Fossil Fuel Combustion and the Economics of Energy

Fossil Fuel Emissions Information

- Tabulations of emissions by country:
  - Distribution within country by political subunit and population density
  - Oak Ridge National Lab (Greg Marland) http://cdiac.esd.ornl.gov/authors/marland.html
  - Andres et al (1996)
- US DoE Energy Information Administration
  - http://www.eia.doe.gov

GLOBAL CARBON PROJECT

All the data is shown in GtC

1 Gigatonne (Gt) = 1 billion tonnes = 1×10^{15}g = 1 Petagram (Pg)

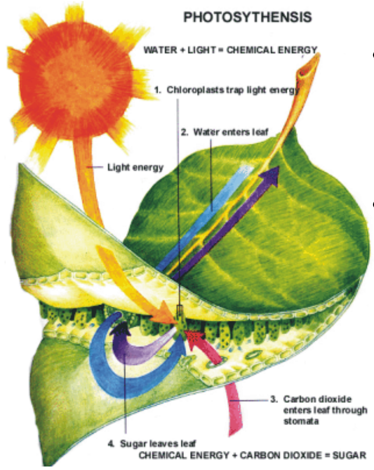
1 kg carbon (C) = 3.664 kg carbon dioxide (CO_2)

1 GtC = 3.664 billion tonnes CO_2 = 3.664 $GtCO_2$

Disclaimer

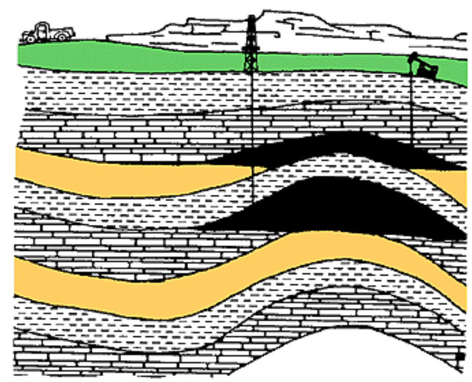
The Global Carbon Budget and the information presented here are intended for those interested in learning about the carbon cycle, and how human activities are changing it. The information contained herein is provided as a public service, with the understanding that the Global Carbon Project team make no warranties, either expressed or implied, concerning the accuracy, completeness, reliability, or suitability of the information.

Carbon, Life, and Energy



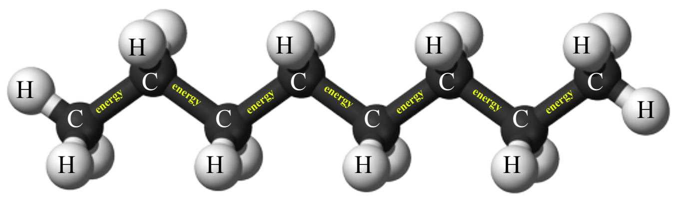
- Photosynthesis uses energy from the sun to convert inorganic air (CO_2) to living biomass!
- Most of this energy is released through respiration (back to CO_2) when plants are eaten by animals, bacteria, people

Fossil Fuels

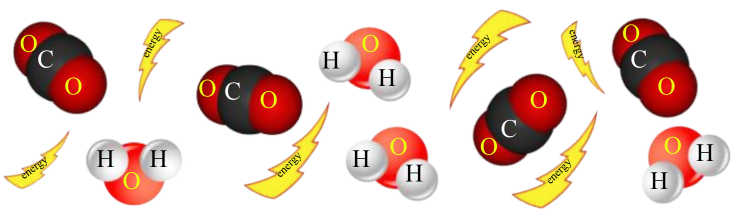


Some of the stored solar energy in biomass can be preserved in fossilized remains

Hydrocarbons, Energy, and CO_2

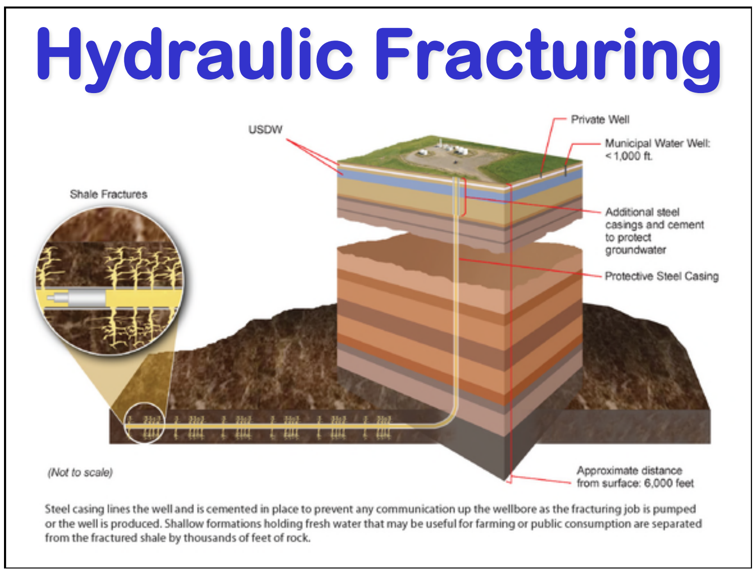


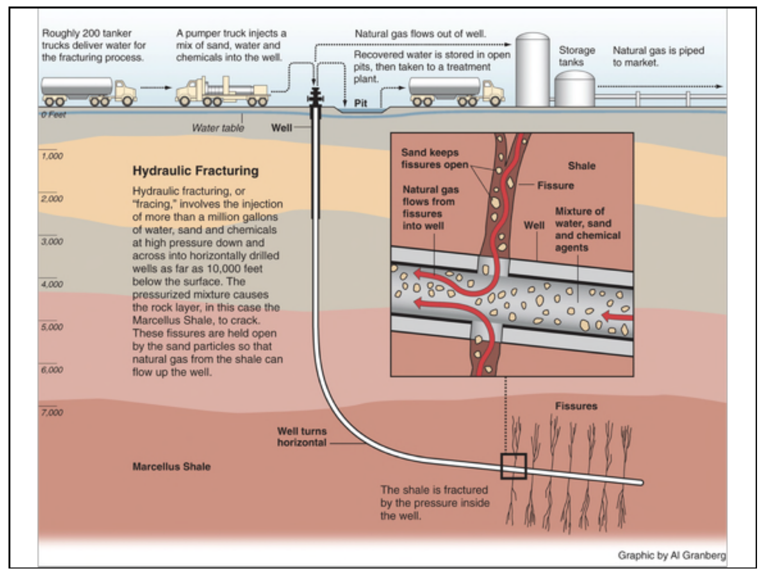
We dig this stuff ("fossil fuels") up and burn it, harvesting the stored energy to power civilization



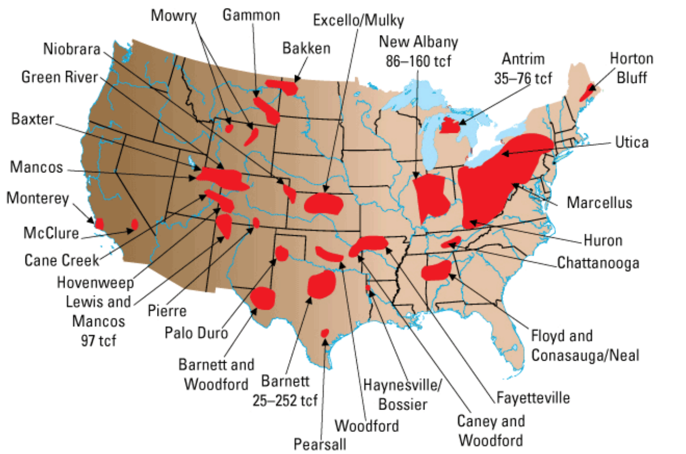

Mining Coal


F10

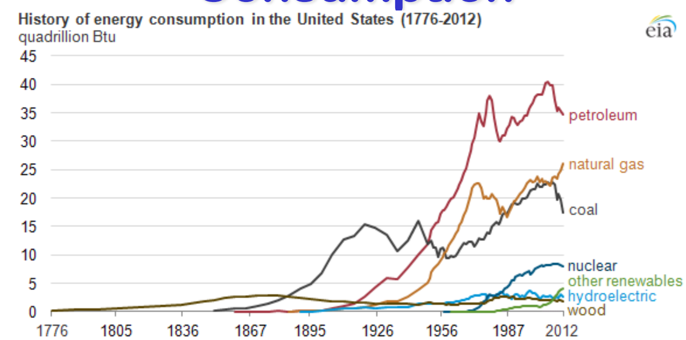

Hydraulic Fracturing
USDW
Private Well
Municipal Water Well: < 1,000 ft.
Shale Fractures
Additional steel casings and cement to protect groundwater
Protective Steel Casing
(Not to scale)
Approximate distance from surface: 6,000 feet
Steel casing lines the well and is cemented in place to prevent any communication up the wellbore as the fracturing job is pumped or the well is produced. Shallow formations holding fresh water that may be useful for farming or public consumption are separated from the fractured shale by thousands of feet of rock.


Roughly 200 tanker trucks deliver water for the fracturing process.
A pumper truck injects a mix of sand, water and chemicals into the well.
Natural gas flows out of well.
Recovered water is stored in open pits, then taken to a treatment plant.
Storage tanks
Natural gas is piped to market.
Pit
0 Feet
Water table
Well
1,000
2,000
3,000
4,000
5,000
6,000
7,000
Hydraulic Fracturing
Hydraulic fracturing, or "fracing," involves the injection of more than a million gallons of water, sand and chemicals at high pressure down and across into horizontally drilled wells as far as 10,000 feet below the surface. The pressurized mixture causes the rock layer, in this case the Marcellus Shale, to crack. These fissures are held open by the sand particles so that natural gas from the shale can flow up the well.
Sand keeps fissures open
Shale
Fissure
Natural gas flows from fissures into well
Well
Mixture of water, sand and chemical agents
Fissures
Well turns horizontal
Marcellus Shale
The shale is fractured by the pressure inside the well.
Graphic by Al Granberg

US Gas Reserves from Fracking



Changes in US Energy Consumption



Wood … then Coal … then Oil … then Gas … then Nuclear … then Renewables

The "Kaya Identity"

CO_2: CO_2 emissions resulting from human activities E: Primary energy consumption G: GDP P: Population

Kaya Identity: Formula that represents the relationship between human activities and CO_2 emissions

$$CO_2 = \frac{CO_2}{E} \times \frac{E}{G} \times \frac{G}{P} \times P$$

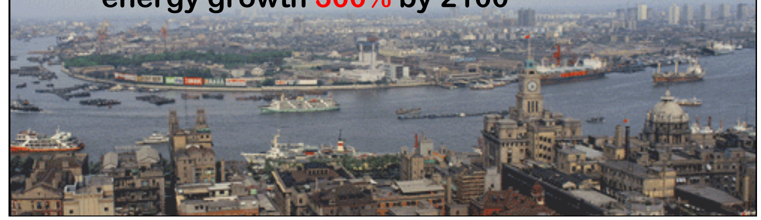
CO_2 emissions per unit energy consumption | Energy efficiency of economic activities | Economic level per capita

- **Four factors determine future emissions:**
  - Population
  - Economic activity
  - Energy efficiency of economy
  - Carbon efficiency of energy

Billions and Billions

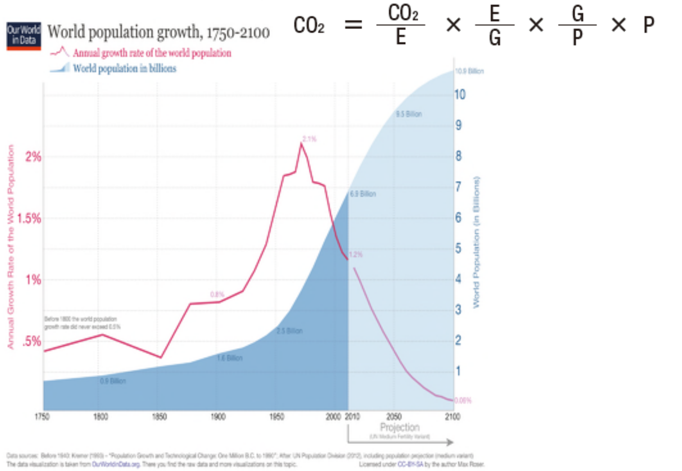
Shanghai 1991 and 2012

- **Currently 7 billion people on Earth but only 1 billion use lots of energy**
- **Rapid development to 4 billion energy users over coming decades**
- **Population growth only 30% but energy growth 300% by 2100**



Population

$$CO_2 = \frac{CO_2}{E} \times \frac{E}{G} \times \frac{G}{P} \times P$$



2014 Population Growth Rates

Rank	Country	Population growth rate (%)
1	Lebanon	9.37
2	Zimbabwe	4.36
3	South Sudan	4.12
4	Jordan	3.86
5	Qatar	3.58
6	Malawi	3.33
7	Burundi	3.28
8	Niger	3.28
9	Uganda	3.24
10	Libya	3.08
11	Burkina Faso	3.05
12	Mali	3
13	Gaza Strip	2.91
14	Ethiopia	2.89
15	Western Sahara	2.89
16	Zambia	2.88
17	Benin	2.81
18	Tanzania	2.8
19	Angola	2.78
20	Yemen	2.72
21	Togo	2.71
22	United Arab Emirates	2.71
23	Rwanda	2.63
213	Hungary	-0.21
214	Slovenia	-0.23
215	Romania	-0.29
216	Saint Vincent and the Grenadines	-0.29
217	Lithuania	-0.29
218	American Samoa	-0.35
219	Micronesia, Federated States of	-0.42
220	Serbia	-0.46
221	South Africa	-0.48
222	Montenegro	-0.49
223	Virgin Islands	-0.56
224	Latvia	-0.62
225	Ukraine	-0.64
226	Puerto Rico	-0.65
227	Estonia	-0.68
228	Bulgaria	-0.83
229	Moldova	-1.02
230	Saint Pierre and Miquelon	-1.02
231	Cook Islands	-3
232	Syria	-9.73

Definition: The average annual percent change in the population, resulting from a surplus (or deficit) of births over deaths and the balance of migrants entering and leaving a country. The rate may be positive or negative. The growth rate is a factor in determining how great a burden would be imposed on a country by the changing needs of its people for infrastructure (e.g., schools, hospitals, housing, roads), resources (e.g., food, water, electricity), and jobs. Rapid population growth can be seen as threatening by neighboring countries.

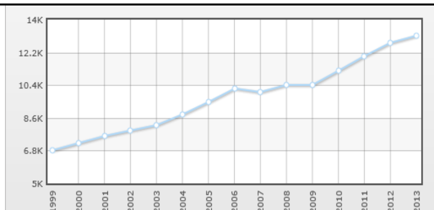
Source: CIA World Factbook - Unless otherwise noted, information in this page is accurate as of January 1, 2014

USA = +0.77 %/yr

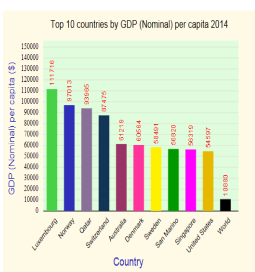
$$CO_2 = \frac{CO_2}{E} \times \frac{E}{G} \times \frac{G}{P} \times P$$

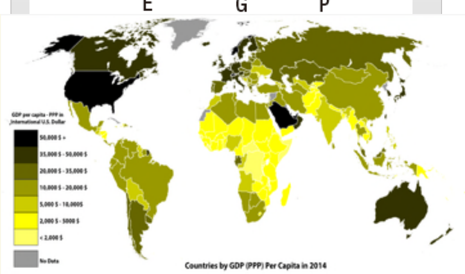
GDP/ Population

- Luxembourg-10.27x world
- United states- 5.02x world



$$CO_2 = \frac{CO_2}{E} \times \frac{E}{G} \times \frac{G}{P} \times P$$

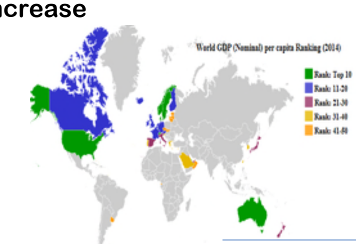




http://statisticstimes.com/economy/world-gdp-capita-ranking.php
Source: International Monetary Fund World Economic Outlook

GDP/Population

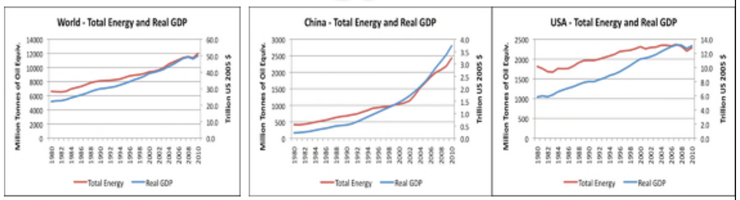
- Affluence- average consumption of each person in the population
  - It is assumed that as the GDP increases, consumption of good/services/energy will increase



$$CO_2 = \frac{CO_2}{E} \times \frac{E}{G} \times \frac{G}{P} \times P$$

http://statisticstimes.com/economy/world-gdp-capita-ranking.php
http://www.imf.org/external/pubs/ft/weo/2015/01/weodata

Energy/GDP



- The energy intensity required to produce a unit of GDP is falling in most countries of the world
- China GDP grew by about 10% a year between 1980 and 2005, while energy use grew by a little less than 6% per year
- Between 2005 and 2010, real GDP continued to grow by about 10% per year, while energy use grew by about 7.5% per year
- Up until 2005, the USA was able to increase real GDP by 3% per year, while increasing energy use by only 1% per year

$$CO_2 = \frac{CO_2}{E} \times \frac{E}{G} \times \frac{G}{P} \times P$$

CO2/Energy

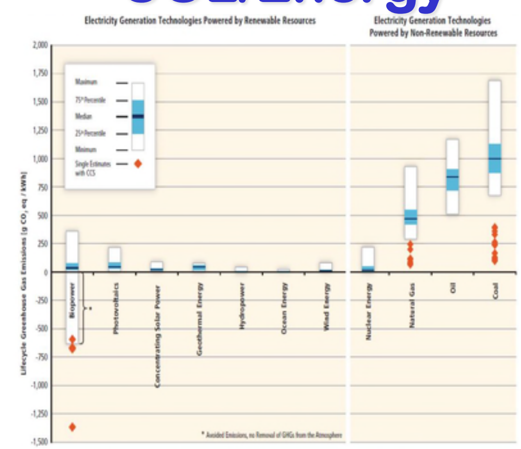
Lifecycle greenhouse gas emissions by electricity source.[9]

Technology	Description	50th percentile (g CO_2/kWh$_e$)
Hydroelectric	reservoir	4
Wind	onshore	12
Nuclear	various generation II reactor types	16
Biomass	various	18
Solar thermal	parabolic trough	22
Geothermal	hot dry rock	45
Solar PV	Polycrystaline silicon	46
Natural gas	various combined cycle turbines without scrubbing	469
Coal	various generator types without scrubbing	1001

2014 IPCC

$$CO_2 = \frac{CO_2}{E} \times \frac{E}{G} \times \frac{G}{P} \times P$$

CO2/Energy



Source: IPCC, 2011: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation

lbs. CO2e/kWh

- Natural Gas: 0.6-2
- Coal: 1.4-3.6 lbs.
- Wind 0.02 to 0.04
- Solar 0.07 to 0.2
- Geothermal 0.1 to 0.2

$$CO_2 = \frac{CO_2}{E} \times \frac{E}{G} \times \frac{G}{P} \times P$$

Decarbonization: Reduce CO2/Energy

- Declining average carbon intensity of primary energy over time
- Figure 2-11 shows rate of 0.3% per year decline
  - Global rate is decreasing but in some countries carbon intensity is increasing
- Median scenarios indicate rate of 1.1%
- most intensive uses of fossil fuels lead to no reduction
- Highest decarbonization rate of 2.5% per year indicate complete transition to non fossil fuels

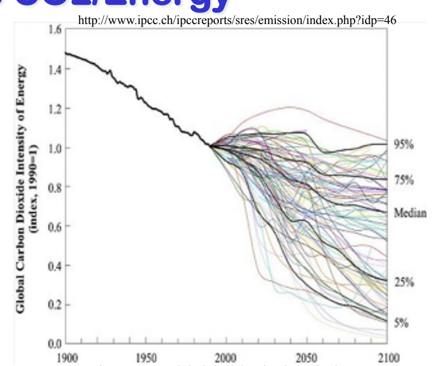


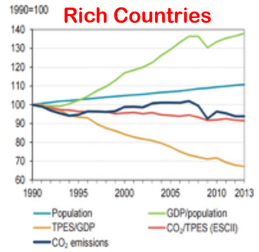
Figure 2-11: Global decarbonization of primary energy - historical development and future scenarios, shown as an index (1990 = 1). The median (50th), 5th, 25th, 75th and 95th percentiles of the frequency distribution are shown. Statistics associated with scenarios from the literature do not imply probability of occurrence. Data source: Nakicenovic, 1996; Morita and Lee, 1998.

$$CO_2 = \frac{CO_2}{E} \times \frac{E}{G} \times \frac{G}{P} \times P$$

Kaya Components

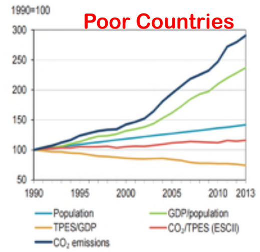
$$CO_2 = \frac{CO_2}{E} \times \frac{E}{G} \times \frac{G}{P} \times P$$

Figure 17. Annex I CO_2 emissions and drivers (Kaya decomposition)[12]



Key point: Emissions in Annex I countries declined in recent years. This decline was driven by a significant reduction in the energy intensity of GDP, coupled with a slight fall in the carbon intensity of the energy mix, more than offsetting GDP growth.

Figure 18. Non-Annex I CO_2 emissions and drivers (Kaya decomposition)[12]



Key point: In non-Annex I countries, emissions growth was driven by strong increases in per-capita economic output and in population.

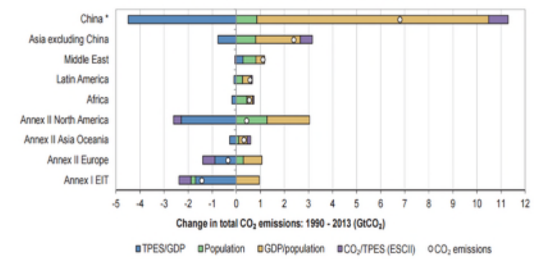
- TPES (Total Primary Energy Supply)
- CO2 emissions: 6% lower in 2013 than 1990
- Carbon intensity: declined 8*

- CO2 emissions almost tripled
- +137% GDP/ population
- +42% population growth
- C intensity increase due to increased Coal use

Components of Emissions Growth

$$CO_2 = \frac{CO_2}{E} \times \frac{E}{G} \times \frac{G}{P} \times P$$

Figure 19. Global CO_2 emissions and drivers (Kaya decomposition): 1990-2013[12]



Key point: GDP growth has been a key driver of emissions across the globe, however, significant decoupling of GDP growth from energy consumption has occurred across regions.

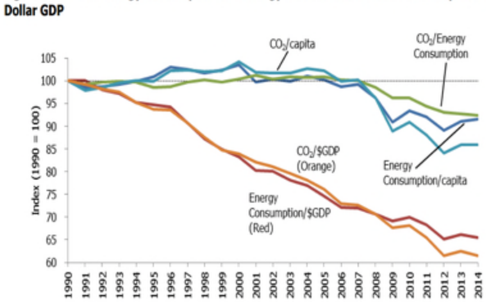
https://www.iea.org/publications/freepublications/publication/CO2EmissionsFromFuelCombustionHighlights2015.pdf

Case Study: United States

- CO2/Energy Consumption is 8.2% lower than 1990 levels

- Energy Consumption and CO2/GDP - Shift from a manufacturing economy to a service-based economy, increases in efficiency, energy consumption and energy-related CO2 emissions per dollar of gross domestic product (GDP) have both declined since 1990

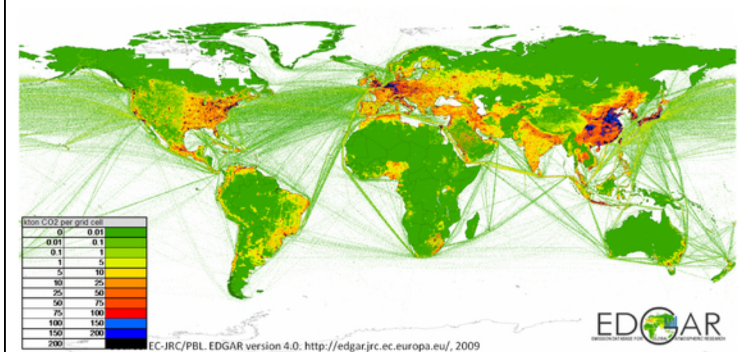
Figure 3-14: U.S. Energy Consumption and Energy-Related CO_2 Emissions Per Capita and Per Dollar GDP



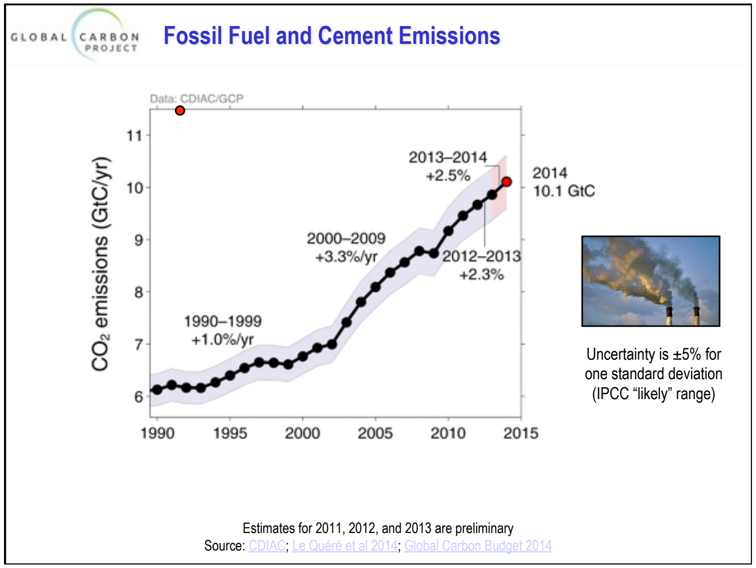
https://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2016-Chapter-3-Energy.pdf

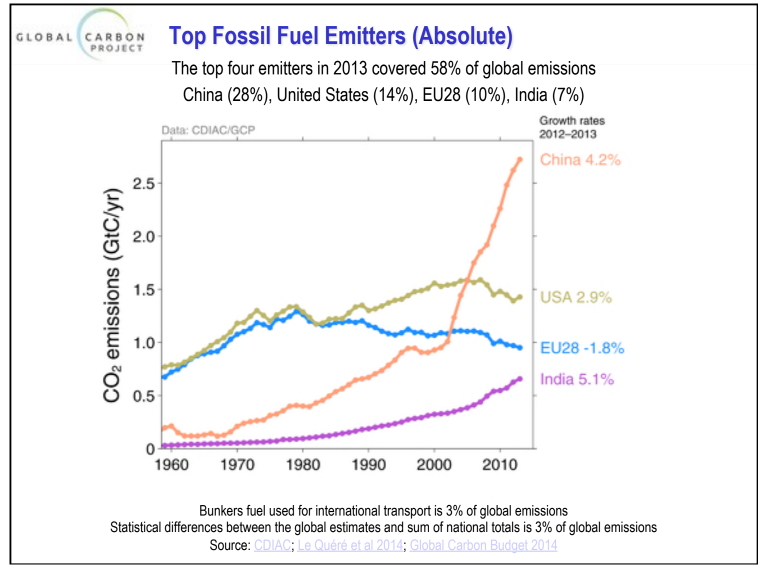
$$CO_2 = \frac{CO_2}{E} \times \frac{E}{G} \times \frac{G}{P} \times P$$

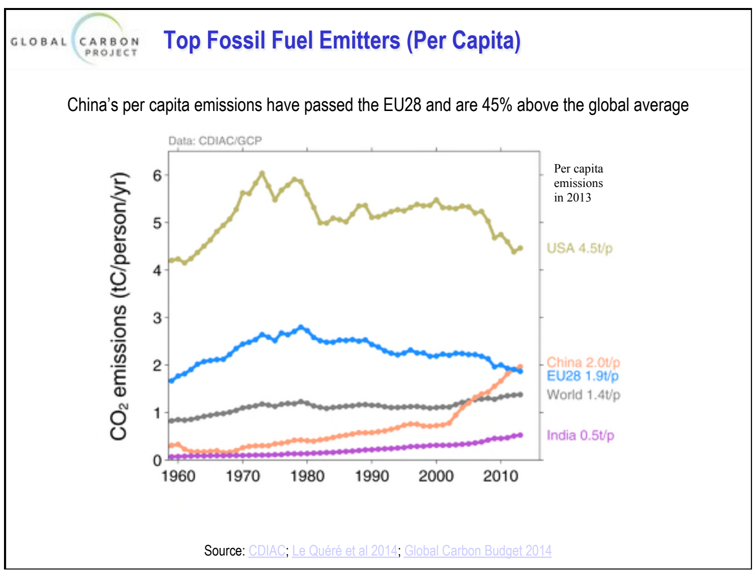
Global Fossil Fuel Emissions (2009)

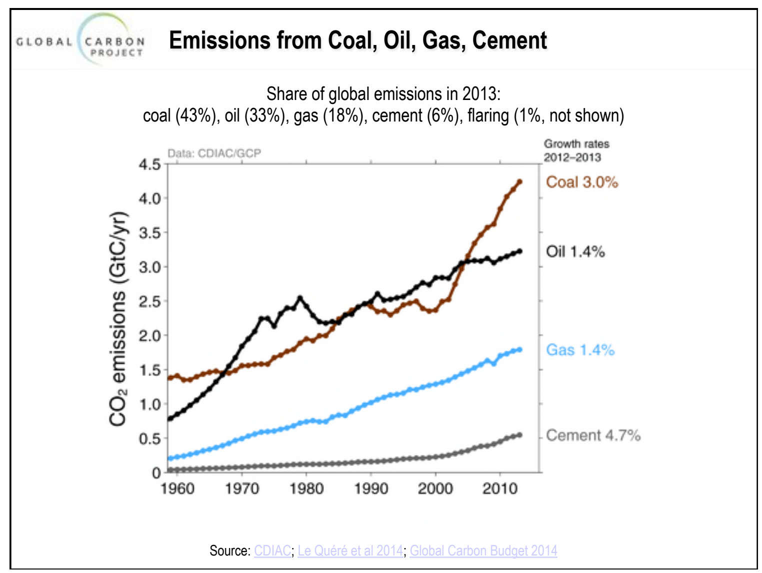


Supply-Based Inventory Methods (“follow the fuel”)


GLOBAL CARBON PROJECT
Fossil Fuel and Cement Emissions
Data: CDIAC/GCP
CO2 emissions (GtC/yr)
11
10
9
8
7
6
1990
1995
2000
2005
2010
2015
1990–1999
+1.0%/yr
2000–2009
+3.3%/yr
2012–2013
+2.3%
2013–2014
+2.5%
2014
10.1 GtC
Uncertainty is ±5% for one standard deviation (IPCC “likely” range)
Estimates for 2011, 2012, and 2013 are preliminary
Source: CDIAC; Le Quéré et al 2014; Global Carbon Budget 2014

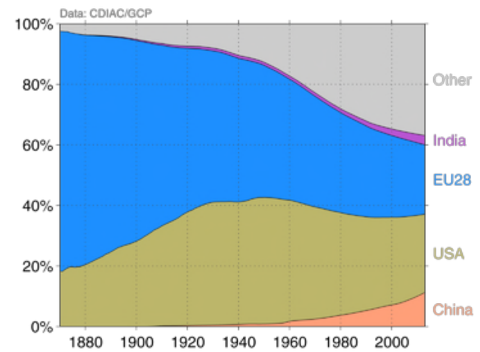

GLOBAL CARBON PROJECT
Top Fossil Fuel Emitters (Absolute)
The top four emitters in 2013 covered 58% of global emissions
China (28%), United States (14%), EU28 (10%), India (7%)
Data: CDIAC/GCP
Growth rates 2012–2013
CO2 emissions (GtC/yr)
2.5
2.0
1.5
1.0
0.5
0
1960
1970
1980
1990
2000
2010
China 4.2%
USA 2.9%
EU28 -1.8%
India 5.1%
Bunkers fuel used for international transport is 3% of global emissions
Statistical differences between the global estimates and sum of national totals is 3% of global emissions
Source: CDIAC; Le Quéré et al 2014; Global Carbon Budget 2014


GLOBAL CARBON PROJECT
Top Fossil Fuel Emitters (Per Capita)
China's per capita emissions have passed the EU28 and are 45% above the global average
Data: CDIAC/GCP
CO2 emissions (tC/person/yr)
6
5
4
3
2
1
0
1960
1970
1980
1990
2000
2010
Per capita emissions in 2013
USA 4.5t/p
China 2.0t/p
EU28 1.9t/p
World 1.4t/p
India 0.5t/p
Source: CDIAC; Le Quéré et al 2014; Global Carbon Budget 2014


GLOBAL CARBON PROJECT
Emissions from Coal, Oil, Gas, Cement
Share of global emissions in 2013:
coal (43%), oil (33%), gas (18%), cement (6%), flaring (1%, not shown)
Data: CDIAC/GCP
Growth rates 2012–2013
CO2 emissions (GtC/yr)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
1960
1970
1980
1990
2000
2010
Coal 3.0%
Oil 1.4%
Gas 1.4%
Cement 4.7%
Source: CDIAC; Le Quéré et al 2014; Global Carbon Budget 2014

Historical Cumulative Emissions by Country

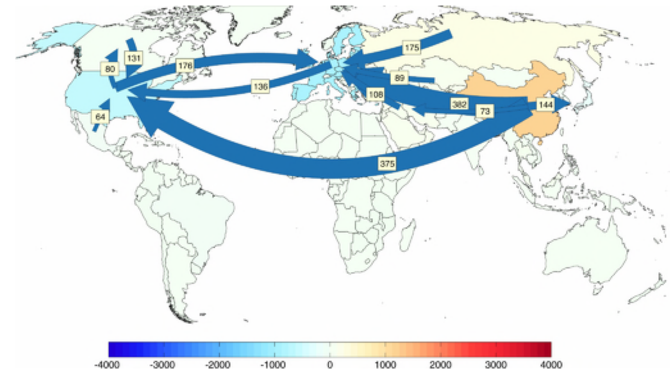
Cumulative emissions from fossil-fuel and cement were distributed (1870–2013):
USA (26%), EU28 (23%), China (11%), and India (3%) covering 63% of the total share



Cumulative emissions (1990–2013) were distributed USA (20%), China (20%), EU28 (14%), India (5%)
'Other' includes all other countries along with bunker fuels and statistical differences
Source: CDIAC; Le Quéré et al 2014; Global Carbon Budget 2014

Major Flows from Production to Consumption

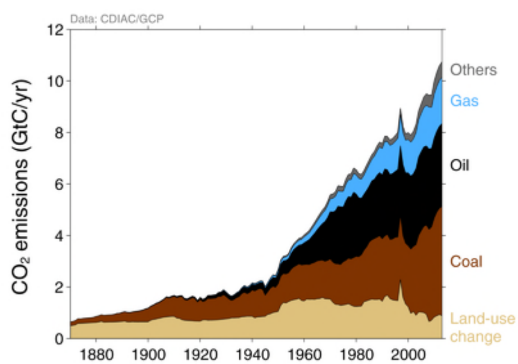
Start of Arrow: fossil-fuel combustion
End of arrow: goods and services consumption



Values for 2007. EU is treated as one region. Units: $MtCO_2$
Source: Peters et al 2012

Total Global Emissions by Source

Land-use change was the dominant source of annual CO_2 emissions until around 1950
Coal consumption continues to grow strongly



Others: Emissions from cement production and gas flaring
Source: CDIAC; Houghton et al 2012; Giglio et al 2013; Le Quéré et al 2014; Global Carbon Budget 2014