Correlation Between Carbon Dioxide Emissions and Population: How Governments Can Mitigate the Effects of Population Growth

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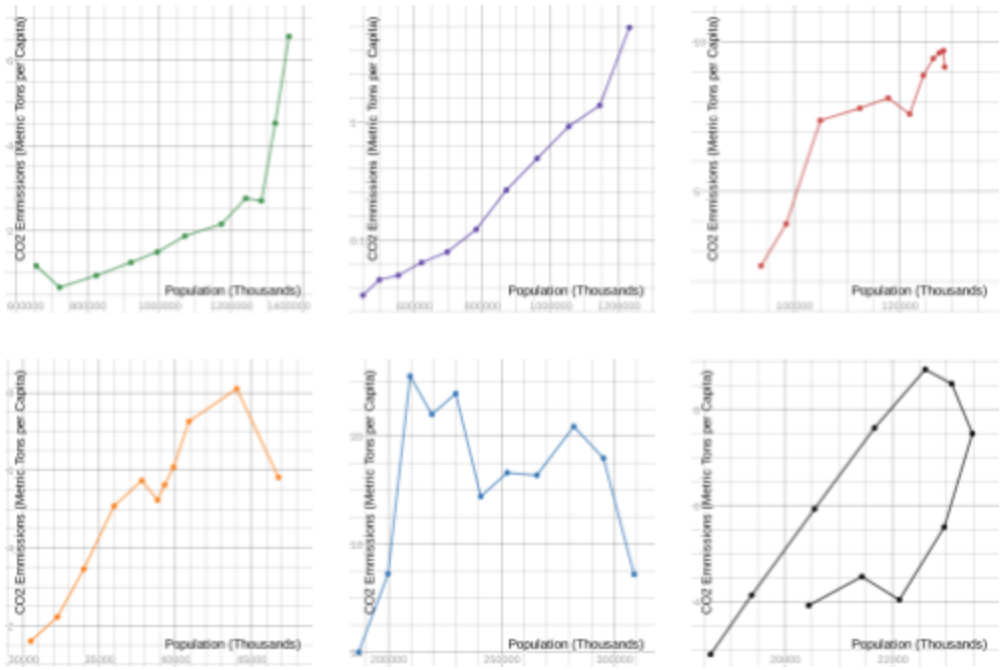


Graphs of Population and CO_2 Emissions (per capita) for six select countries: (top row, left to right) China, India, Japan, (bottom row, left to right) Spain, U.S., and Romania. Each graph is discussed in detail later.

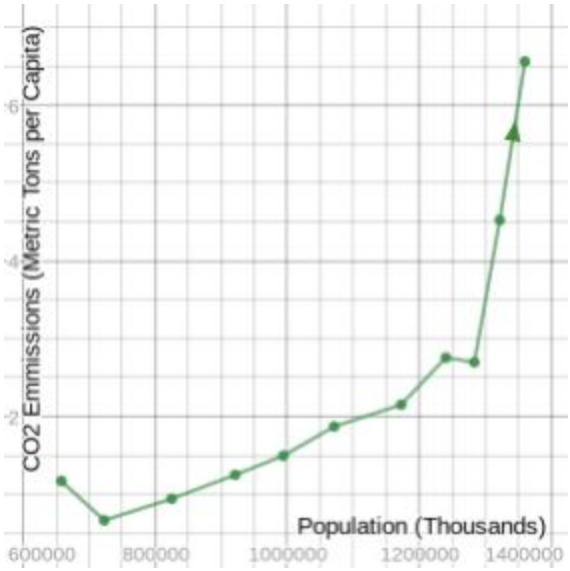
In recent years, both carbon dioxide emissions and population have been rapidly increasing in the world as a whole, in a remarkably correlated fashion. Some countries mirror that worldwide trend, while some do not. The following six graphs shows the trend between CO_2 emissions and population for six countries selected for their importance to our math class or for their importance in the world. The graphs show CO_2 emissions graphed against population to show the correlation between the two variables. CO_2 is measured in metric tons per capita, so that the correlation can be investigated further than the obvious "more people emit more CO_2" observation, and makes it easier to see unique patterns in each country's data. Each data point represents the data for the country at a specific point in time, with data being plotted every five years from 1960 to 2010 (inclusive). The points are connected temporarily, with an arrowhead representing the direction of time, allowing one to infer population growth by the distance between two points. When we look at the six graphs bearing their design in mind, there seems to be, in general, a clear a linear correlation between CO_2 emissions and population growth (note that this linear correlation in the per capita data represents a quadratic correlation in overall CO_2 emissions). The correlation between CO_2 emissions and population growth is likely mainly caused by a third variable, something like economic development, which leads to both. However, population growth has been shown to lead to pollution and global warming in general, factors

which can can be approximated by CO_2 emissions. Additionally, situations in countries which have created interesting CO_2 graphs, notably government programs in reducing emissions, demonstrate how governments can mitigate the other effects of population growth, such as unemployment, health care, and human rights. By analyzing the trends shown on the graphs, it becomes clear that an increase in population is usually correlated to a quadratic increase in CO_2 emissions, although this trend can be diminished or even reversed by government policies or other extraneous situations affecting a country.

Population data acquired from United Nations Department of Social Affairs Population Division, *World Population Prospects: The 2017 Revision*. Carbon Dioxide Emissions data acquired from Carbon Dioxide Information Analysis Center Environmental Sciences Division in Oak Ridge National Laboratory, Tennessee, USA via the World Bank's *World Development Indicators*.

China

In recent years China has experienced a rapid increase in CO_2 emissions as China also rises to the top of world manufacturing. In fact, China has surpassed the U.S. as #1 emitter of carbon dioxide (total, U.S. is still far above in per capita emissions)[1]. China also holds the #1 spot in total population. As the Chinese population rapidly increased in the past 50 years, its economy developed to focus on industry and manufacturing, causing energy consumption and pollution to soar. Additionally, the abundance of coal in China has led to 66% of China's consumed energy being produced from coal in 2012[2]. CO_2 emissions per capita have also skyrocketed as China becomes a more developed nation and citizens begin increasing their "carbon footprint" as large CO_2 emitters like cars and airplanes begin to play a role in a significant portion of the population's life. Despite the seemingly-never-ending increase in carbon emissions of China between 1960 and 2010 (the domain of the graph on the right), the Chinese government has been working diligently to improve China's environmental impact, and has seen surprising success. China has signed the Paris Agreement, committing to peak its Greenhouse gas emissions by 2030. However, estimates from 2017 indicate that China's CO_2 emissions may have already peaked, and that China is on the right track to reach its national targets under the Paris Agreement. Chinese government policies designed to decrease China's dependence on coal: in the 13th Five Year Plan, the Chinese government set the goal of sourcing only 58% of energy from coal[3]. Along with the stabilization of CO_2 emissions, China's rate of population growth has also began to slowly decrease. After its 50-year period of incredibly

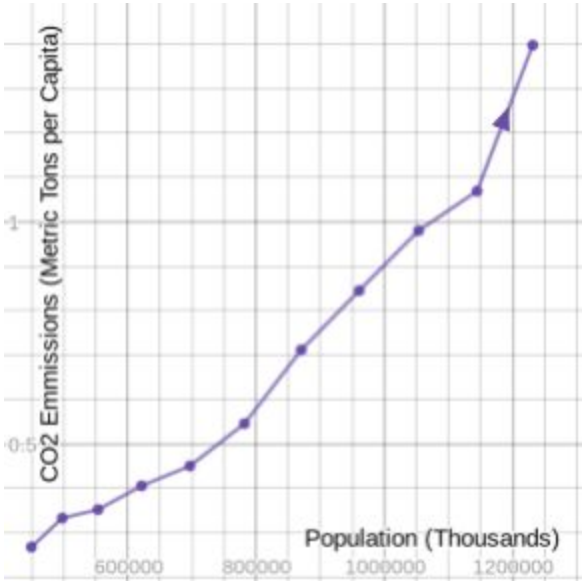


[1] "China now no. 1 in CO2 emissions; USA in second position," Netherlands Environmental Assessment Agency.
[2] *International Energy Statistics*, U.S. Energy Information Administration.
[3] "Climate Action Tracker," ECOFYS, Climate Analytics, and New Climate Institute.

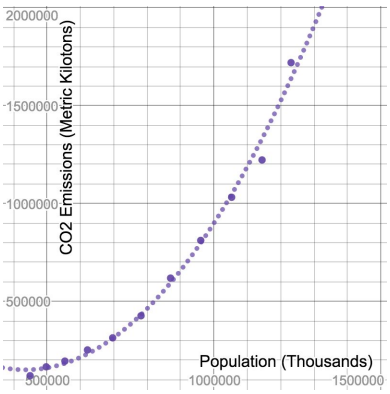
rapid growth in CO_2 emissions and population (ending in a period of 10 years where the population to CO_2 emissions ratio increase was dramatically greater than order n^2), China seems to have finally begun to slow its growth, partially due to government programs.

India

India's history of CO_2 emissions has closely followed the path of China, although India hasn't developed as rapidly in industry or manufacturing as China. Like in China, coal plays a major role in India's CO_2 emissions: in 2008 it made up 71% of emissions[4].



India has grown into the fourth largest CO_2 emitter, and, throughout the same period, has experienced rapid population growth, placing it as the second most populous country, soon to rival China in population. This dramatic population growth has led to overpopulation in some places, which has resulted in the release of many pollutants, including CO_2. However, despite India's impressive standing in total CO_2 emissions, India has relatively low emissions per capita compared to other countries with high total emissions[4], most likely due to population growth "keeping up" with growth of CO_2 emissions in a quadratic trend.



India's carbon emissions per capita increase quite linearly with population, unlike China, where CO_2 emissions per capita started to grow dramatically faster than population over time. India's linear correlation in per capita emissions translates to a quadratic correlation between total CO_2 emissions and population (shown left) with a remarkable R^2 value of 0.992. Both India's population growth rate and CO_2 emissions rate seem to be decreasing in recent years (past the domain of the graphs), although neither is expected to plateau anytime in the near future. India, in a similar fashion to China, has signed the Paris Agreement and is making considerable progress towards its goals. By implementing policies to replace coal power with renewable energy, India has put itself on the right track to overachieve its 2030 Nationally Determined Contribution under the Paris Agreement[5]. India is a country that is experiencing both extreme population growth and increase in CO_2 emissions, however due to limits to development and government policies, India has been able to keep population quadratically correlated with CO_2 emissions.

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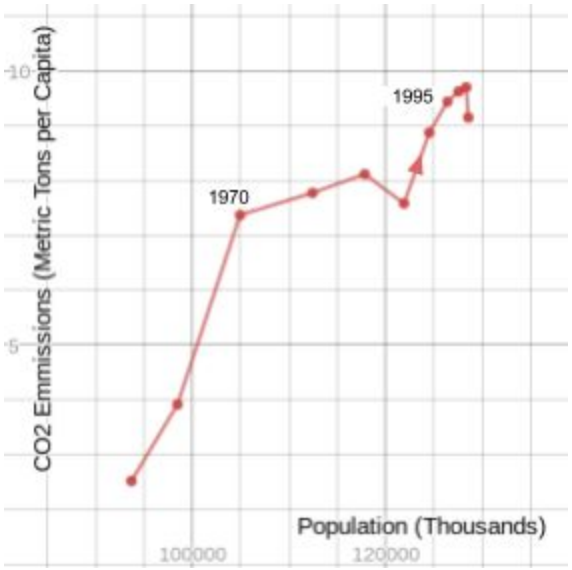
[4] "India Fossil-Fuel CO2 Emissions," Carbon Dioxide Information Analysis Center.
[5] "Climate Action Tracker," ECOFYS, Climate Analytics, and New Climate Institute.

Japan

If India is a snapshot of China's CO_2 emissions before their massive growth, Japan can be thought of as a possible direction China's CO_2 emissions may go after they plateau. After World War II, Japan saw soaring economic development as the result of a new-found place in international affairs and good relations with the United States[6], paired with increased CO_2 emissions. However, in 1973, CO_2 emissions began to slow along with post-war development, clear in the graph as growth in emissions per capita begins to slow. Until around 1995 CO_2 emissions showed a steady increase, albeit decreased since original post-war levels. After 1995, as Japan developed further, population growth slowed and the population has even begun to decrease, with CO_2 emissions following a similar trend. Still, Japan has consistently been among the top ten emitters of CO_2 in the past couple decades. High development leading to large personal carbon footprints and reliance on coal has contributed to these large emissions. Large amounts of deforestation as a result of population growth have also contributed to increased CO_2 emissions. Recently however, government policies have been able to greatly decrease Japan's CO_2 emissions. The Japanese government has worked to halt the development of future coal power plants, and to aid renewable energy projects. Through these efforts, Japan's CO_2 emissions have been set on a decisive downward trend, set to hit Japan's 2030 Nationally Determined Contribution under the Paris Agreement[7]. Patterns similar to that of Japan, where both CO_2 emissions and population eventually decrease, aided by government programs, will likely be seen in other countries as they develop further.

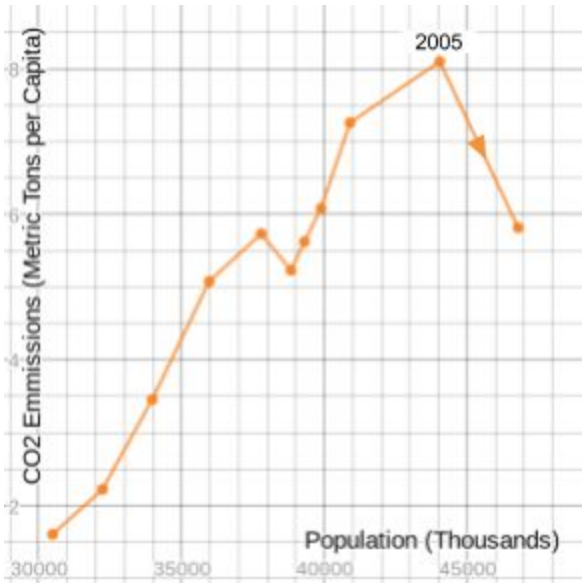


Spain

While Spain's population grew at a relatively constant, albeit rather low, rate from 1960 to 2010 (consistent with the rest of Europe), Carbon Dioxide emissions have shown a less decisive increase, with per capita emissions decreasing in recent years. Spain has never held a position as a "world leader" in CO_2 emissions, currently ranking in the mid-20s for total emissions[8]. However, population growth in Spain, which has led to extreme urbanization, has strained Spain's water supply, air quality, and land availability, causing the Spanish Government to take action against CO_2 emissions[9]. Historically, Spain's CO_2 emissions were mainly impacted by a high reliance on coal as an energy source. Recently Spain has

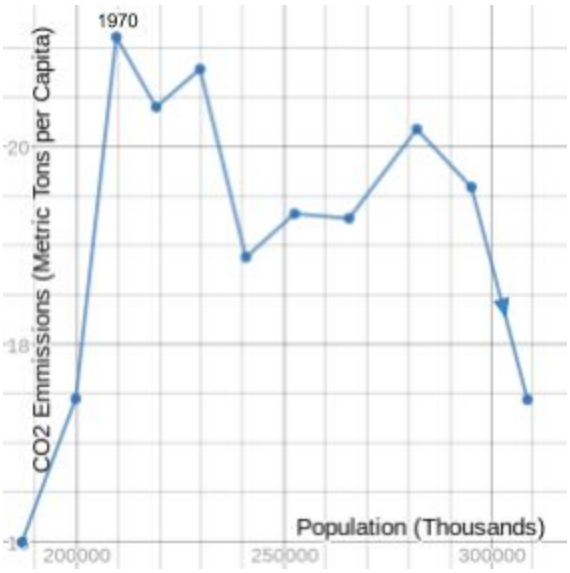
[6] "Japanese Industrialization and Economic Growth," Economic History Association.
[7] "Climate Action Tracker," ECOFYS, Climate Analytics, and New Climate Institute.
[8] "CO2 time series 1990-2015 per region/country," Netherlands Environmental Assessment Agency.
[9] "Spain country briefing—The European Environment: State and Outlook 2015," European Environment Agency, European Union.

begun relying on energy from renewable sources and natural gases (which cause less pollution than coal, although they are not a permanent fix) as a step in decreasing CO_2 emissions[10]. The success of wind and hydroelectric power in Spain allowed for almost 50% of Spain's energy to come from renewable sources in 2016, an achievement which has had an impact on Spanish carbon emissions[11]. Spain's government has also played a significant role in this decrease, most notably with the Spanish Climate Change Adaptation Plan in 2006, which provided resources for the creation of many programs that produced notable change in Spain's emissions[9]. Overall, Spain, through the aid of government plans and other environmental initiatives, has made notable steps towards decreasing CO_2 emissions and connected environmental problems caused by population growth.



United States

The Unites States' urban and industrial economy and large individual carbon footprint, due to high development along with a large and steadily growing population, has led to massive CO_2 emissions, both per capita and in total. Despite this, it is clear from the graph that after the rapid growth in CO_2 emissions up to 1970, CO_2 emissions per capita have followed a very loose downward trend. This is mostly due to the United States government's many policies concerning CO_2 emissions, mainly developed and implemented through the Environmental Protection Agency, founded in 1970. The EPA's effects have become increasingly pronounced in recent years, especially during the Obama administration. Recent actions from the EPA include a notable attempt at decreasing the emissions from transportation and power generation (the U.S.'s two largest sources of carbon emissions), through vehicle greenhouse gas rules and the Clean Power Program[12]. These policies, along with a slew of other government measures, have been able to reduce the

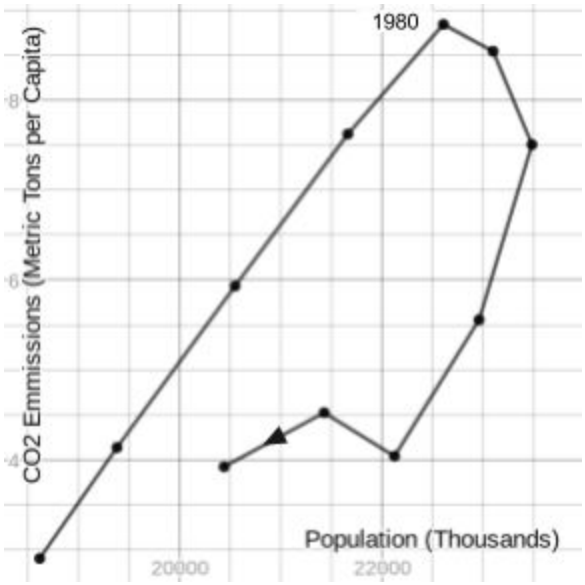


[10] "Spain Fossil-Fuel CO2 Emissions," Carbon Dioxide Information Analysis Center.
[11] Red Electrica de Espana
[12] "What the EPA is doing," United States Environmental Protection Agency.

effects of population growth on CO_2 emissions, leading to an overall downward correlation between per capita emissions and population since 1970.

Romania

Romania's unique history creates a trend between CO_2 emissions and population that is unlike the five previously analyzed countries. This trend is most influenced by policies concerning population and industrialization were implemented during Nicolae Ceausescu's time as the Communist Party of Romania's General Secretary, from 1965 until his overthrow in 1989. Ceausescu issued a decree in 1996 banning abortions and encouraging larger families, in an attempt to artificially increase the shrinking population[13]. This rapid population growth caused by this decree paired with government policies of industrialization led to CO_2 emissions per capita also increasing during Ceausescu's reign. On the graph, it is clear that CO_2 emission per capita increased linearly with population up until 1980, following a trend similar to that seen in India and many other rapidly industrializing countries. Following Ceausescu's fall from power in the 1989 Romanian Revolution, population growth rapidly fell from the unsustainable levels of Ceausescu's time. Additionally, around this time the Soviet Union was beginning to dissolve, taking with it the economic protection it had provided Romania and much of the rest of Eastern Europe[14]. The economic stipulations of the fall of the USSR, paired with the decrease in population, led to a decrease in per capita CO_2 emissions following the Romanian Revolution. Interestingly, this has led to CO_2 emissions decreasing somewhat linearly with population after 1960, giving the overall dataset a somewhat linear correlation. This shows that even in Romania, with its unique circumstances, population and total CO_2 emissions are correlated quadratically. This idea, along with the influence of government policies on the relationship between CO_2 emissions and population, seem to be the underlying forces driving the trends between population and carbon dioxide emissions throughout the world.



[13] "Romania's Demographic Policy," U.S. Library of Congress
[14] "A Globe Redrawn," *The Economist*.