Energy needs and proposed solutions for the future

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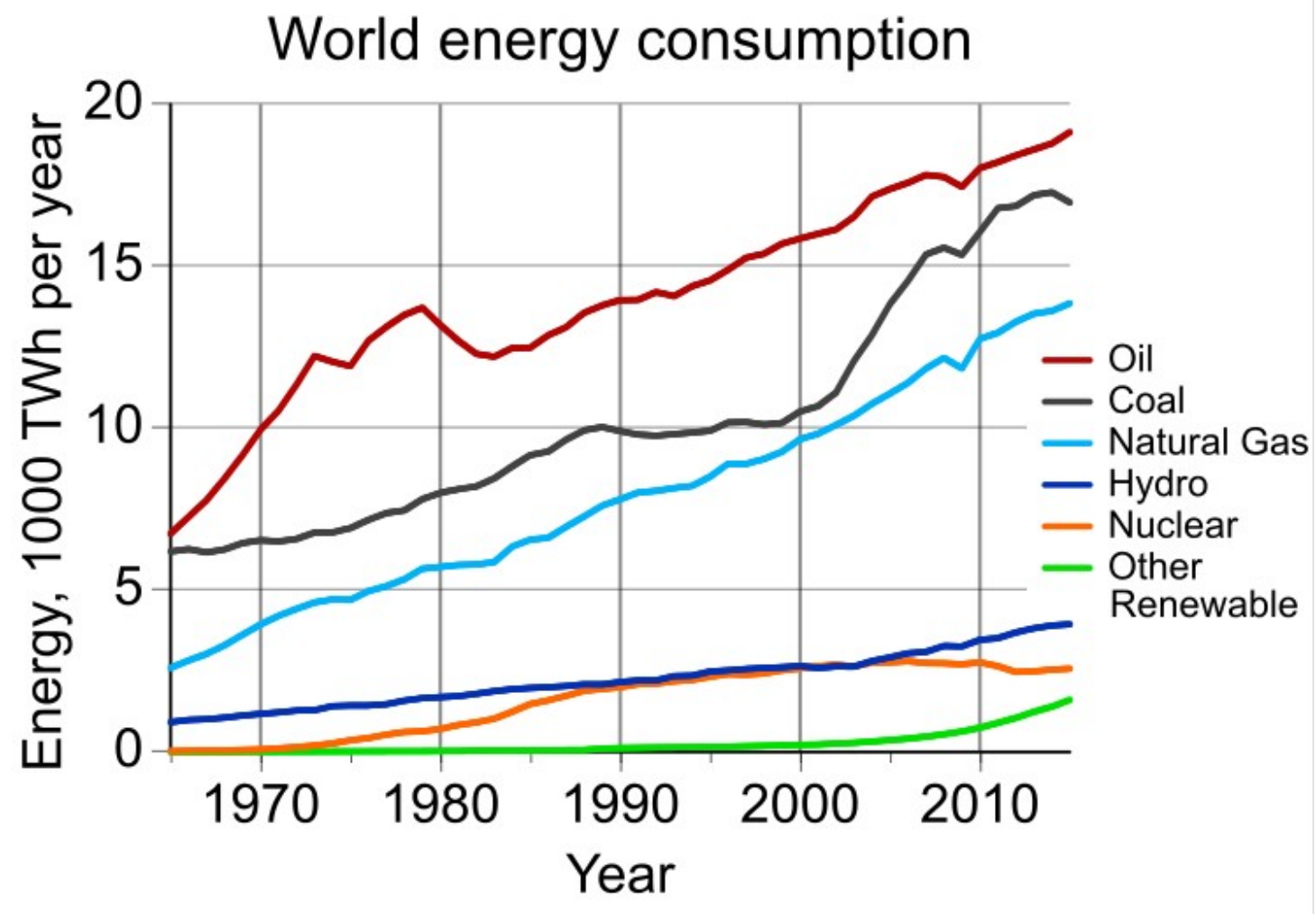
Outline

- **How (much) does human development impact energy consumption and, thus, required energy production?**
- **How does the choice of energy sources affect the environment? ⇒ Is it sustainable?**
- **(Why) do we need fusion?**

Energy consumption

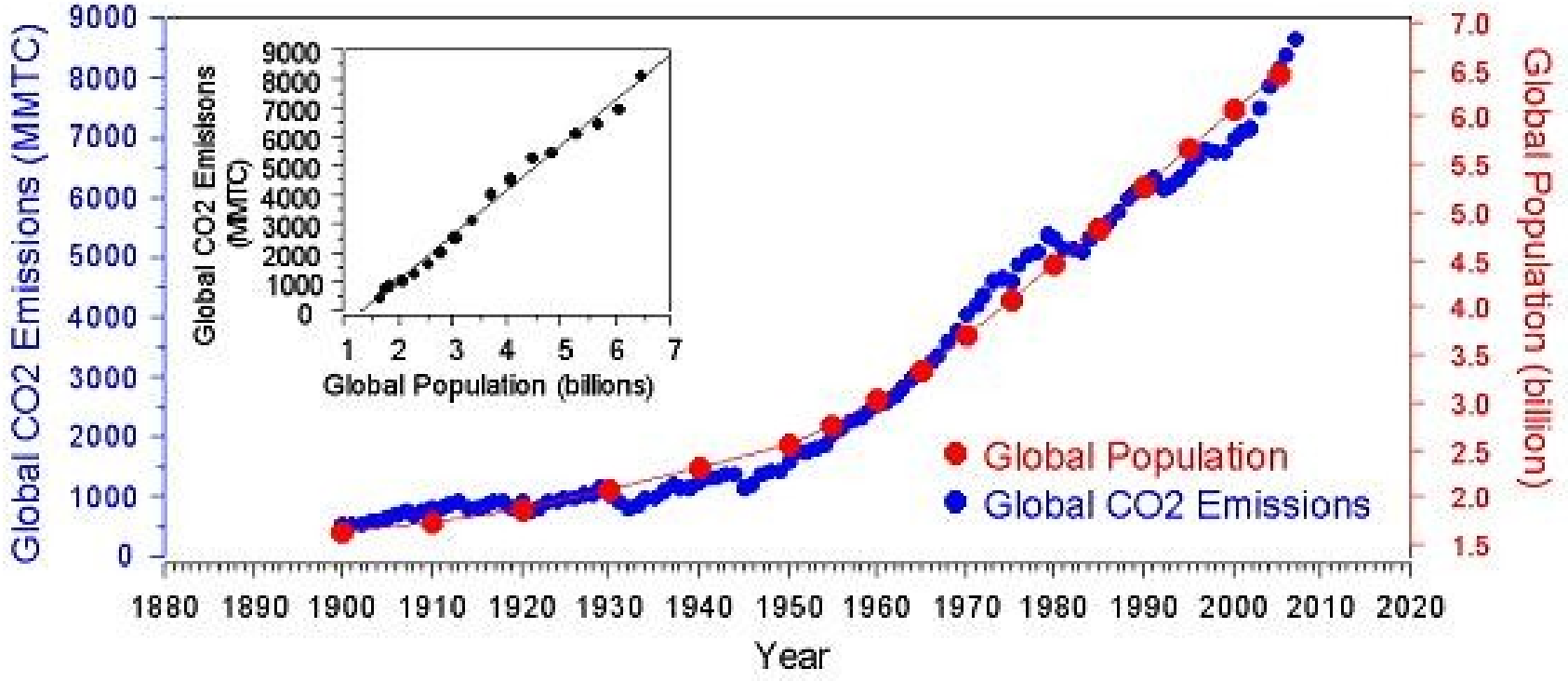
World energy consumption has been and is continuously increasing



Wikipedia (2016)

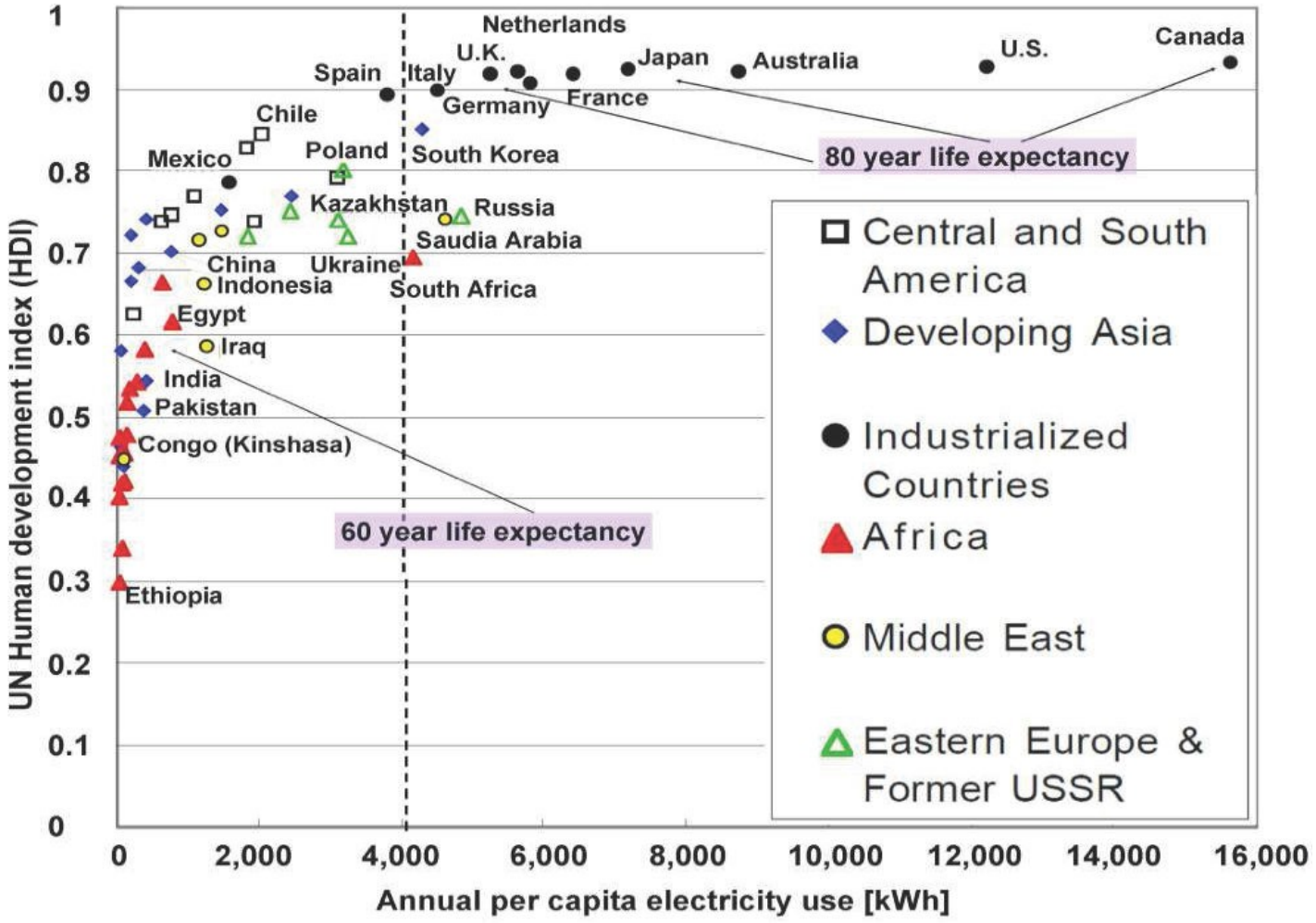
Growth of population goes hand-in-hand with increase in energy demand and CO_2 emission

World climate report 2008



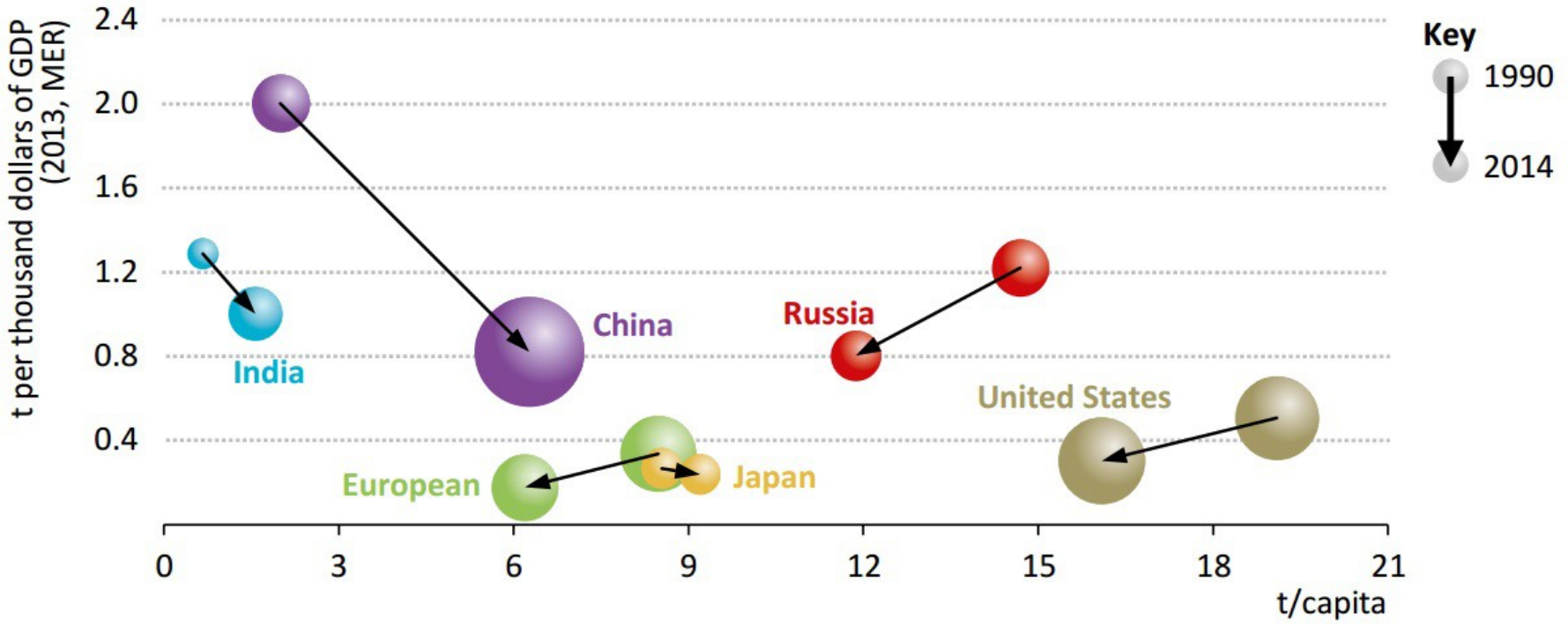
www.worldclimatereport.com
cdiac.ornl.gov/trends/emis/tre_glob.htm
www.census.gov/ipc/www/idb/worldpopinfo.htm

Electricity consumption increases with human development ⇒ developing countries improve fast



Pasternak, US-DOE, LLNL (2000)

China significantly increased their total CO_2 emission as well as their CO_2 emission per capita

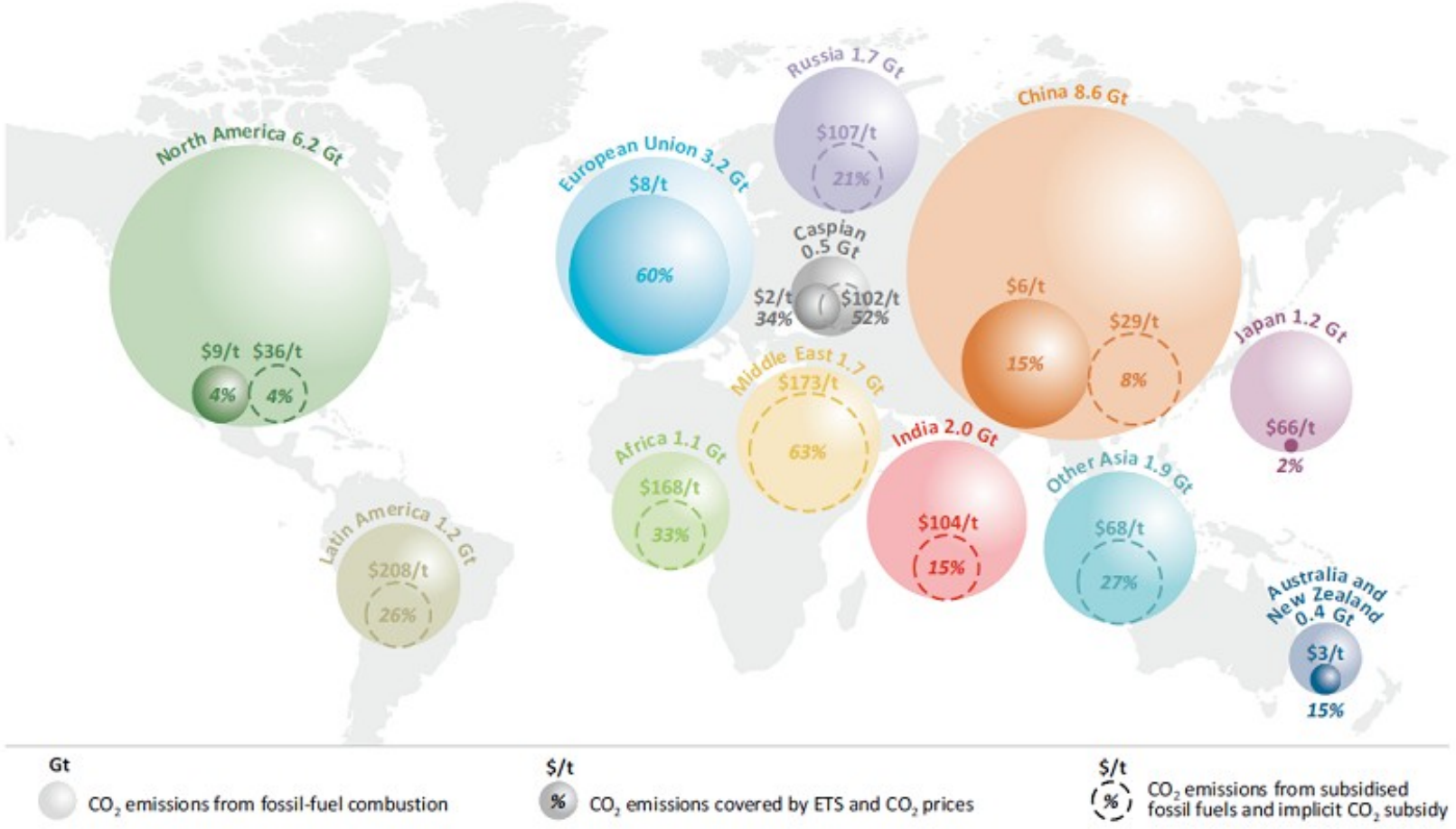


Notes: Bubble area indicates total annual energy-related CO_2 emissions. MER = market exchange rate.

IEA, 2015

China and the USA alone produced about 46% of the world-wide, energy-related CO_2 emission (32 GT, 2014)

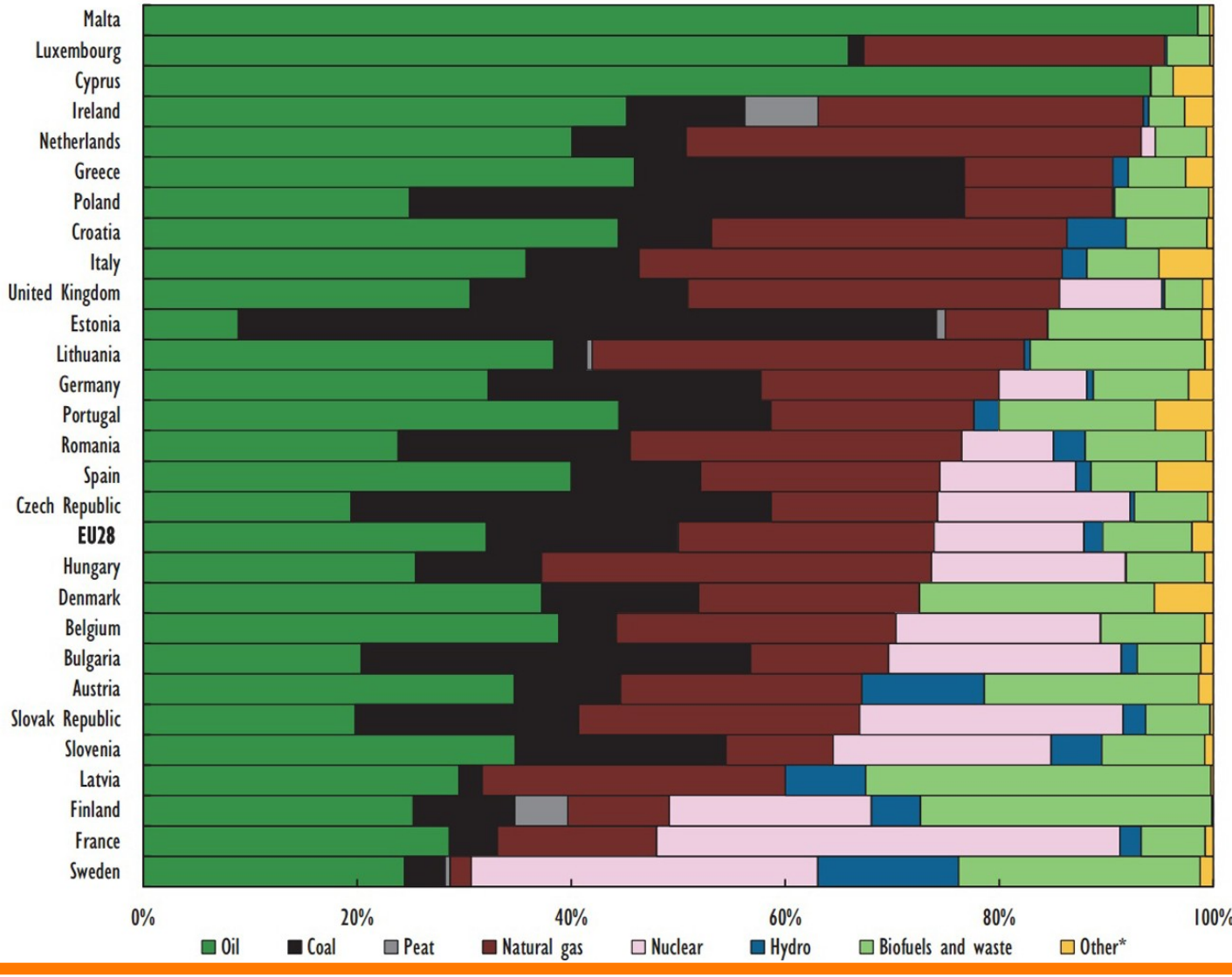
Energy-related CO2 emissions in selected regions, 2014



IEA, 2015

ETS = emissions trading scheme

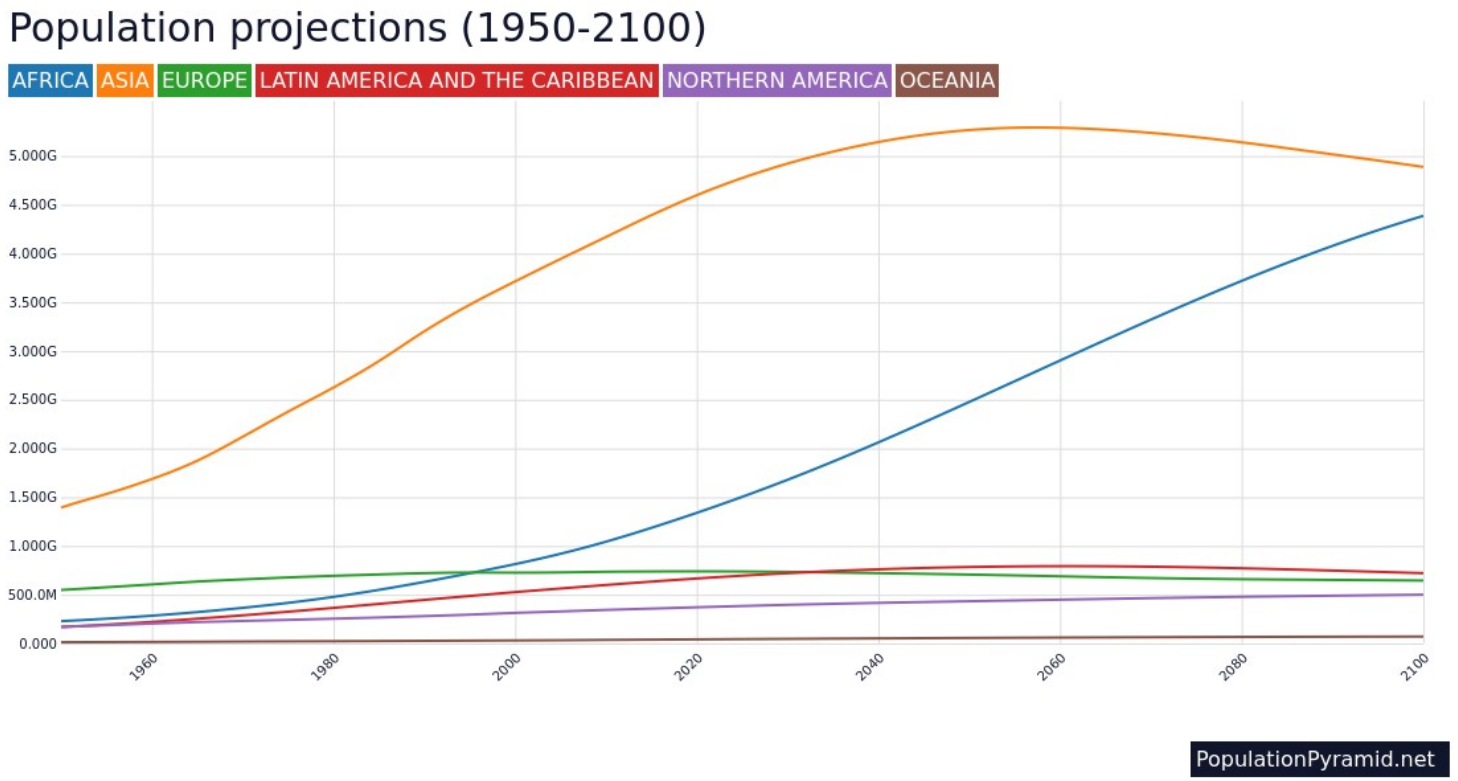
Total primary energy supply for EU member states: Finland's consumption still dominated by fossil fuels



http://stat.fi

Projected energy consumption in 2100

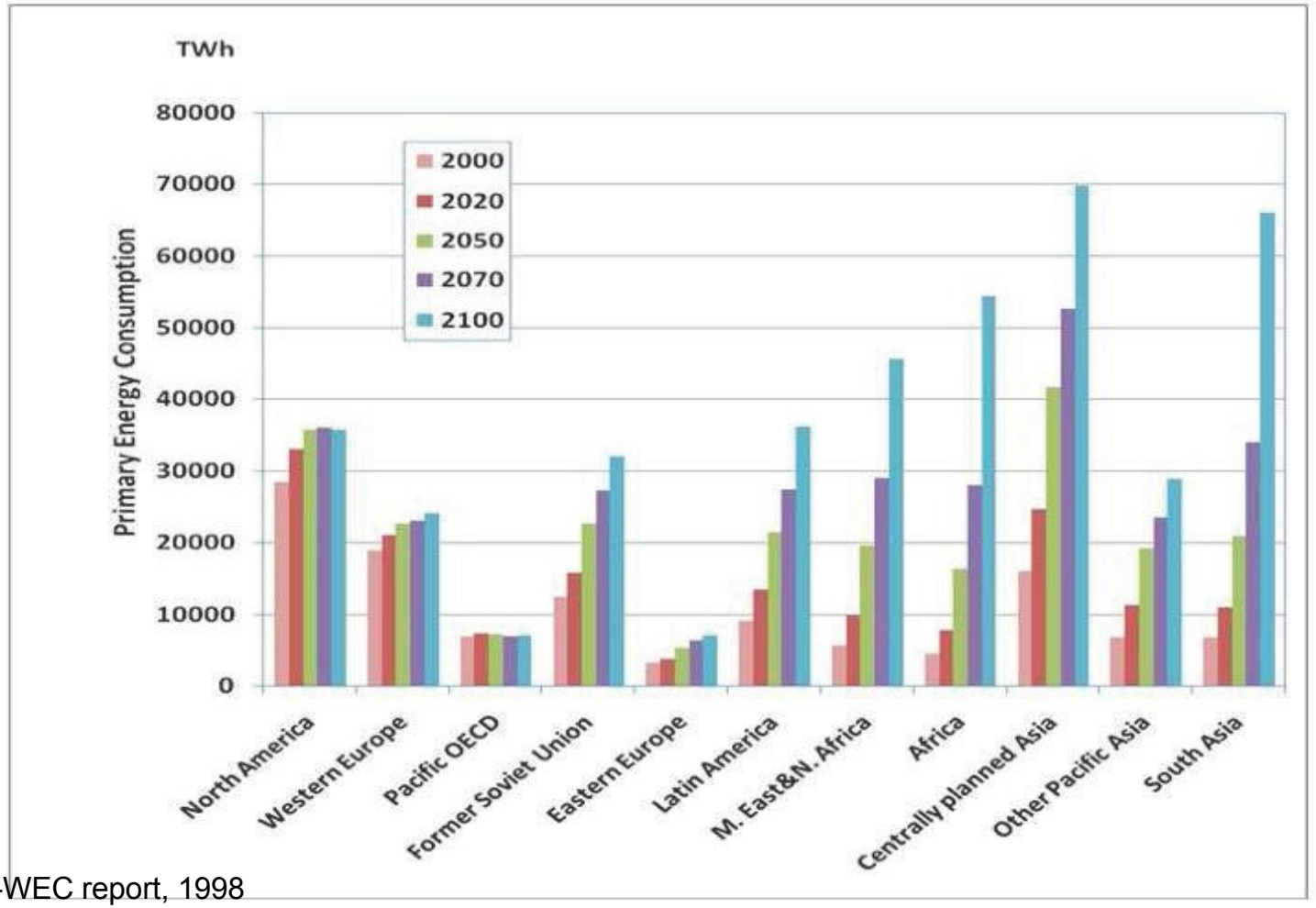
Population continues to increase



www.populationpyramid.net (UN data)

By 2100, Asian countries are predicted to dominate the world-wide energy consumption

Primary Energy Consumption split in regions

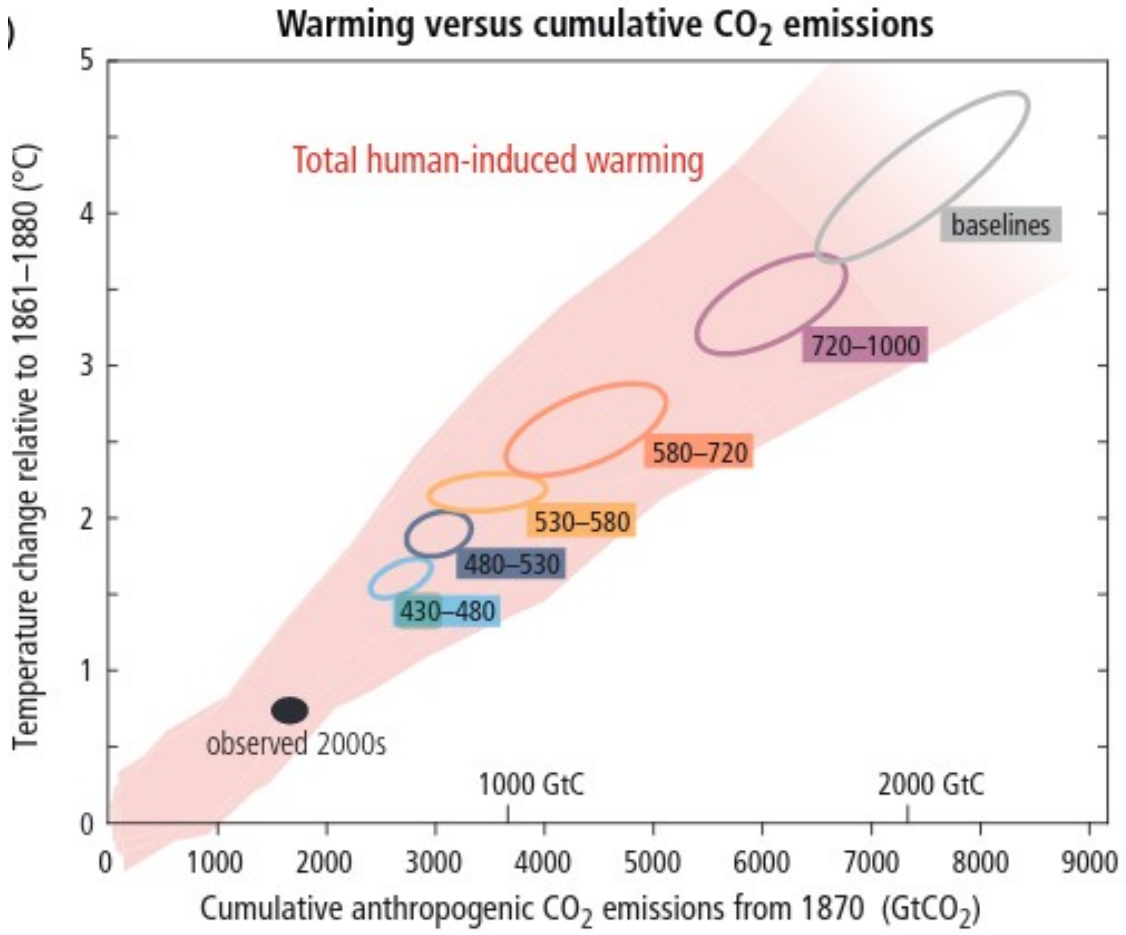


IIASA-WEC report, 1998

Centrally planned Asia: China, Hong Kong, Vietnam...

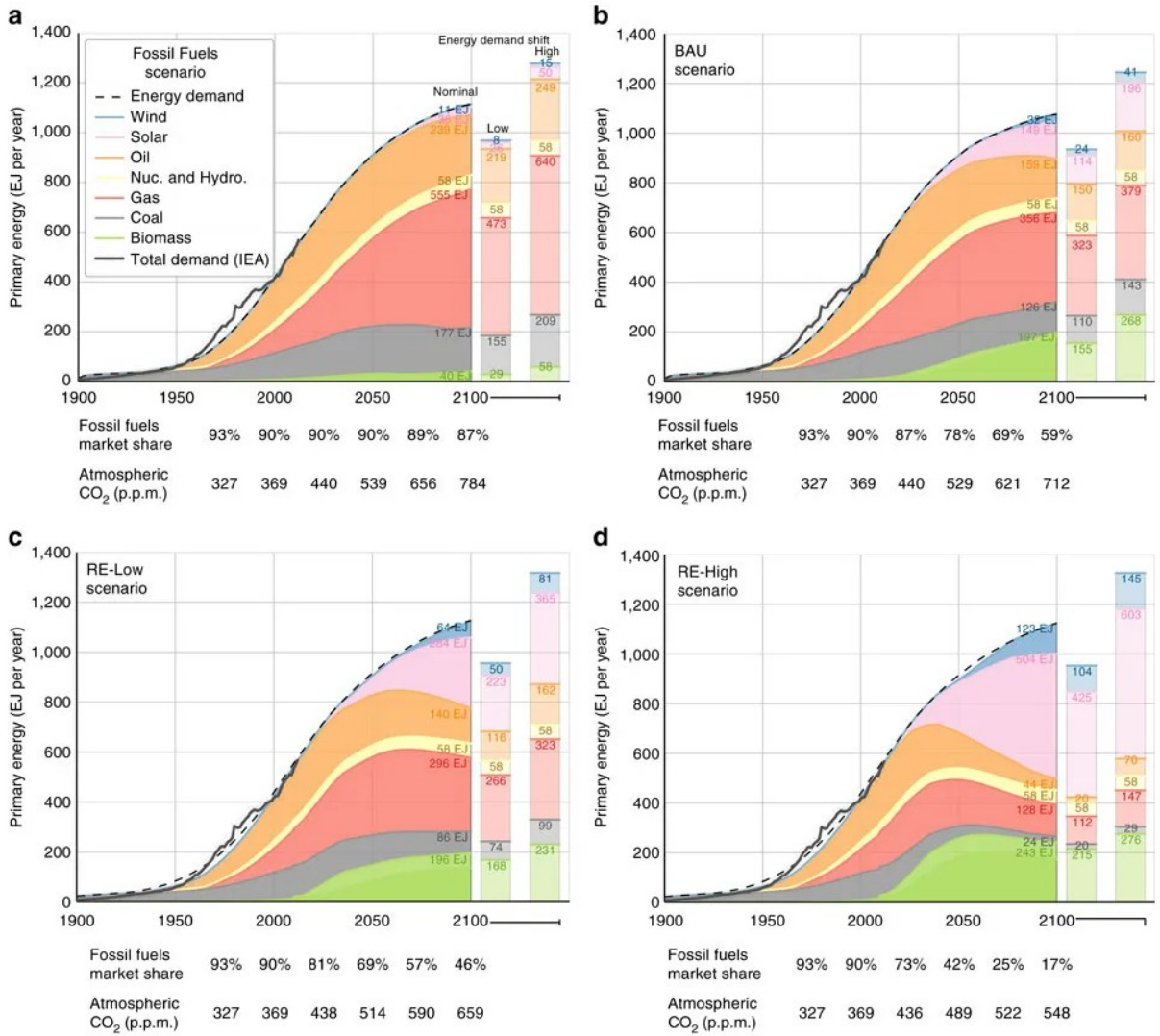
South Asia: India, Afghanistan, Pakistan...

Anthropogenic warming in 2100 versus cumulative CO2 emissions from 1870 to 2100



IPCC summary for policy makers 2014

Different scenarios for Global Primary Energy Consumption (source of energy)

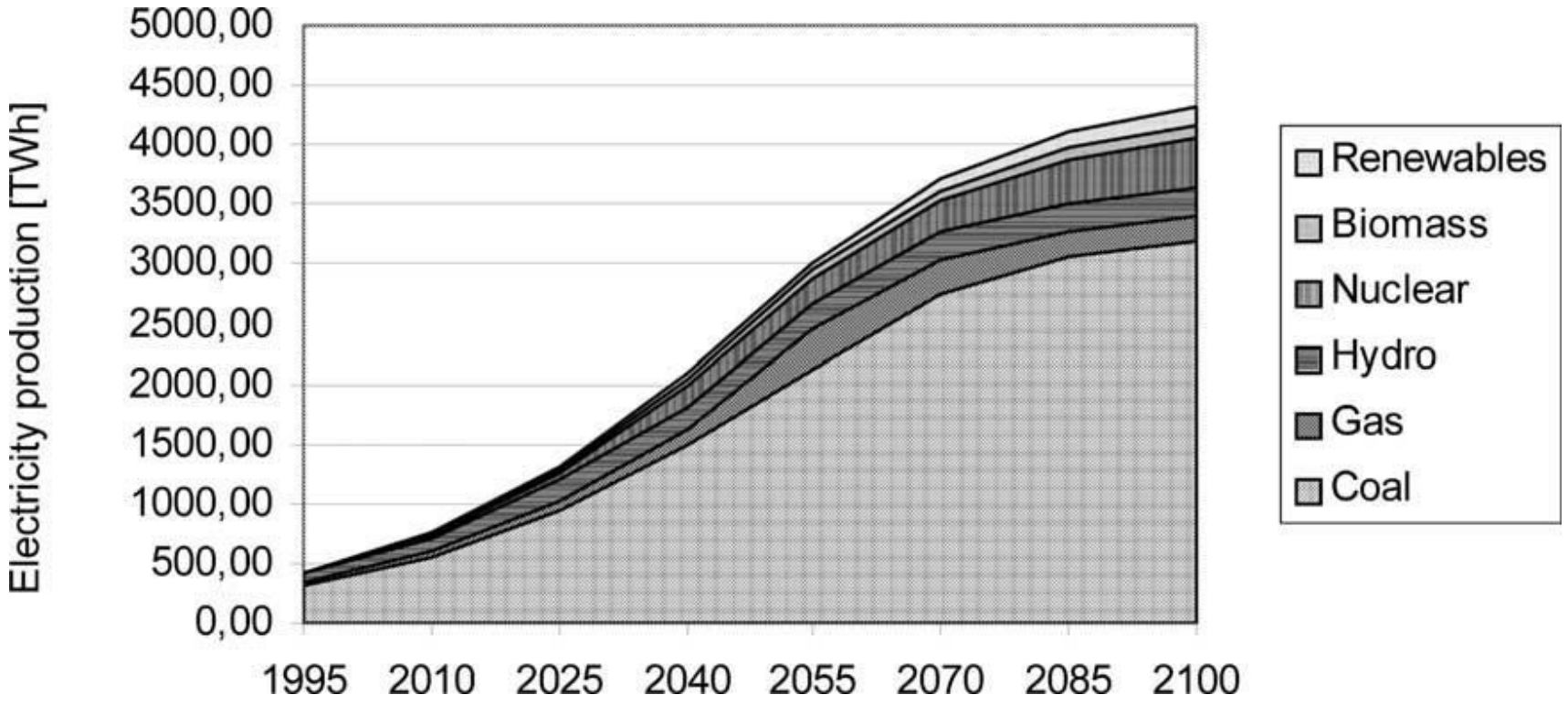


(a) Share of Fossil Fuels remains constant,
(b) Business as usual (BAU),
(c) renewables accelerate modestly (RE-Low) or
(d) rapidly (RE-High). Even RE-High leads to ΔT= 2.5˚C so it needs to be combined with carbon capture and sequestration (CCS) or utilization to meet goals of Paris agreement (ΔT= 1.5˚C)

Walsh et al, Nature communications, 2017

Example: India relying on the “cheap solution” of burning coal …

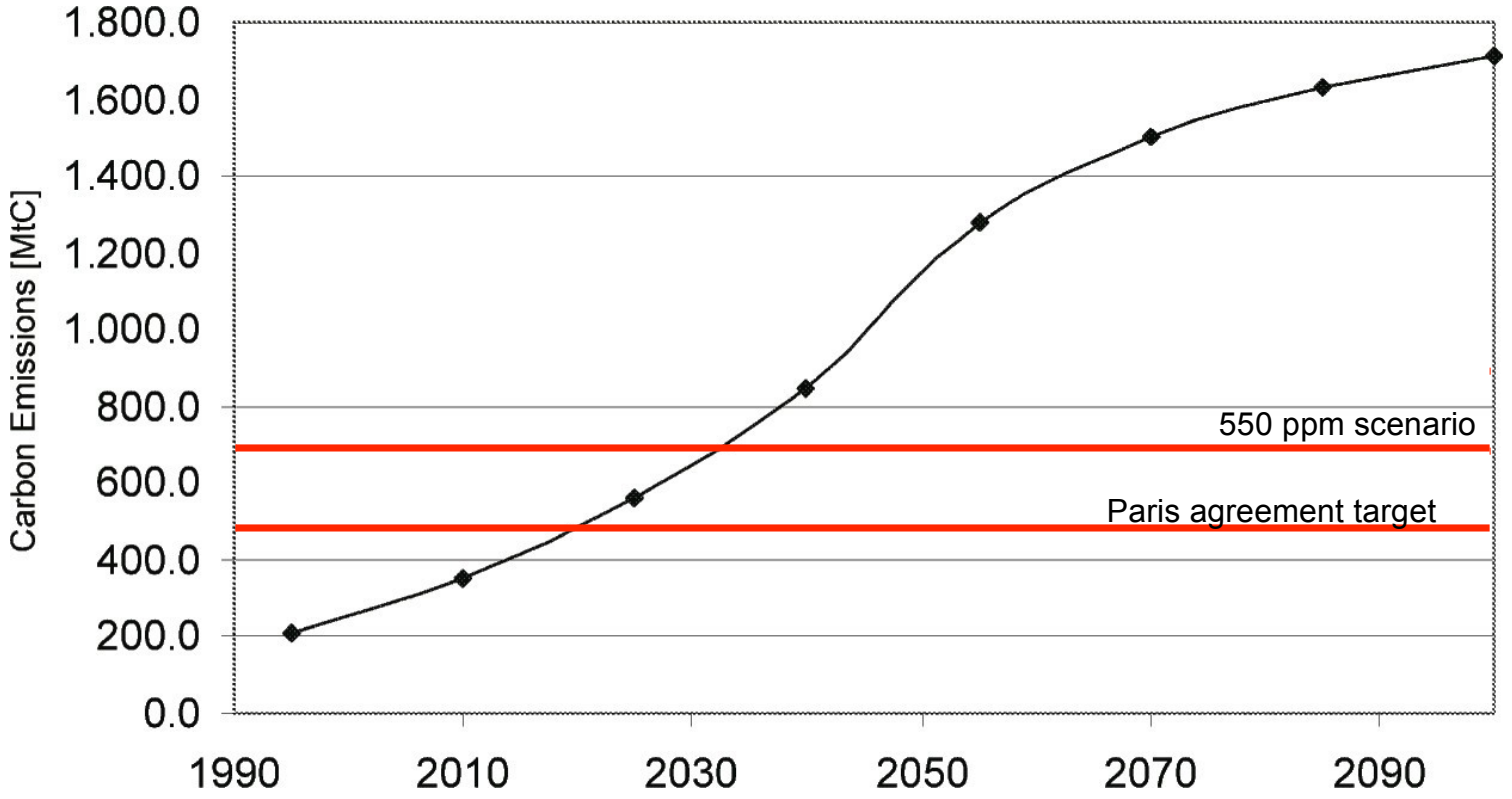
Forecast of energy mix of India by 2100



Hamacher, Fusion Eng. Design 2003

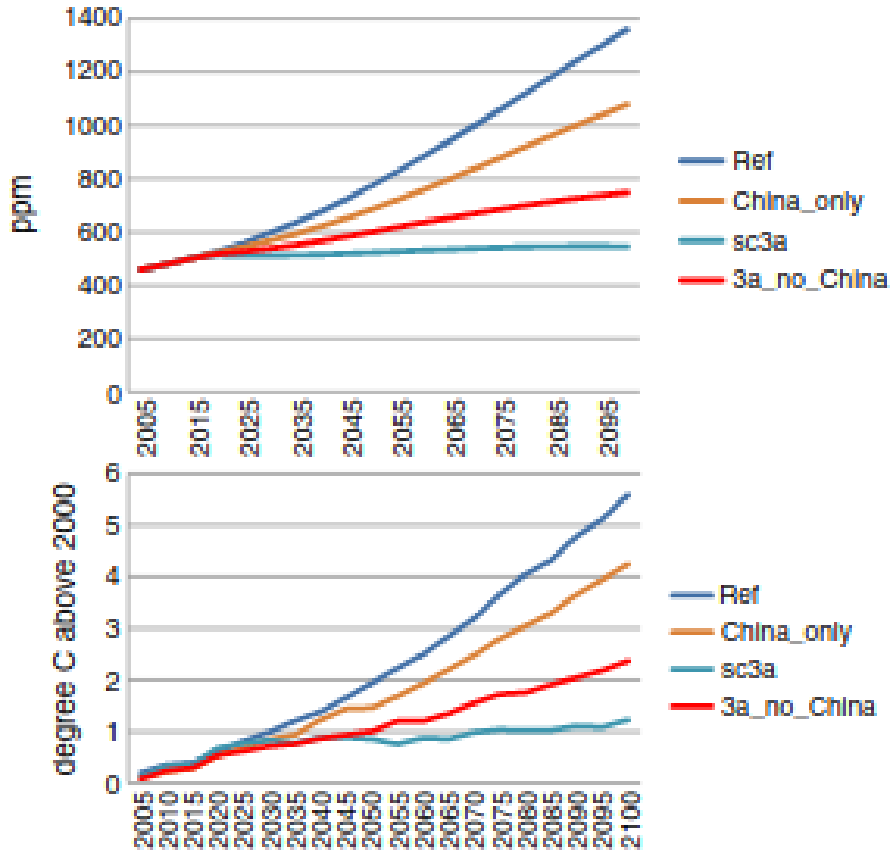
... at the cost of producing roughly a quarter of the year-2000 global CO_2 emission by 2100

- **Restriction of world-wide CO2 emission to 980 GtC during 1990 to 2100 period ⇒ India ≈ 7.5% = 735 MtC / year**



Hamacher, Fusion Eng. Design 2003

Example: Importance of China in mitigating climate change



Different scenarios: China *or* rest of the world *or* both follow scenario where carbon price is imposed to reach the stabilization by 2100

Paltsev et al, Energy Economics, 2012

Future energy mix

Present primary energy sources and their drawbacks

- **Fossil fuels (coal, natural gas, petroleum): depleting resources (≈ 200, 60, 40 years) ⇒ CO_2 pollution, global warming**
  - **Oil and gas are local sources ⇒ political and military conflicts**
- **Fission: public acceptance, proliferation, waste, Chernobyl/Fukushima-type accidents**
- **Solar and wind: low energy density (to power plants, large cities) and availability**

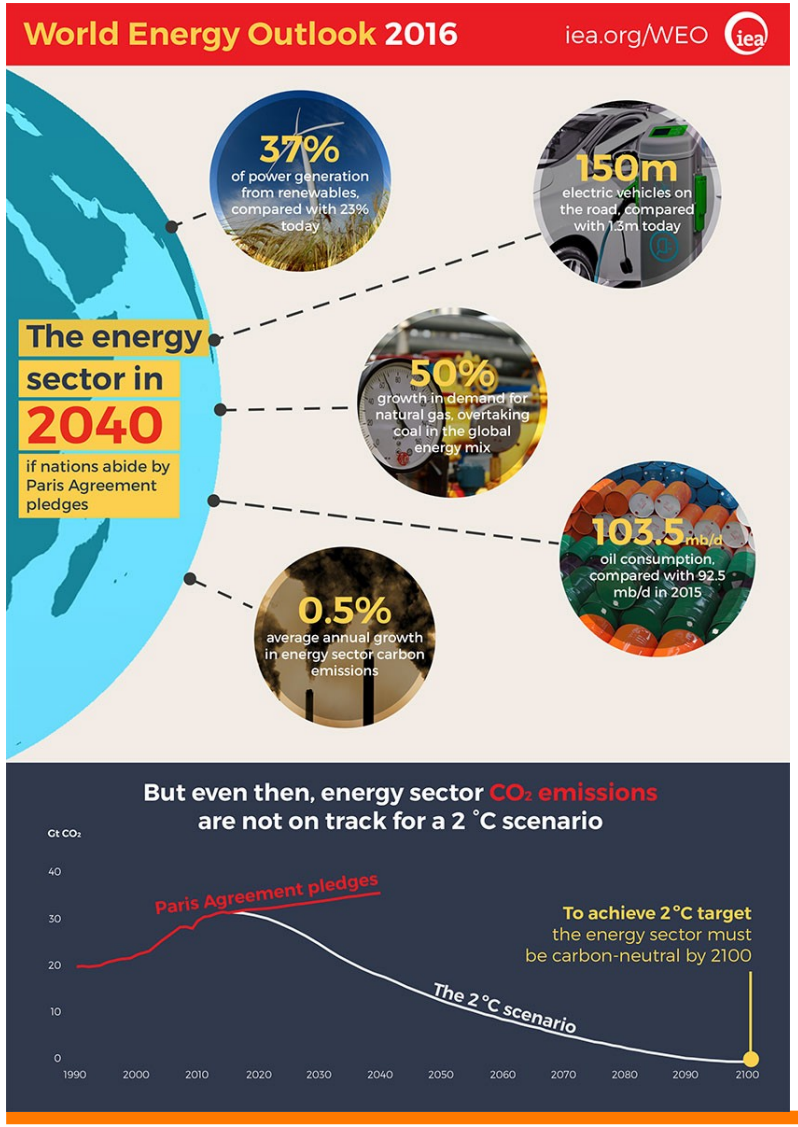
Development of new energy sources has long lead time

New energy resources will require …

- **Efficient and clean energy conversion**
- **Publicly accepted**
- **Sustainable across the entire world ⇒ virtually inexhaustible and globally available, independent from politically unstable regions**
- **Sufficiently high energy density capable of driving large-scale industries without requiring widely distributed installations**

⇒ **Near-term (20 - 30 years): solar, biofuels, and nuclear energy ⇒ long-term (end of 21st century) will require more advanced solution**

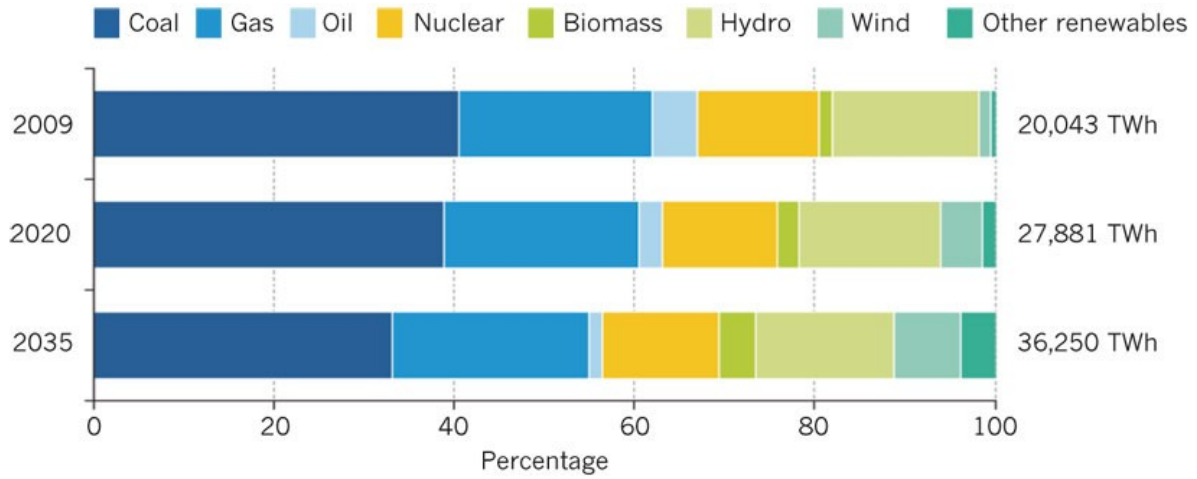
Energy sector in 2040

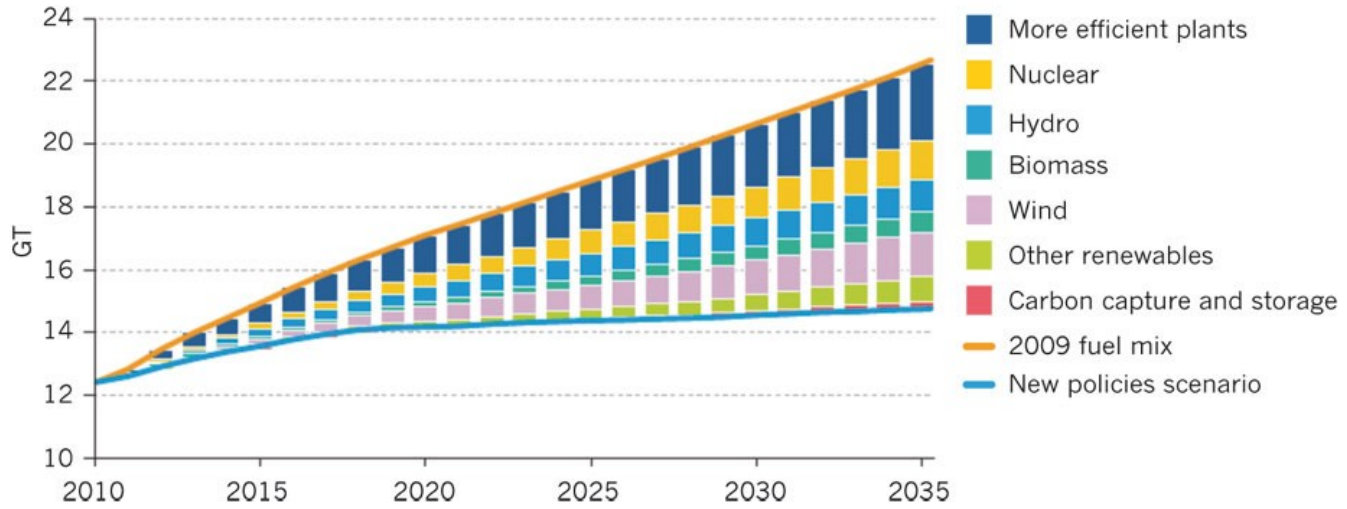


- **Future energy mix depends on interaction between**
  1. **Technology development**
  2. **Climate targets**
  3. **Public policy**

- **Trends up to 2040:**
  1. **Renewable energies**
  2. **Electric cars**
  3. **Yet, use of fossil fuels still increasing …**

Gradual shift of energy sources away from fossil fuels is taking place





- **IEA scenario expects share of renewables to significantly increase**
- **Carbon emissions, however, is expected to increase, but slower than the 2009 fuel-mix curve**

Potential role of fusion as future energy source

How/can we establish the sun's internal energy production process on earth?

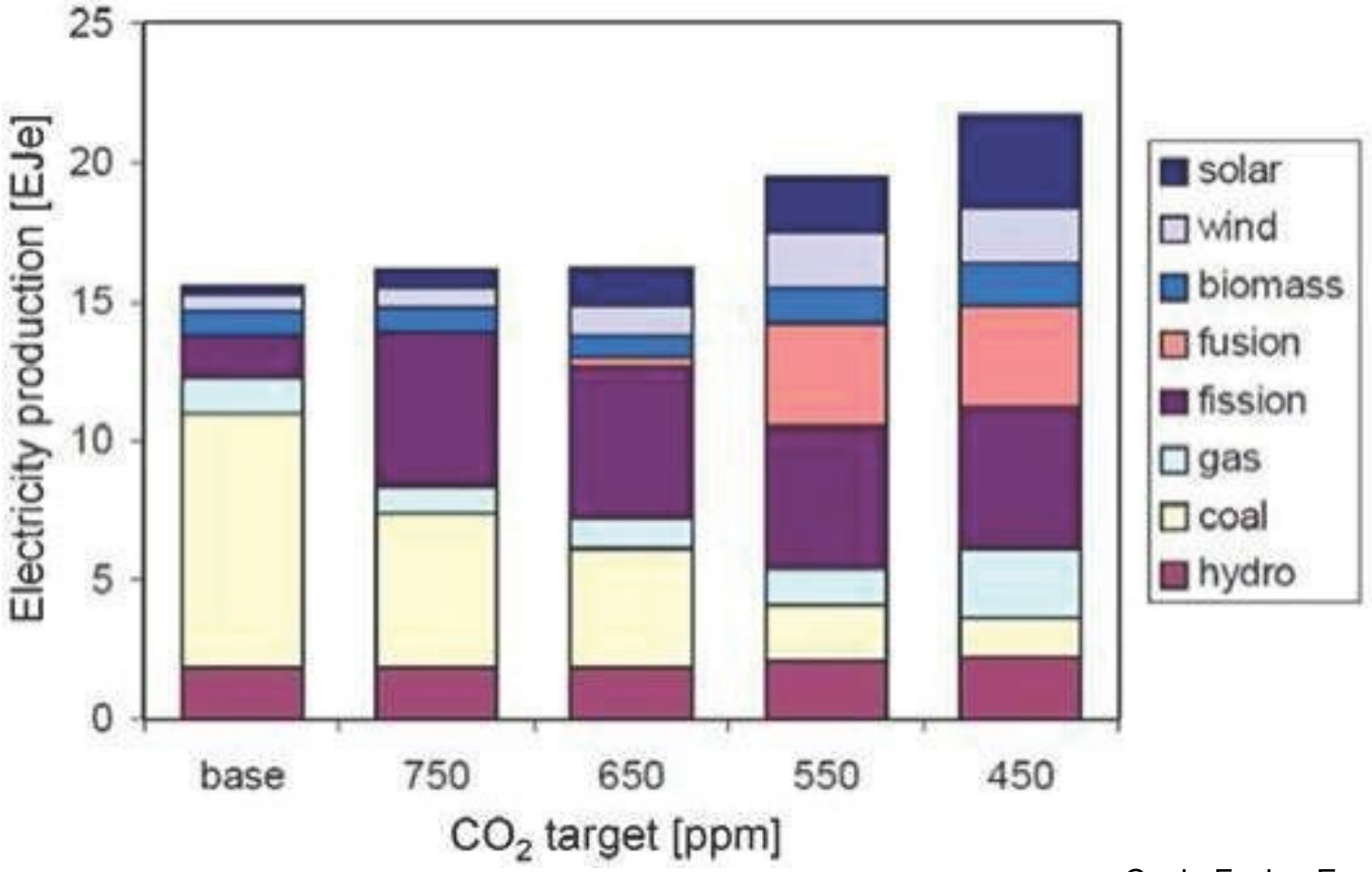
- **Core of the sun produces 380 yottawatts (3.8 x 10^{26} W) via fusion**
- **Reaction based on merging of hydrogen isotopes to helium:**

$$4\,{}^{1}H \rightarrow {}^{4}He + 2e^{+} + 2\nu^{+} + 3\gamma +$$

$$26.8MeV$$

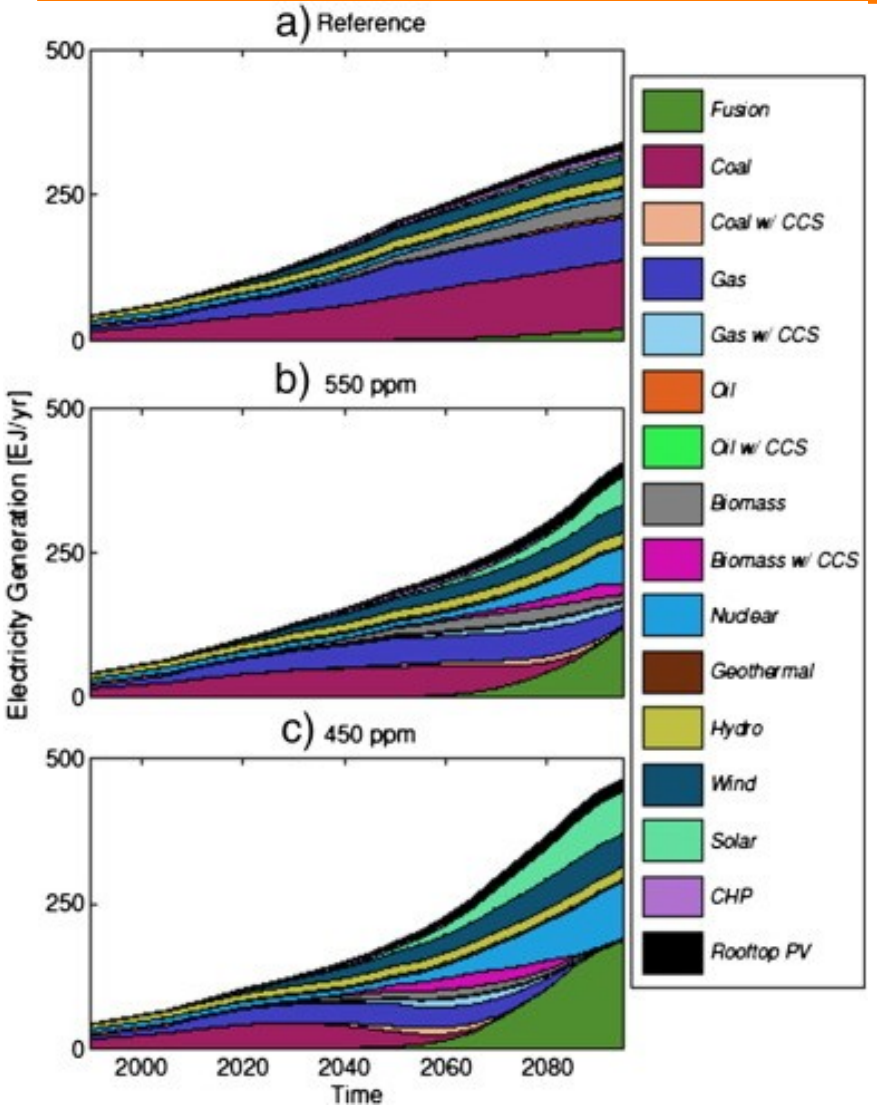
Fusion could potentially play a significant role in reducing the CO_2 content in earth's atmosphere

Projections for CO_2 emission constrained energy scenarios in Western Europe in 2100



Cook, Fusion Eng. Design 2002

The share of fusion in the future energy mix depends on several factors

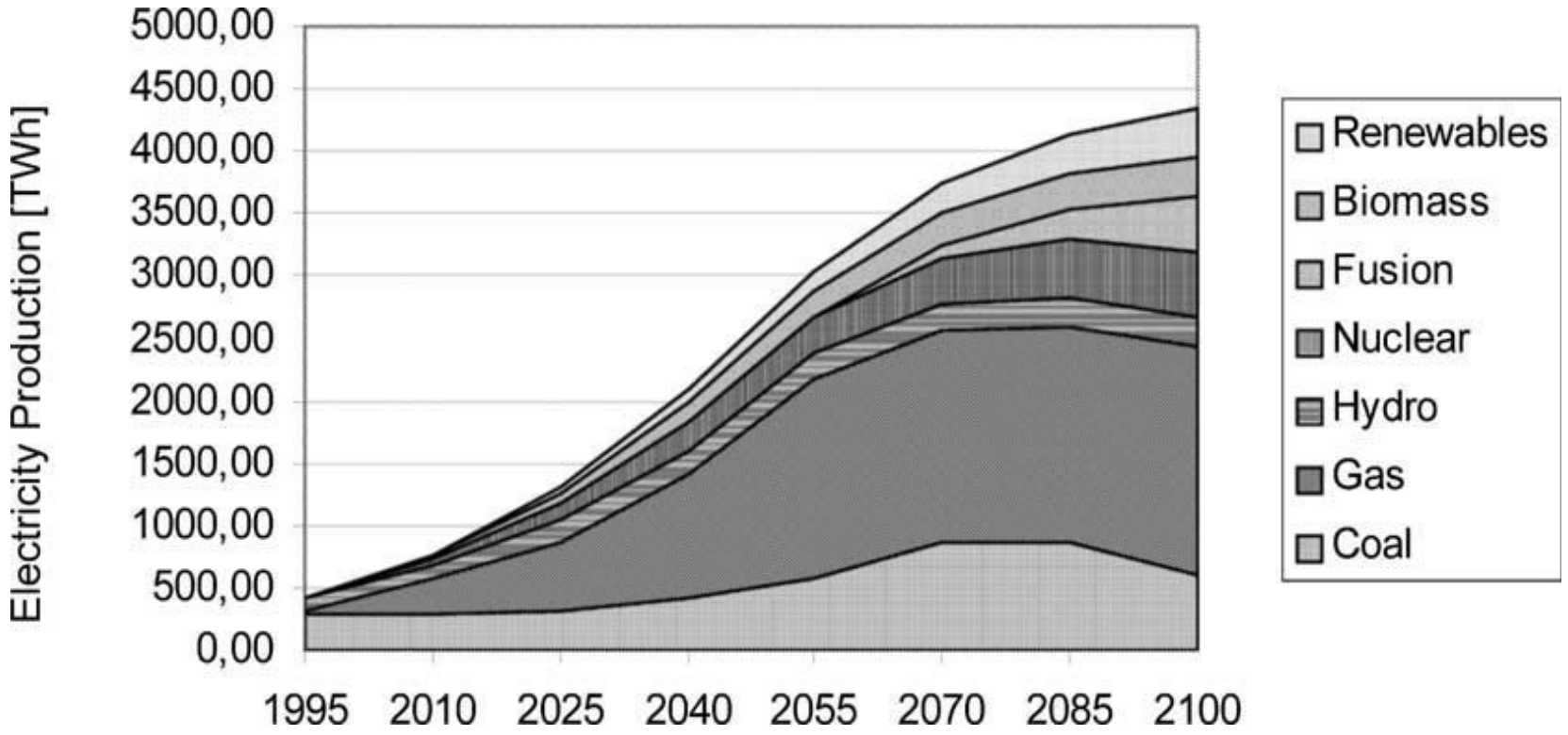


- **Chosen carbon mitigation target**
- **Availability of competing carbon-neutral options for baseload electrical power**
  - **Nuclear fission**
  - **Carbon capture and storage**
  - **Renewables combined with energy storage**
- **Initial year of availability**
- **Assumed costs of fusion electricity**

Turnbull, Energy Economics, 2015

Introduction of fission, fusion and renewables could meet India's energy demands

- **Fusion at the level of 10% makes only an inroad to the system ⇒ could potentially be expanded significantly**



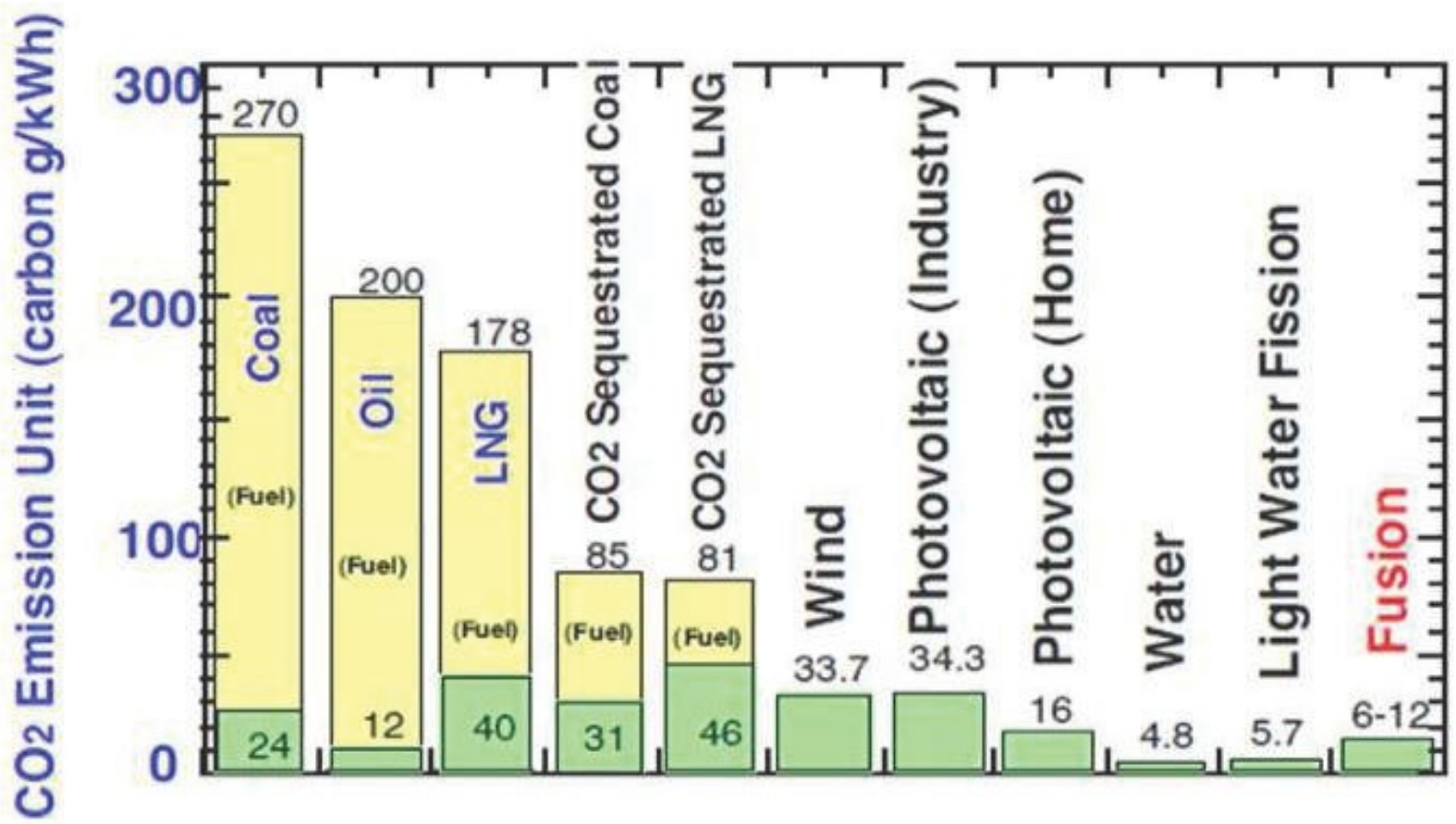
Hamacher, Fusion Eng. Design 2003

Benefits of fusion

- **Fusion fuels are abundantly available**
- **Efficient energy source:** only small amounts (g's) of hydrogen isotopes necessary ⇒ 250 kg of fuel per year (c.f., coal plant 2.7 million tons)
- **Energy output at GW level**
- **Process is inherently safe:** no run-away process (plasma will quench)
- **No pollution or greenhouse gas production, no immediate radioactive waste:** reaction product (helium) is an inert, non-toxic gas
- **No proliferation, low activation of materials**

Fusion reactors could potentially be the third-lowest CO2 polluter, still lower than sequestrated coal plants

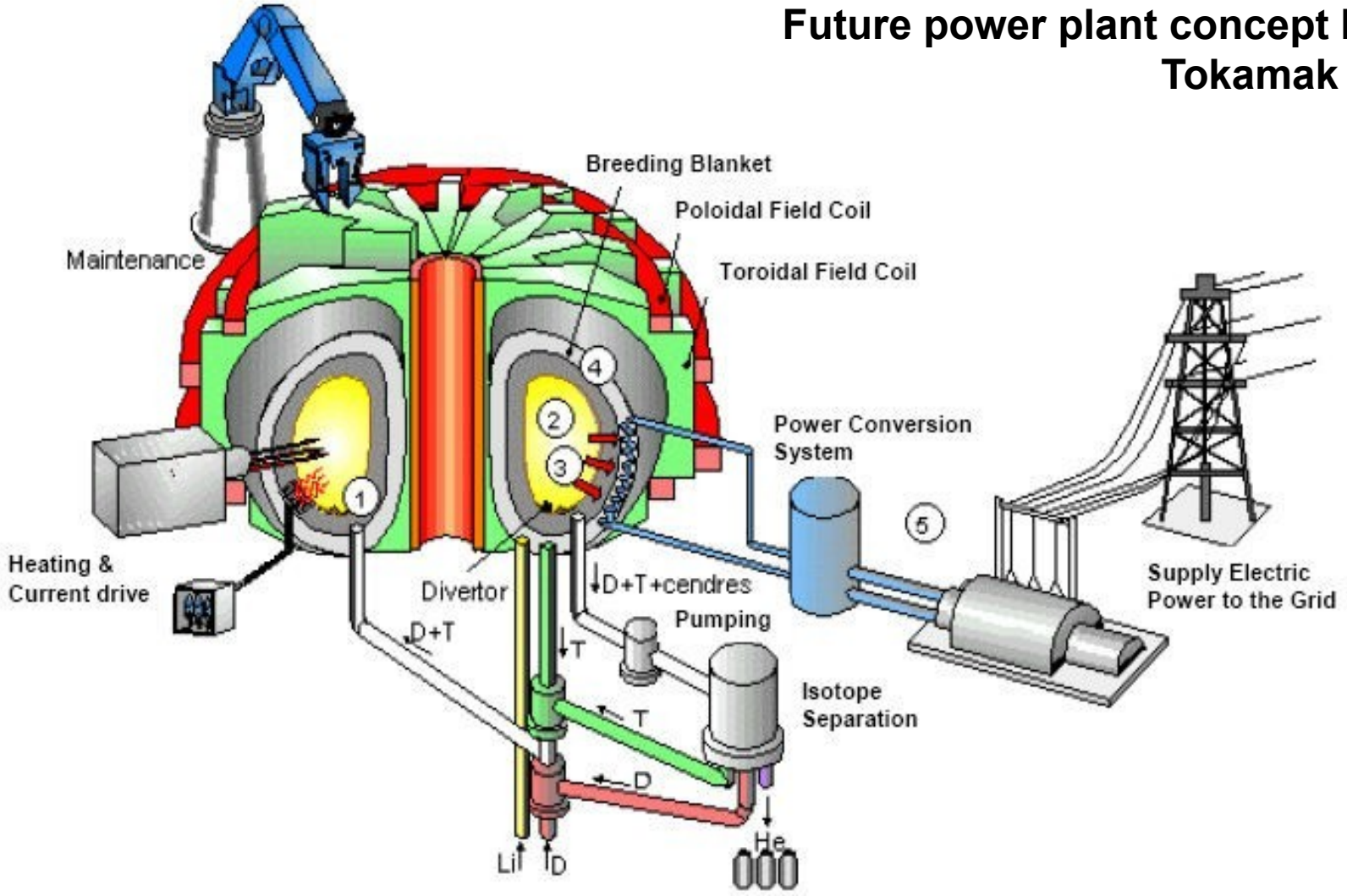
CO_2 exhaust of power reactors in their entire life cycle



Kikuchi, Proc. 18th World Energy Conference 2001

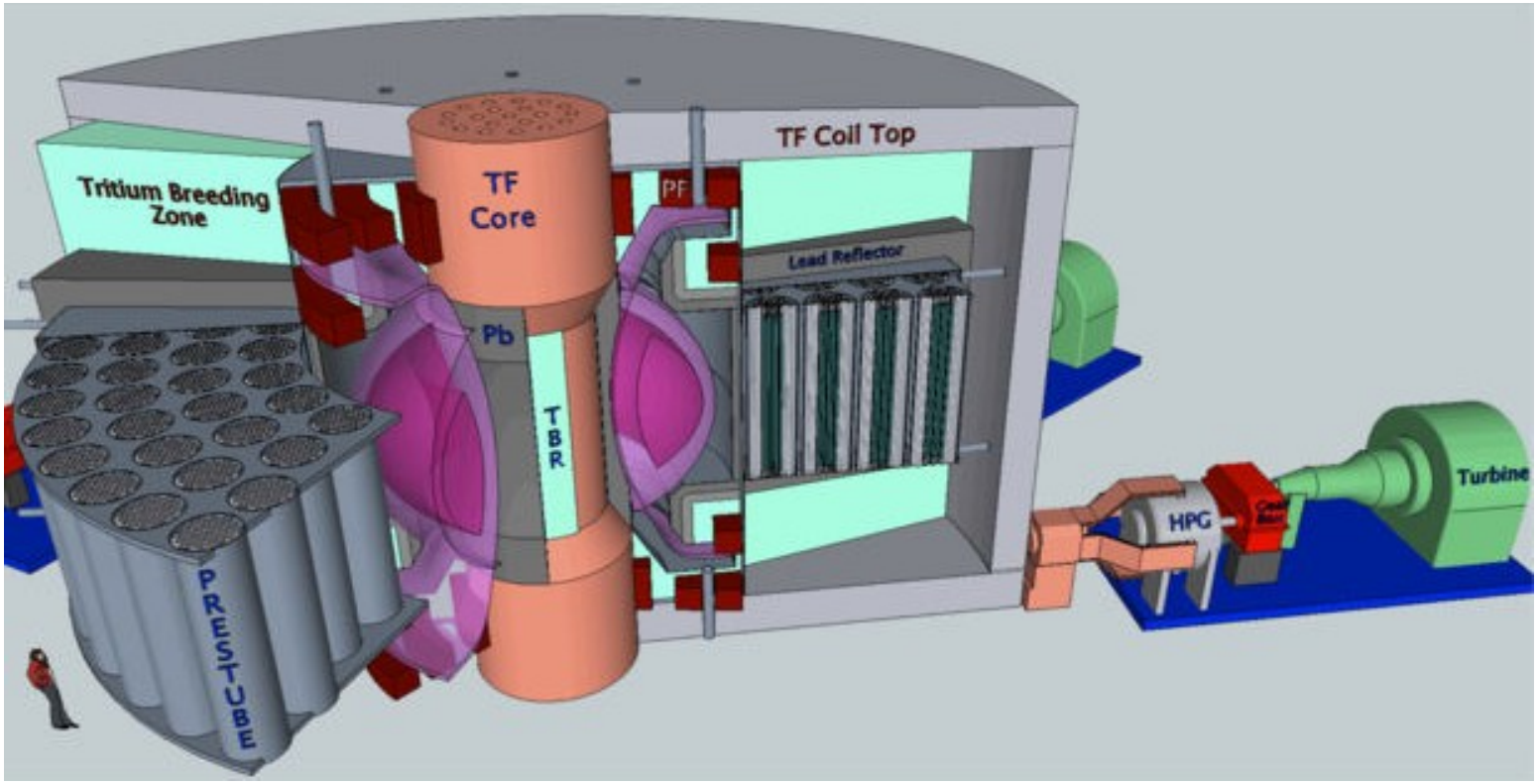
The principle of fusion power plants is similar to conventional plants: heat a blanket and drive a turbine

Future power plant concept based on Tokamak principle



The increase the efficiency of nuclear energy, fusion-fission hybrids are also considered

- **Excess fusion neutrons for high-yield fission reactions in the surrounding, sub-critical fissionable blankets ⇒ up to 300% gain in energy output + reduced nuclear waste**



Summary

- **Increase in human development goes hand-in-hand with the increase in energy consumption**

⇒ **Rapidly developing countries, (e.g., China and India) are predicted to consume approx. 5 times more energy by 2100 compared to today**

- **Current (fossil) energy sources could meet energy demands, but exploitation is predicted to lead to unacceptably high CO_2 emission ⇒ global warming and degrading of environment (e.g., smog, acid rain, reduction in life quality)**

- **Fusion of hydrogen isotopes can potentially be a major energy source in the future, offering significant benefits**

F. Wagner studies on energy mix in Europe (IPP Summer School 2017)

Conclusion for fusion

I doubt that a complete decarbonisation with mostly intermittent RES will be possible: A second system is needed

- fission, on basis of fast neutron reactors of Gen. IV
- CCS (carbon capture and sequestration)
- fusion (interesting: in case of sector coupling, a base-line supply is still required)

RES = Renewable Energy System
Sector Coupling = integration of energy end-use and supply sectors with one another improving the efficiency and flexibility of the energy system