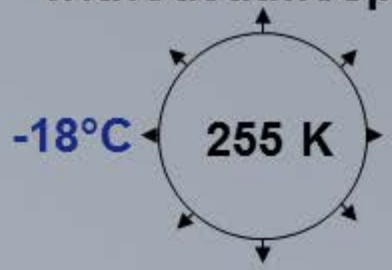
Source: renac

Physical reasons
of the greenhouse effect

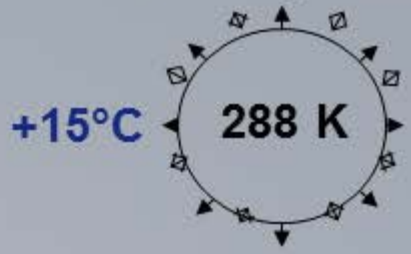


Surface temperature

without atmosphere



with atmosphere



Atmospheric absorption and scattering at different electromagnetic wavelengths. The largest absorption band of carbon dioxide is in the infrared.

Source: http://en.wikipedia.org/wiki/Greenhouse_gas

Greenhouse effect
due to greenhouse gases (GHG)

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Natural greenhouse effect

ca. 33 K (-18°C → +15°C)

Gas	Temperature contribution
H_2O	20.6 K
CO_2	7.2 K
O_3	2.4 K
N_2O	1.4 K
CH_4	0.8 K
Other gases	0.6 K

Gas	Formula	Contribution in %
Water Vapor	H_2O	36 – 72 %
Carbon Dioxide	CO_2	9 – 26 %
Methane	CH_4	4 – 9 %
Ozone	O_3	3 – 7 %

http://en.wikipedia.org/wiki/Greenhouse_gas

Anthropogenic greenhouse effect

ca. 0,5…1,0 K

Gas	contribution in %
CO_2	50 %
CFC	22 %
CH_4	**13 %**
O_3	7 %
N_2O	**5 %**
H_2O (stratospheric)	3%

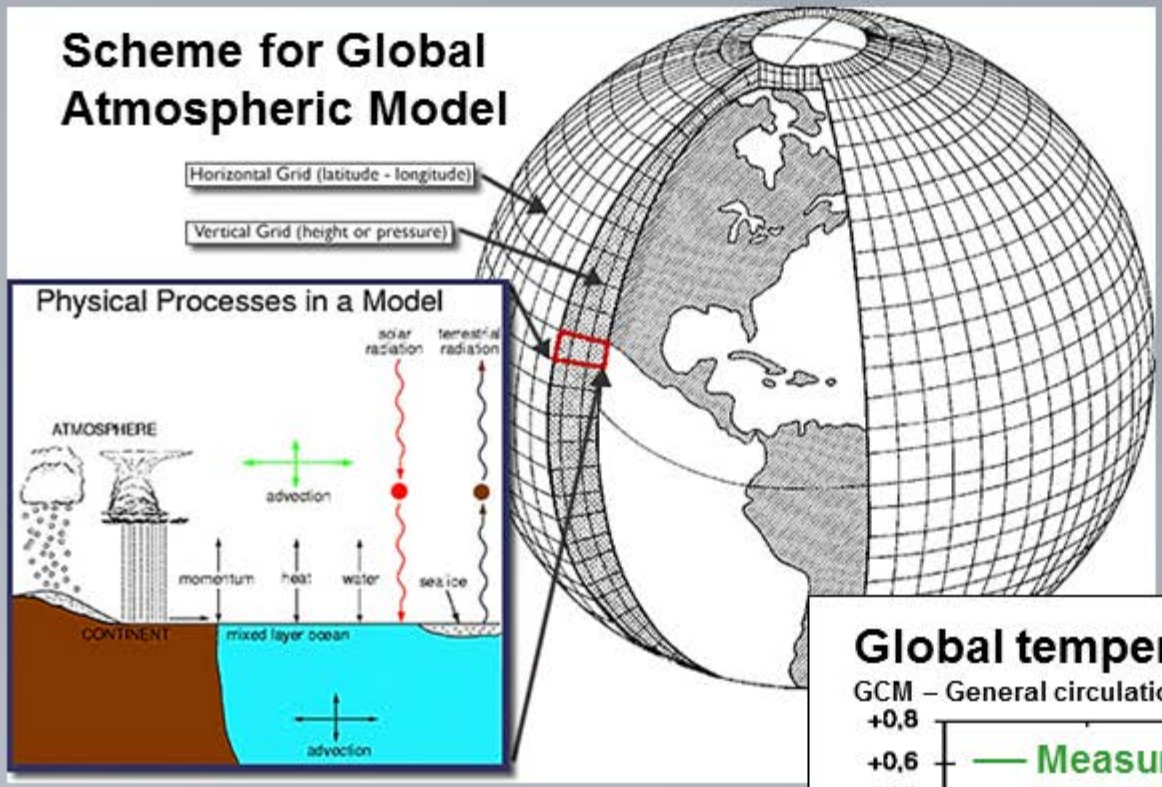
See also later!

!!!

CFC = Chlorofluorocarbons
N_2O = Nitrous Oxide

Source: renac

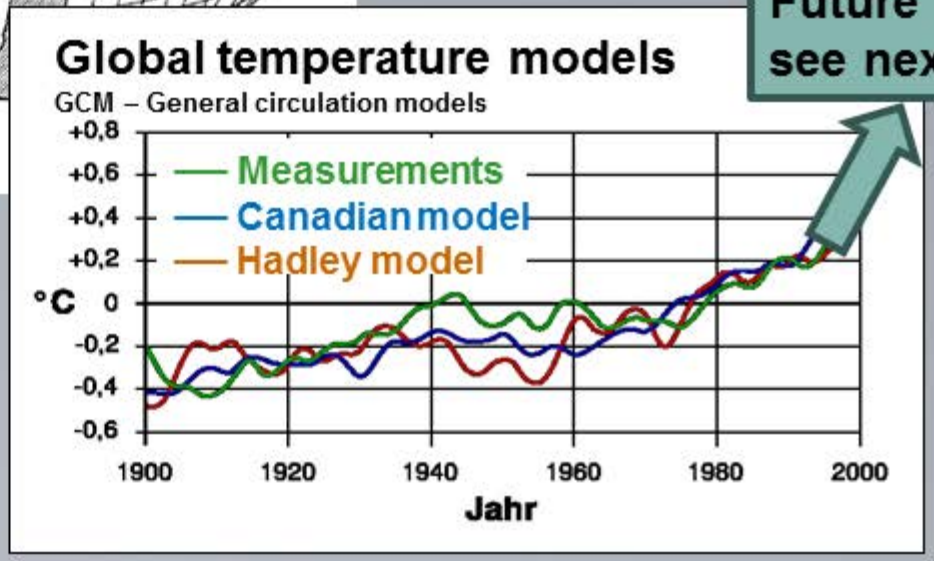
Prediction of climate change
by global climate models



Source: http://de.wikipedia.org/wiki/Klimamodell

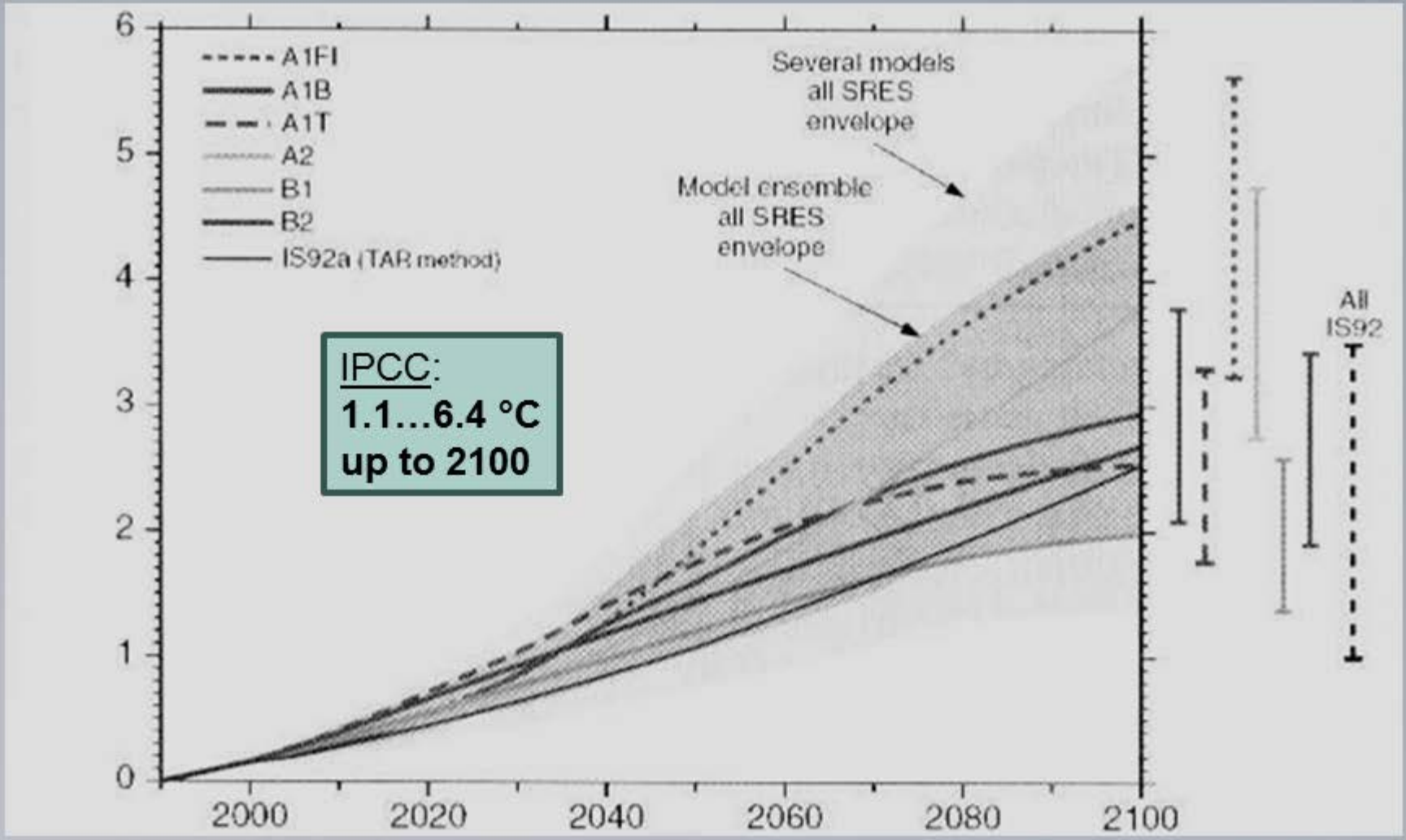
Climate models are systems of differential equations based on the basic laws of physics, fluid motion, and chemistry. To "run" a model, scientists divide the planet into a 3-dimensional grid, apply the basic equations, and evaluate the results.

Atmospheric models calculate winds, heat transfer, radiation, relative humidity, and surface hydrology within each grid and evaluate interactions with neighboring points.



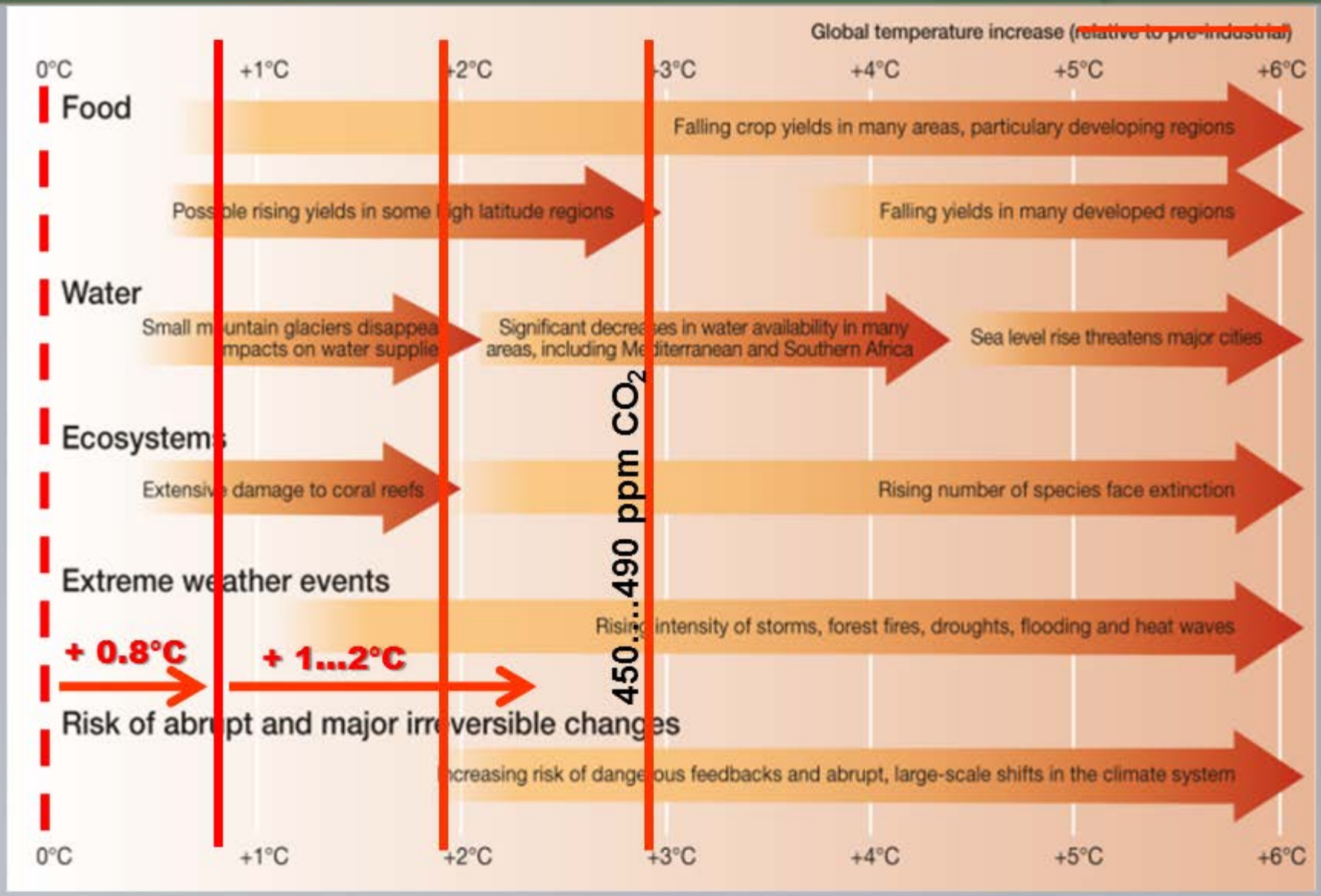
Temperature increase
due to greenhouse effect

Selected forecast models up to 2100



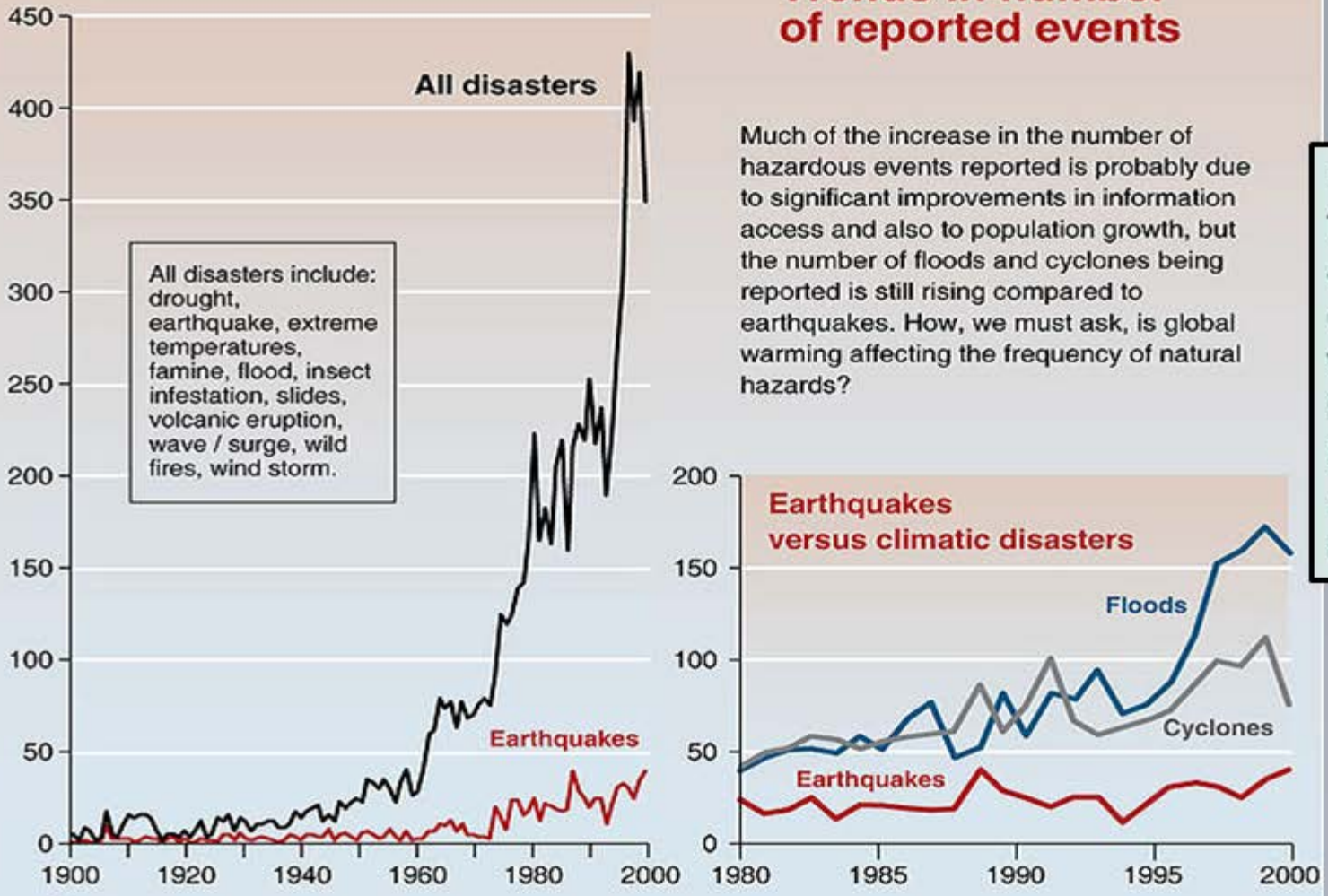
Source: IPCC: Online report of the **Intergovernmental Panel of Climate Change**.

Impacts of climate change
on human being and environment



Source: renac

Increase in natural disasters
An effect of climate change?



Trends in number of reported events

Much of the increase in the number of hazardous events reported is probably due to significant improvements in information access and also to population growth, but the number of floods and cyclones being reported is still rising compared to earthquakes. How, we must ask, is global warming affecting the frequency of natural hazards?

Reduction of flood and associated extreme weather costs is the primary benefit of climate change mitigation.

Source: http://en.wikipedia.org/wiki/Mitigation_of_global_warming

Relevant GHGs
and other pollutant gases

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Climate gases (GHG) (Kyoto gases)

CO_2	-	Carbon dioxide
CH_4	-	Methane
N_2O	-	Nitrous Oxide
SF_6	-	Sulfur hexafluoride
PFC	-	Perfluorocarbons
HFC	-	Hydrofluorocarbons (HCF≈CFC=FCKW)

Source: Intergovernmental Panel Climate Change (IPCC)

Other pollutant gases

SO_2	-	**Sulfur dioxide**
NO_X	-	**Nitrogen oxide**
HCl	-	**Hydrochloric acid**
HF	-	**Hydrofluoric acid**
CO	-	**Carbon Monoxide**
NMVOC	-	**Volatile Organic Compounds hydrocarbons**
H_2S	-	**Hydrogen sulfide**
NH_3	-	**Ammonia**

Potential of the greenhouse effect

Equivalent of CO_2 (GWP)

Global Warming Potential (GWP) calculated for 100 years

CO_2	1
CH_4	21
N_2O	310
SF_6	23.900
PFC	6.500 - 9.200
HFC	140 - 11.700
C_4H_{10} (Butane)	4

Potential of acidification

Equivalent of SO_2

SO_2	1
NO_X	0,696
HF	1,601
HCl	0,878
H_2S	0,983
NH_3	3,762

Source: renac

Sources and impacts
of the Kyoto gases

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on global warming effect

Greenhouse gas (Kyoto gas)		Anthropogenic sources	Global warming potential	Anthropogenic share of global warming *
Carbon dioxide	CO_2	Fossile energy sources	1	64%
Methane	CH_4	Rice production, Cattle, Biomass	21	20%
Nitrous oxide	N_20	Fertilizer, Fossile energy	310	6%
Hydroflourcarbons	HCFC	Cooling fluids	100-12000	10%
Perflourcarbons	PFC	Solvents, Alumin., Fire extenguisher	6500-9200	
Sulphur hexaflouride	SF_6	Electrical indutry, Isolations	23900	

* http://de.wikipedia.org/wiki/Emissionsrechtehandel

Calculation of CO2 emissions
caused by combustion of fossil fuels

Oxidation of C to CO_2 (combustion of coal): **$C + O_2 \rightarrow CO_2$** with and oxidation C_xH_y to CO_2 and H_2O (combustion of oil and gas)

ΔH = -393 kJ/mol

Example Lignite:

1 kg coal = 500 g H_2O + 50 g ash + 135 g volatiles + **315 g C**

315 g C → **1.155 kg CO_2** (with atomic weight C = 12 e O = 16)

1.155 kg / 44.0 kg/kmol (molecular weight) **= 26.25 mol CO_2**

To heat up 500 g H_2O from 10 to 100°C: - 0.188 MJ
and to evaporate 500 g H_2O (2.256 MJ/(kg K): - 1.128 MJ
} → **9.0 MJ/kg = 2.5 kWh/kg_{coal}**

1.155 kg CO_2 / 2.5 kWh **= 462 g CO_2/kWh**

The oxidation of volatile produces more 3 MJ = 0.833 kWh → **345 g CO_2/kWh in total**

→ A power plant with efficiency of 35 % produces approx. **1 kg CO_2/kWh_{el}**

Volume of mole:
CO_2 = 22.86 m³/kmol
Air = 22.47 m³/kmol

The exact figures
may vary because of varying compositions of fuels.

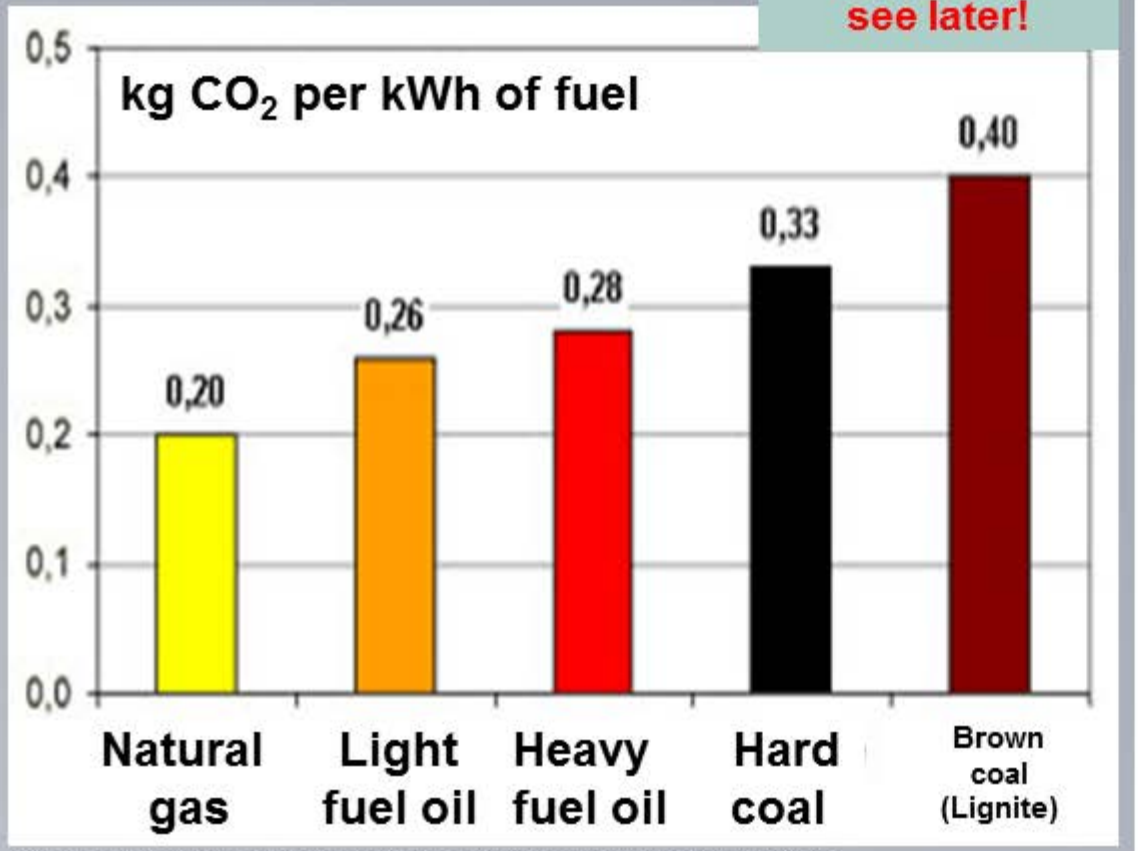
Only CO_2 from combustion!

See next slides!

Source: renac

Pure CO2 emissions
of the various types of fossil fuels

The total GHG emissions see later!

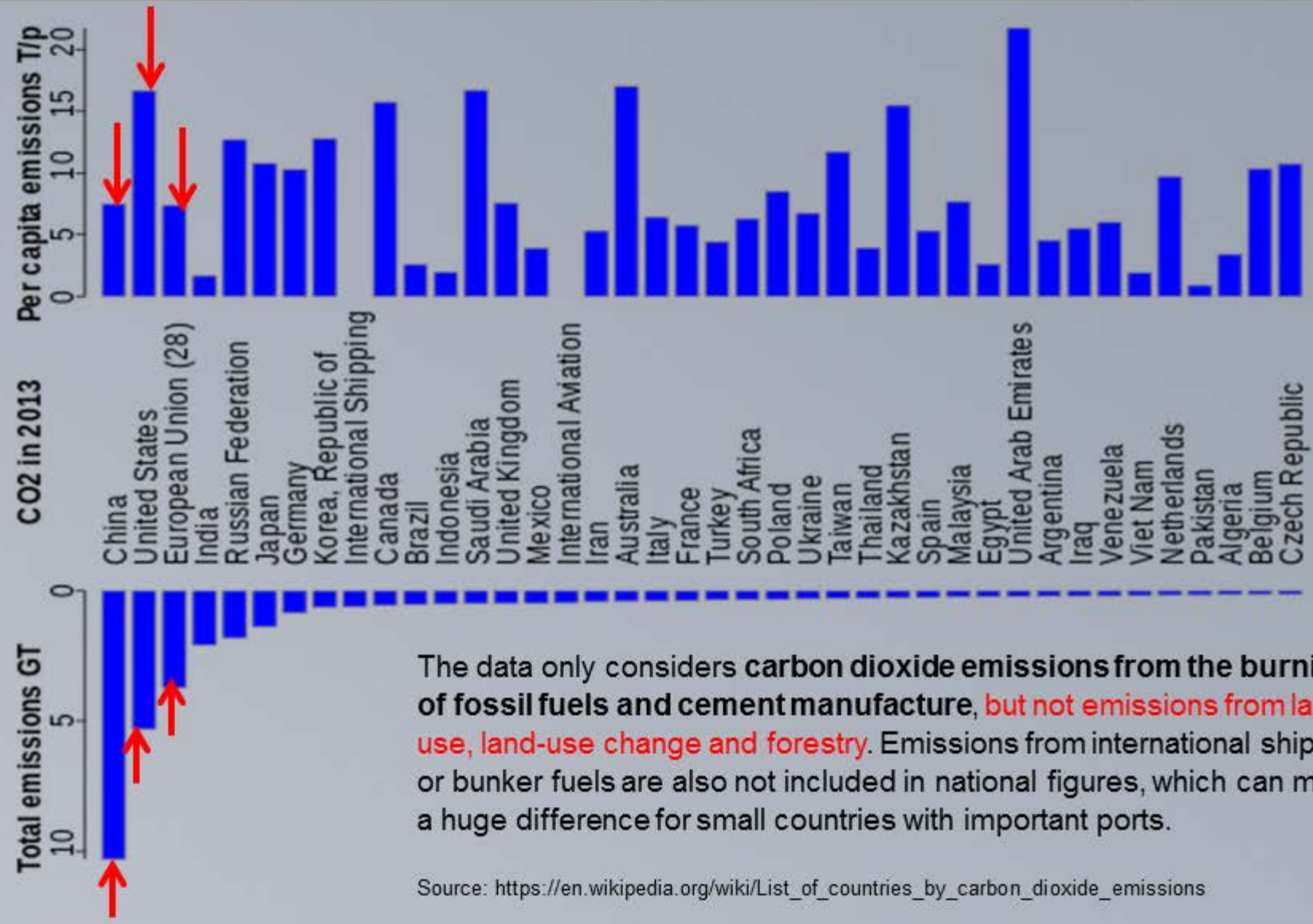


Source: http://www.baunetz.de/sixcms_4/sixcms/detail.php?id=142928

See also: IPCC emission factors
http://www.carbonmetrics.com/ipcc.html

Fuel name	CO_2 emitted (lbs/10^6 Btu)	CO_2 emitted (g/10^6 J)
Natural gas	117	50.30
Liquefied petroleum gas	139	59.76
Propane	139	59.76
Aviation gasoline	153	65.78
Automobile gasoline	156	67.07
Kerosene	159	68.36
Fuel oil	161	69.22
Tires/tire derived fuel	189	81.26
Wood and wood waste	195	83.83
Coal (bituminous)	205	88.13
Coal (subbituminous)	213	91.57
Coal (lignite)	215	92.43
Petroleum coke	225	96.73
Coal (anthracite)	227	97.59

Global CO2 emissions
caused by fossil fuels



The data only considers **carbon dioxide emissions from the burning of fossil fuels and cement manufacture**, but not emissions from land use, land-use change and forestry. Emissions from international shipping or bunker fuels are also not included in national figures, which can make a huge difference for small countries with important ports.

Source: https://en.wikipedia.org/wiki/List_of_countries_by_carbon_dioxide_emissions

Total GHG emissions
of fossil fuels

Total GHG emissions depend on fuel and utilization!

Fuel	Emission factors* for		
	Thermal use g $CO_{2\text{-equ.}}$/MJ	Transport g $CO_{2\text{-equ.}}$/MJ	Electricity g $CO_{2\text{-equ.}}$/kWh_{el}
Hard coal	88 - 106	-	822 - 1080
Brown coal	94 - 124	-	729 - 1230
Fuel oil	73 - 84	-	890 - 893
Diesel	-	84 - 91	-
Gasoline	-	84 - 94	-
Natural gas	51 - 68		(49) 599–751
Wood chips	10	-	-
Solar collector	10	-	-

* incl. the main GHGs and all processes for recovery, processing and transport of these sources

1 kWh = 3.6 MJ

Sources: http://www.umweltdaten.de/publikationen/fpdf-l/3761.pdf, http://www.bundestag.de/bic/analysen/2007/CO2-Bilanzen_verschiedener_Energietraeger_im_Vergleich.pdf
http://en.wikipedia.org/wiki/Emission_factor and Holzenergie-Fibel, Stuttgart 2003 and other

Total GHG emissions
of power generation in Germany

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No savings!

Electrical power from	CO_2 equivalents* in g/kWh_{el}
Nuclear power station	16 - 126
Hard coal power station	622 - 1080
Brown coal power station	729 - 1230
Mineral oil	890
Natural gas power station or CHP	49 - 640
Wind power station	9 - 24
Hydroelectric power station	4 - 40
Photovoltaik plant	27 - 160
Biogas CHP plant	-400 - 170
German mix (2012)	**559**

CO_2 savings e.g.
559 – (9-24) = 550–535

* incl. all prior processes and material consumption for production of these plants

Source: http://www.bundestag.de/bic/analysen/2007/CO2-Bilanzen_verschiedener_Energietraeger_im_Vergleich.pdf

Total GHG emissions
of liquid biofuels in g CO2/kWh

Fuel (underlying raw material)	Emission factor [g CO_2-eq/kWh]
Petrol/diesel (fossil)	301.7
Biodiesel (rapeseed)	165.6
Biodiesel (soy)	180.0
Biodiesel (palm oil)	115.2
Biodiesel (waste)	36.0
Vegetable oil (rapeseed)	126.0
Vegetable oil (soy)	152.6
Bioethanol (grain)	180.0
Bioethanol (beets)	118.8
Bioethanol (sugar cane)	86.4
Bioethanol (other)	36.0
Biodiesel (weighted)	157
Vegetable oil (weighted)	126
Bioethanol (weighted)	132

Average figures for Germany
without direct and indirect land use changes

The GHG emissions of biofuels result from:

- **use of fossil energy (CED) for production, conversion and transport of crops and biofuels**
- **the use of emissions causing materials**
- **emissions during cultivation of crops (N_2O, CH_4)**
- **....**

but not from CO_2 emissions during combustion of these fuels!

Source: Renewable Energy in Figures. BMU 2010
http://www.bmu.de/english/renewable_energy/downloads/doc/5996.php
(http://www.umweltdaten.de/publikationen/fpdf-l/3761.pdf)

GHG savings
of liquid biofuels in t CO2/ha p.a.

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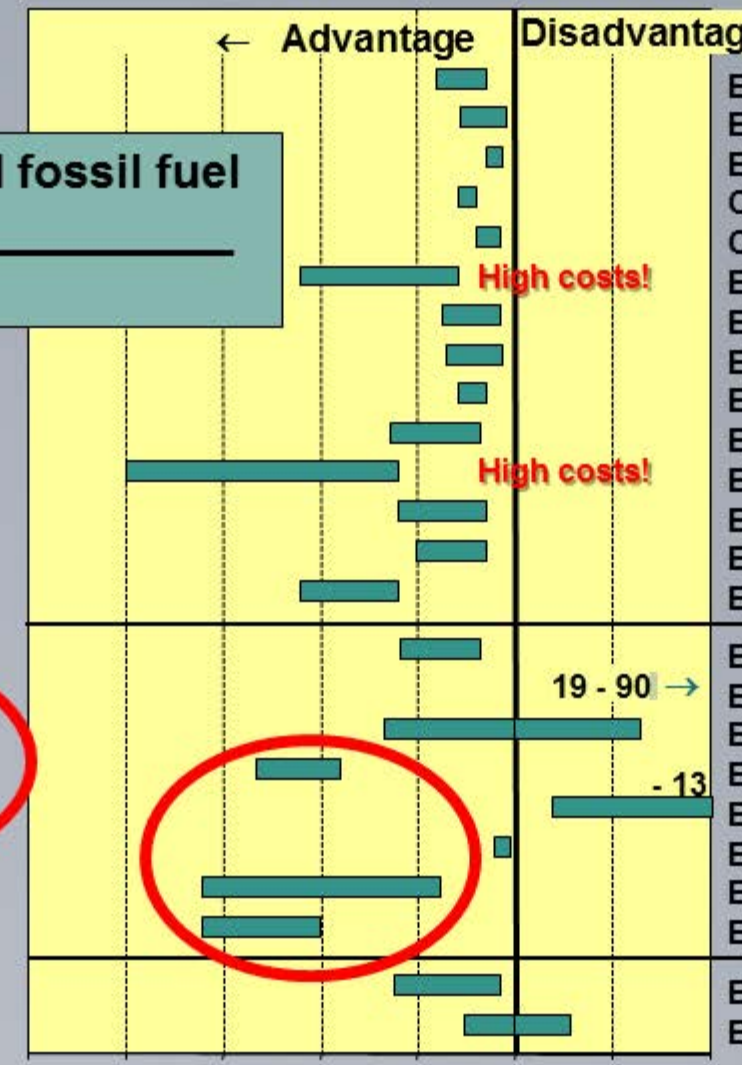
Remember!

GHGs of substituted fossil fuel
- GHGs of biofuel
GHG savings



Biofuels from temperate areas

Biofuels from humid tropical areas

Biofuels from arid areas

Biodiesel of sunflower
Biodiesel of rapeseed
Biodiesel of canola
Crude oil of sunflower
Crude oil of rapeseed
EtOH of sugar beet
EtOH of wheat
EtOH of potatos
EtOH of corn
EtOH of lignozellulosicos
ETBE of sugar beet
ETBE of wheat
ETBE of potatos
BTL of willow and poplar
Biodiesel of palm (jungle)
Biodiesel of palm (swamp)
Biodiesel of palm (plantation)
Biodiesel of palm (vacant lot)
Biodiesel of soybean (jungle)
Biodiesel of soybean (swamp)
EtOH of sugar cane (natural vegetation)
EtOH of sugar cane (vacant lot)
Biodiesel of Jatropha (vacant lot)
Biodiesel of Jatropha (forest)

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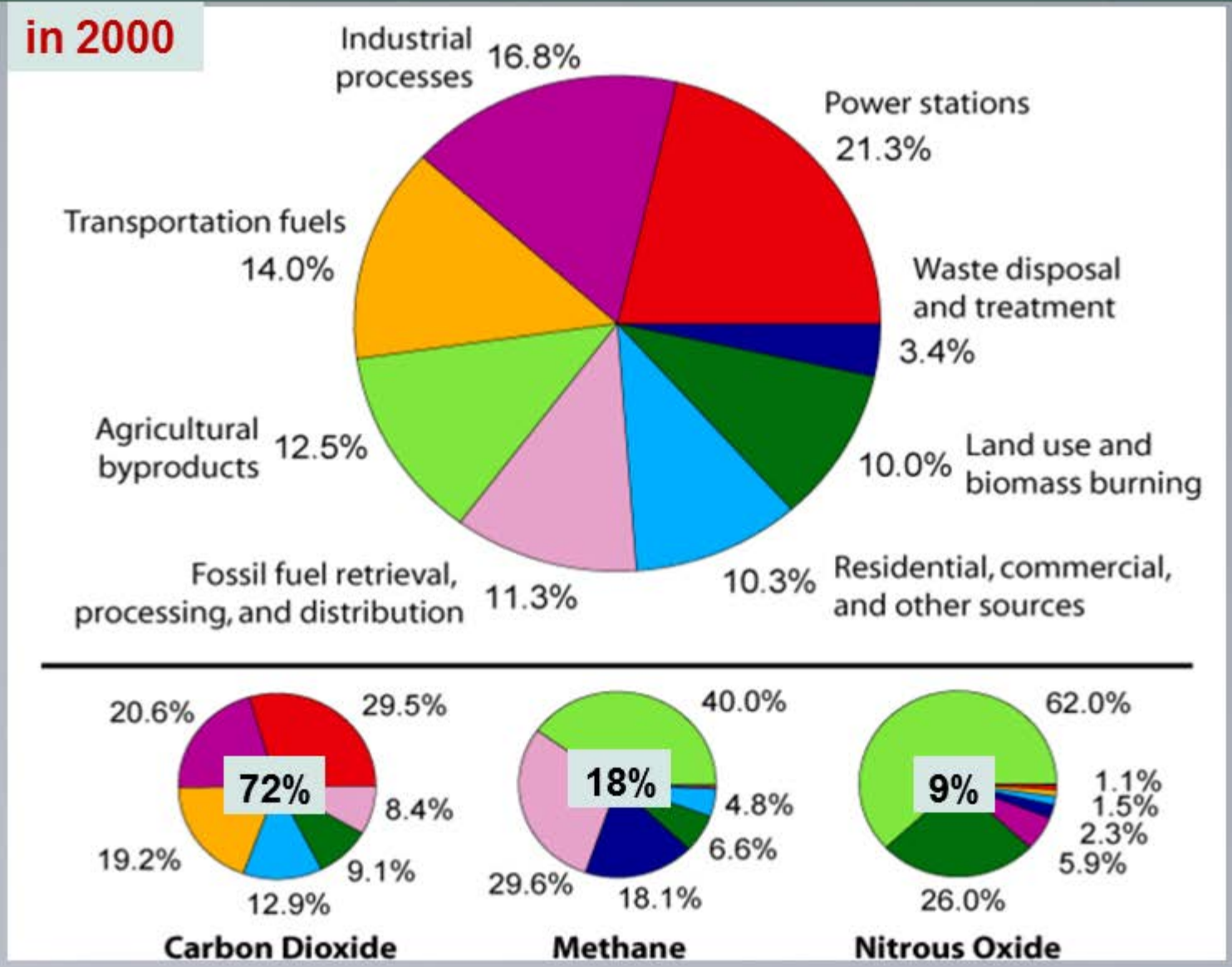
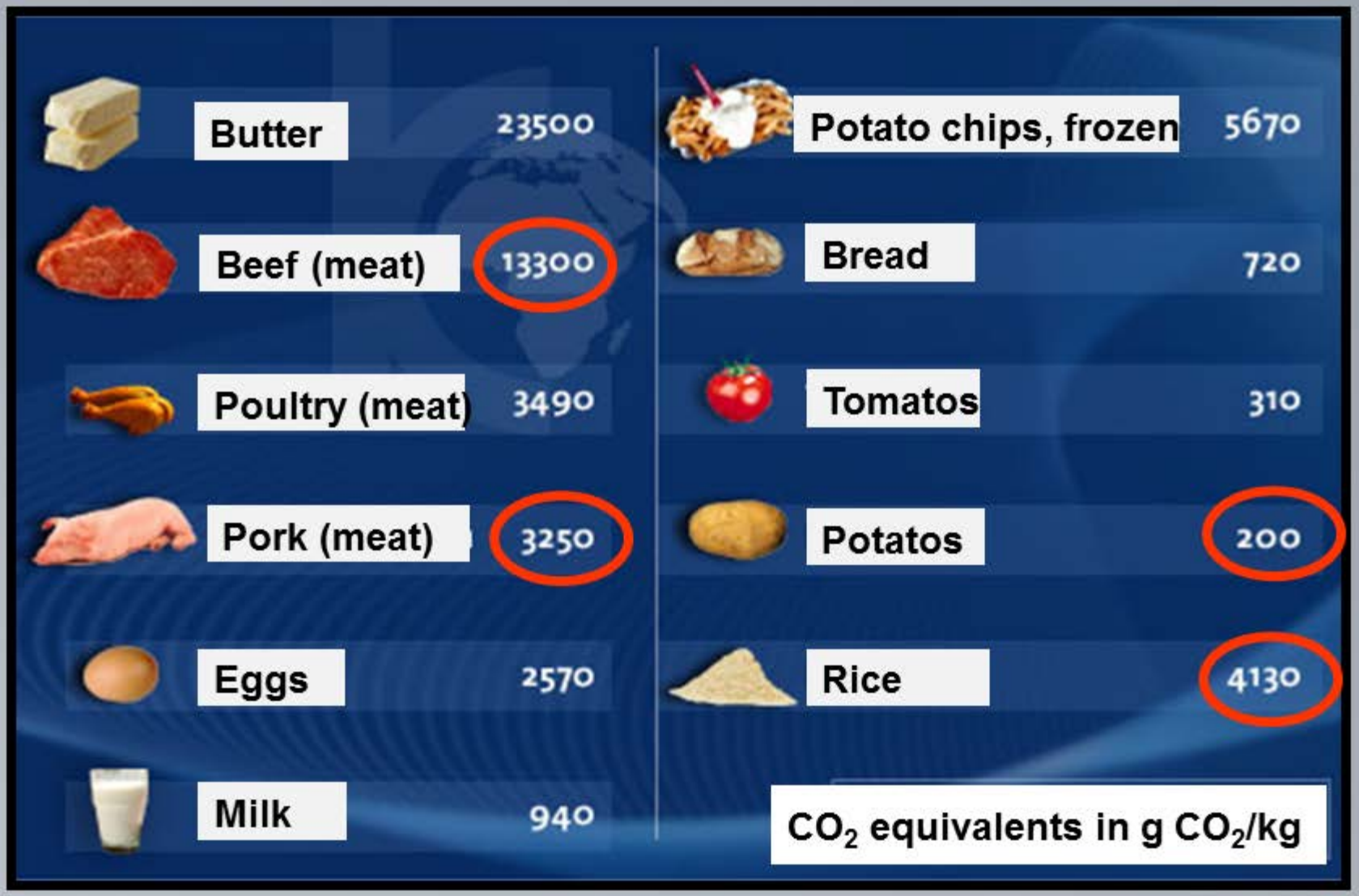
Source: IFEU 2008

Global total GHG emissions
by sectors incl. agriculture



Source: http://en.wikipedia.org/wiki/File:Greenhouse_Gas_by_Sector.png

GHG emissions
of selected foods



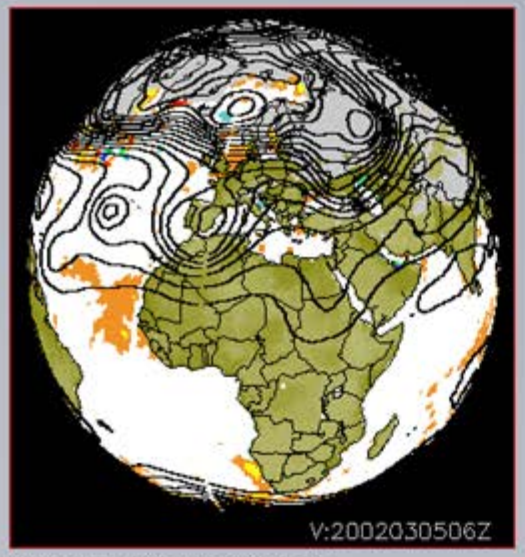
Source: Tagesschau.de In: http://www.agenda21-treffpunkt.de/daten/treibhausgase.htm

Calculation of GHG emissions
by means of professional software

RETScreen® Canada

http://www.nrcan.gc.ca/energy/software-tools/7465

RETScreen is a Clean Energy Management Software system for energy efficiency, renewable energy and cogeneration project feasibility analysis as well as ongoing energy performance analysis.



Source: Environment Canada

GEMIS Germany

www.iinas.org/gemis.html

IINAS is the host of **GEMIS** (Global Emissions Model for Integrated Systems), a public domain life-cycle and material flow analysis model and database that IINASprovides freely.

GEMIS was first released in 1989, and is continuously updated and extended since then. It is used by many parties in more than 30 countries for environmental, cost and employment analyses of energy, materials and transport systems.

Freely available tools to calculate your ecological footprint

Thank you

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