Carbon Economics

Module 10





Kaya Identity

Four factors determine fossil fuel emissions:

- Population
- Economic activity
- Energy efficiency of economy
- Carbon efficiency of energy





• CONSUMPTION: Population & per-capita income are deeply interconnected through the process of economic development

Kaya Identity

• TECHNOLOGY: Energy efficiency & decarbonization of energy are controlled by technical & design choices

World Population



Data sources: Before 1940: Kremer (1993) – "Population Growth and Technological Change: One Million B.C. to 1990"; After: UN Population Division (2012), including population projection (medium variant) The data visualization is taken from OurWorldinData.org. There you find the raw data and more visualizations on this topic. Remember *"The Population Bomb"*?

CO₂

 $\frac{\$}{P} \times \frac{E}{\$} \times$

- World population has more than doubled in my lifetime
- It will never double again
- Population growth rate is half what it was when I was a teenager
- Expected to reach zero population growth by 2100

Child mortality vs level of prosperity, 2017

Countries below the grey line achieve better child health than predicted by their income. Countries above the line achieve better health than predicted.



East Asia and Pacific

- Sub-Saharan Africa
- South Asia
- Europe and Central Asia
- Middle East and North Africa
- Latin America and Caribbean
- North America

Source: World Bank, Population (Gapminder, HYDE(2016) & UN (2019))



- Infant mortality falls with economic growth
- Fertility falls a generation later

Children per woman





Source: United Nations – Population Division (2019 Revision) Note: Children per woman is measured as the total fertility rate, which is the number of children that would be born to the average woman if she were to live to the end of her child-bearing years and give birth to children at the current age-specific fertility rates.



The map shows estimates of the **under-5 mortality rate** — the probability that a child born in a given year dies before reaching age 5 given current age-specific mortality rates.

Population & Kaya

- Population growth has fallen dramatically due to economic development! (demographic transition)
- Fertility is now near or even below the replacement rate in most of the world
- Rapid population growth is now pretty much limited to the poorest 10% of people – they aren't burning much carbon!
- The richest 10% burn a huge amount of carbon, but their population is stable or slowly shrinking
- Even as population stabilizes over the coming decades, it will have little impact on CO₂ emissions

UN Sustainable Development Goals

- 1. Eliminate Extreme Poverty
- 2. Improve Equality of Opportunity
- 3. Don't Destroy the World



How is the **world's wealth** shared amongst its population?



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How is the **world's wealth** shared amongst its population?



"Wealth" is defined as the marketable value of financial assets plus non-financial assets (principally housing and land) owned by an adult, less debts Source: Global Wealth Report 2013. Zurich: Celoft Suisse

Read the report #Outlook2015

Extreme Poverty Has Fallen 10-Fold Since 1800

EXTREME POVERTY RATE FROM 1800 TO TODAY



SDG 1: End Extreme Poverty

Total population living in extreme poverty, by world region

Numbers are in millions of people. Extreme poverty is defined as living with per capita household consumption below 1.90 international dollars per day (in 2011 PPP prices). International dollars are adjusted for inflation and for price differences across countries.



• < \$1.90 / day

- 0.9 billion people worldwide
- Cut in half since
 1990!
- Almost all in South Asia & Tropical Africa

Source: PovcalNet (World Bank)

OurWorldInData.org/extreme-poverty/ • CC BY

Note: Consumption per capita is the preferred welfare indicator for the World Bank's analysis of global poverty. However, for about 25% of the countries, estimates correspond to income, rather than consumption.

The Two 10 Percents

- There are 8 billion people on Earth
- 10% of us live well beyond the dreams of the kings of old
- 10% of us live in unbearable poverty

10% of People < \$1,000 per year





50% of people



10% of people >\$16,000 per year







ranspo

















000







Distribution of population between different poverty thresholds, World, 1981 to 2017



All figures are adjusted to account for inflation and price differences across countries, and are expressed in international dollars at 2011 prices.

80% of People Neither Extremely Rich nor Extremely Poor



Source: World Bank, PovcalNet (2021)

Note: Consumption per capita is the preferred welfare indicator for the World Bank's analysis of global poverty. However, for a number of countries poverty is measured in terms of income. An income basis is common amongst high income countries and Latin American countries.

CCBY

The global poverty gap, in international-\$

The poverty gap is the amount of money that would be theoretically needed to lift the incomes of all people in extreme poverty up to the international poverty line of \$1.90 a day. These estimates are expressed in international dollars using 2011 PPP conversion rates. This means that figures account for differences in prices levels, as well as for inflation.



Our World in Data

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Global inequality in living conditions

between the world's worst-off and best-off countries

SDG2



Data source: all data for 2017 is taken from various UN publications. Historical estimates for 1800 are from OECD – How was life? and Our World in Data This is a visualization from OurWorldinData.org, where you find data and research on the world's largest problems.

Licensed under CC-BY by the author Max Roser.

Our World in Data



Our World

Economic Convergence

GDP per capita, 1951 to 2018

GDP per capita adjusted for price changes over time (inflation) and price differences between countries – it is measured in international-\$ in 2011 prices.



Rich countries grow slowly

Middleincome grow faster

Poor countries grow fastest

Source: Maddison Project Database 2020 (Bolt and van Zanden (2020))

OurWorldInData.org/economic-growth • CC BY

Our World in Data

Catch-Up Growth Shanghai 1991 and 2012

- In the 1990s, China began a very rapid period of economic convergence with the highest income countries
- Adjusted for inflation, per-capita income in China has risen 3000% since 1990
- About 18% of people are Chinese

Convergence Arithmetic A reasonable formula for

economic convergence (Sachs 2015)

Country	Per capita income (PPP) (\$)	Growth rate (tendency per year) (%)
Least-developed	1,613	8.0
Low-income	3,125	6.6
Lower-middle-income	6,250	5.2
Upper-middle-income	12,500	3.8
Lower-high-income	25,000	2.4(=1+1.4)
United States	50,000	1

- Income in richest country (US) grows 1%/year above inflation
- Other countries add 1.4% for each factor of 50% below US

Global income distribution in 1800, 1975, and 2015 ^{Our World} in Data

Income is measured by adjusting for price changes over time (inflation) and for price differences between countries (purchasing power parity (PPP) adjustment). These estimates are based on reconstructed National Accounts and within-country inequality measures. Non-market income (e.g. through home production such as subsistence farming) is taken into account. The *International Poverty Line* is set by the *United Nations* and is the the poverty line that defines extreme poverty.





Data Source: Calculations by Ola Rosing from Gaprimice OurWorldingData.org – Research and data to make progress against the world's largest problems. Licensed under CC-BY by the author Max Roser

The Emerging One-Hump World

- From a poor world in 1800
- To a divided world in 1975
- To a middle-income world in the 21st Century

Consumption & Kaya

- Stabilizing global population is important for overall resource consumption – especially food!
- Whether population stabilizes at 9 billion or 11 billion mostly depends on economic convergence
- The easiest route to population stability (at a lower number) is rapid elimination of extreme poverty



How is the **world's wealth** shared amongst its population?



Energy Intensity

"How much energy to create \$1 of income?"

- Low Income Countries
 - low energy intensity
 - subsistence farming
- Middle Income
 Countries
 - high energy intensity
 - heavy industry
- High Income Countries
 - low energy intensity
 - information economy

kW-hr/\$

$$\begin{array}{rcl} & \text{CO}_2 \\ \text{Emitted} \end{array} &= & \text{P} & \text{x} & \frac{\$}{\text{P}} & \text{x} & \frac{\texttt{E}}{\$} & \text{x} & \frac{\text{CO}_2}{\text{E}} \end{array}$$



Energy intensity



Energy intensity is measured as primary energy consumption per unit of gross domestic product. This is measured in kilowatt-hours per 2011\$ (PPP).



Source: Our World in Data based on BP; World Bank; and Maddison Project Database OurWorldInData.org/co2-and-other-greenhouse-gas-emissions • CC BY

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Source: Our World in Data based on BP; World Bank; and Maddison Project Database OurWorldInData.org/co2-and-other-greenhouse-gas-emissions • CC BY



Emission intensity (emission per unit economic output) generally declines over time. In many countries, these declines are insufficient to overcome economic growth.



GDP is measured in purchasing power parity (PPP) terms in 2010 US dollars.

Source: CDIAC; IEA 2019 GDP to 2016, IMF 2020 growth rates to 2019; Friedlingstein et al 2020; Global Carbon Budget 2020



Global CO₂ emissions growth has generally resumed quickly from financial crises. Emission intensity has steadily declined but not sufficiently to offset economic growth.



Economic activity is measured in purchasing power parity (PPP) terms in 2010 US dollars. Source: <u>CDIAC</u>; <u>Peters et al 2012</u>; <u>Friedlingstein et al 2020</u>; <u>Global Carbon Budget 2020</u>



The 10 largest economies have a wide range of emission intensity of economic activity



Emission intensity: Fossil CO₂ emissions divided by Gross Domestic Product (GDP) Source: <u>Global Carbon Budget 2020</u>



The 10 most populous countries span a wide range of development and emissions per capita



Emission per capita: Fossil CO₂ emissions divided by population Source: <u>Global Carbon Budget 2020</u> The Kaya decomposition illustrates that relative decoupling of economic growth from CO₂ emissions is driven by improved energy intensity (Energy/GDP)

- Energy / \$ has fallen steadily
- GDP growth has outstripped the improvement in energy intensity
- Carbon intensity of energy has been flat for decades

GDP: Gross Domestic Product (economic activity) Energy is Primary Energy from BP statistics using the substitution accounting method Source: Jackson et al 2019; Global Carbon Budget 2020

[©] Global Carbon Project
 Data: CDIAC/GCP/IEA/BP/IMF

Carbon Intensity

"How much carbon to create 1 unit of energy?"

$$\begin{array}{rcl} & \text{CO}_2 \\ \text{Emitted} \end{array} = & \text{P} & \text{x} & \frac{\$}{\text{P}} & \text{x} & \frac{\texttt{E}}{\$} & \text{x} & \frac{\texttt{CO}_2}{\texttt{E}} \end{array}$$

Renewable energy is growing exponentially, but this growth has so far been too low to offset the growth in fossil energy consumption.

Energy use by source

Energy consumption by fuel source from 2000 to 2019, with growth rates indicated for the more recent period of 2014 to 2019

Fossil Fuel Emissions

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 (CO₂)

1 GtC = 3.664 billion tonnes CO₂ = 3.664 GtCO₂

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 (CO₂) to living biomass!
- Most of this energy is released through respiration (back to CO₂) 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 CO₂

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

On a Personal Note

was a wellsite geologist long ago

Petroleum production is extremely dangerous work!

Scott

Hydraulic Fracturing

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.

While China's emissions declined strongly during February, emissions declines in the rest of the world reached their peaks in April.

@ Dpdated from Le Quéré et al. Nature Climate Change (2020); Global Carbon Project

·Figure: @Jones_MattW

Source: Le Quéré et al 2020; https://www.icos-cp.eu/gcp-covid19

Global emissions from surface transport, especially road transport, have been affected the most by the restrictions aimed at reducing infection rates.

⊕ ⊕ Updated from Le Quéré et al. Nature Climate Change (2020); Global Carbon Project

·Figure: @Jones_MattW

Source: Le Quéré et al 2020; https://www.icos-cp.eu/gcp-covid19

☺ ④ Global Carbon Project • Data: CDIAC/GCP

Major flows from production to consumption

GLOBAL

CARBON PROJECT

Flows from location of generation of emissions to location of consumption of goods and services

Values for 2011. EU is treated as one region. Units: MtCO₂ Source: <u>Peters et al 2012</u>

