CO_2 emissions per capita: Industrialized vs. developing countries using the bootstrap method

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Abstract :

This report analyzes the evolution of CO_2 emissions per capita across four country groups: industrialized, developing, emerging, and newly industrialized (NICs) - from 1800 to 2022. The bootstrap method is used to estimate group means and 95% confidence intervals. The method performs reliably across most cases, except for industrialized countries in 1850 and NICs in 2000, where small sample sizes led to unstable distributions. Results show a decline in emissions from industrialized countries in recent decades, while emissions from developing countries continue to rise. This results in a flattening of global mean emissions. Looking ahead, emissions from developing countries are expected to increase unless preventative measures are taken—emphasizing the need for sustainable development strategies that reduce emissions without hindering economic growth.

1 Introduction

In today's society, rising CO_2 emissions pose serious challenges for the planet's future, affecting nearly every aspect of Earth's ecosystem. The surge in emissions began during the Industrial Revolution, and since then, countries have developed at different rates due to factors such as geographical location and international relations. As a result, national CO_2 emission trends have also varied widely. Studying these differences provides valuable insights into how we arrived at the current climate crisis and offers clues about how it may evolve in the coming years.

This report investigates CO_2 emissions per capita over time across different categories of countries using the bootstrap method. The goal is to quantify overall trends and explore the relationship between a country's level of development and its carbon footprint.

2 Data description

The dataset was obtained from Gapminder Foundation, 2025, and contains CO_2 emissions in tonnes per capita from the years 1800-2022, for 194 countries. The bootstrap analysis is done categorizing all countries for the years 1800, 1850, 1900, 1950, 2000 and 2022, as the category assigned to each country changes throughout the years based on its industrial growth and situation. Namely, for the first four decades analysed, countries are classified as industrial or developing. For the year 2000 and 2022, countries are classified as advanced, newly industrialized (NIC), emerging or developing, as dividing into only industrial and developing become to general.

For the years 1800, 1850, 1900 and 1950, the following countries are classified as industrial, with the rest as developing.

Table 1: Industrialized countries for different years.

Year	Countries
1800	UK
1850	UK, Belgium, France
1900	Austria, Belgium, Denmark, France, Germany, Italy, Japan, Netherlands, Sweden, Switzerland, UK, USA
1950	France, Germany, Belgium, Netherlands, Canada, Japan, Australia, Sweden, Switzerland, Denmark, Norway, Italy, Austria, Finland, New Zealand, UK, USA

Categorization of countries in 2000 and 2022 can be found in Appendix A.2.

3 Methods

3.1 The bootstrap method

The bootstrap method is a resampling technique used to estimate the sampling distribution of a statistic computed from a dataset X. By generating multiple resampled datasets (with replacement), it allows estimation of statistical measures such as standard errors, bias, and confidence intervals. This makes it especially useful for quantifying the uncertainty of an estimator, even when the available data is limited.

The bootstrap algorithm is shown in Algorithm 1.

Algorithm 1 Bootstrap Algorithm

Require: Dataset $X = \{x_1, x_2, ..., x_n\}$, number of bootstrap samples B

Ensure: Bootstrap distribution $\{\theta^{*(1)}, \theta^{*(2)}, ..., \theta^{*(B)}\}$

1: **for** $b = 1$ to B **do**
2: Sample n points with replacement from X to form $X^{*(b)}$
3: Compute statistic $\theta^{*(b)} = s(X^{*(b)})$
4: **end for**
5: **return** $\{\theta^{*(1)}, \theta^{*(2)}, ..., \theta^{*(B)}\}$

Here we generate B bootstrap samples using n datapoints from the dataset X, and compute the desired statistic for each sample. The algorithm returns the collection of computed statistics, which can then be used to estimate statistical properties of the entire dataset.

In our case, the target statistics are the means and confidence intervals of CO_2 emissions for different categories of countries for different years.

4 Results

The resulting means and 95% confidence intervals using the bootstrap method are shown in Table 2-5. All results are done using $B = 1000$ bootstrap samples.

Table 2: Industrialized countries for different years.

Year	Mean	95% conf.int.
1800	2.48	-
1850	2.38	[0.54, 4.50]
1900	4.09	[2.45, 5.84]
1950	5.60	[3.77, 7.57]
2000	12.52	[10.85, 14.18]
2022	9.53	[8.46, 10.69]

Table 3: Developing countries for different years.

Year	Mean	95% conf.int.
1800	0.05	[0.03, 0.08]
1850	0.07	[0.05, 0.10]
1900	0.28	[0.19, 0.39]
1950	1.04	[0.75, 1.43]
2000	3.13	[2.54, 3.86]
2022	3.63	[2.85, 4.52]

Table 4: NICs for different years.

Year	Mean	95% conf.int.
2000	14.35	[10.51, 21.27]
2022	10.96	[7.92, 14.97]

Table 5: Emerging countries for different years.

Year	Mean	95% conf.int.
2000	3.62	[2.91, 4.35]
2022	4.27	[3.22, 5.51]

From a mathematical standpoint, the bootstrap method did not yield reliable results for the advanced countries in 1850 and the NICs in 2000. This is primarily due to the very limited sample sizes—only three countries were classified as advanced in 1850, and six as NICs in 2000. With such small datasets, many bootstrap samples become duplicates, resulting in highly discrete resampled means. This is clearly reflected in the histograms, which show isolated spikes and irregular, non-smooth distributions. As a result, the confidence intervals derived for these two cases should be interpreted with caution and are not considered reliable estimates of the population mean uncertainty.

In the other cases, all obtained distributions have an approximate shape of Gaussian distributions. These results supports the validation of the bootstrap method, and thus we are able to draw conclusions from the resulting means and confidence intervals.

For the industrialized countries, we can see a steady increase in CO_2 emissions up until 2000, before it starts to go down in 2022. During the 19th and 20th century, these countries experienced economic growth, and an increasing consumption of fossil fuels. In the 21th century however, recent advances in technology and a large focus on renewable energy sources has contributed to the reduction in CO_2 emissions.

For developing countries, the CO_2 emissions has been drastically lower than that of the industrialized ones. Yet, CO_2 emissions still tends to rise, as the overall industrialization of the world has increased, along with many complex factors. Also, industrialized countries tend to place manufacturing facilitates in developing countries, contributing to their CO_2 emissions.

As for NICs we see CO_2 emissions comparable to industrialized countries, although slightly larger. Emerging countries have emissions larger than that of developing ones, but smaller than industrialized and NICs.

5 Discussion

While it is difficult to precisely predict future global CO_2 emissions due to complex economic and political factors, our findings allow some informed observations. Emissions per capita are declining in industrialized countries, likely due to cleaner technologies, stricter regulations, and shifting production abroad. In contrast, emissions in developing countries continue to rise as they industrialize and expand access to energy and infrastructure. With around 145 developing countries, even modest increases in per capita emissions could significanly raise global emissions. Without global support for low-carbon development in these regions, emissions may continue to grow despite reductions in wealthier nations.

Figure 1 shows the mean emissions for all countries from the year 1800 to 2022.

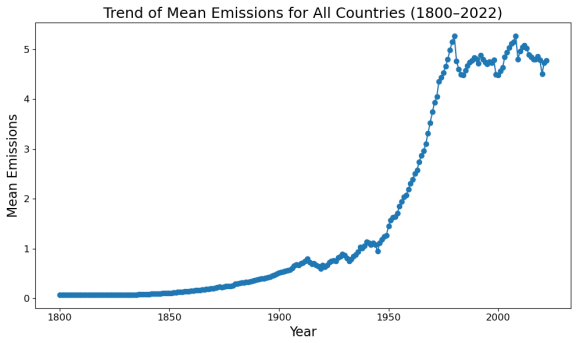

Figure 1. Mean CO_2 emissions per country per year.

After 1980, global mean CO_2 emissions begin to flatten. This shift coincides with a decline in emissions from major industrialized countries, while emissions from developing countries continue to rise. The global average stabilizes because the reductions in advanced economies offset — to some extent — the growth in less developed regions. To prevent a future rise in global emissions, efforts should focus on supporting sustainable development in developing countries. This includes providing access to clean technologies and low-carbon infrastructure, ensuring that economic progress is not hindered while avoiding excessive emissions growth.

6 Conclusion

To conclude, the bootstrap method has been used to study the means and 95% confidence intervals for different classes of countries, and for different decades. Analysis shows that the method works in most cases, where the datasets are sufficiently large. The overall trend is an increase in emissions from developing countries, while a decrease for industrialized. In the future, efforts should limit exploding emissions on developing countries, while not hindering their growth.

References

Gapminder Foundation (2025). *Gapminder Data*. https://www.gapminder.org/data/. Accessed: 2025-05-02.

Appendix

A.1 Github

https://github.com/KristianHaaland/AppStat

A.2 Categorization of countries 2000 and 2022

Table: Country classification in 2000.

Category	Countries
Advanced Industrial	Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, UK, USA
Emerging Industrial	Argentina, Brazil, Chile, China, Malaysia, Mexico, South Africa, Thailand, Turkey, Uruguay
NIC	Greece, Hong Kong, China, Israel, Singapore, South Korea, Taiwan
Developing	All other countries

Table: Country classification in 2022.

Category	Countries
Advanced Industrial	Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Estonia, Finland, France, Germany, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Slovenia, Spain, Sweden, Switzerland, UK, USA
Emerging Industrial	Argentina, Brazil, Chile, China, India, Indonesia, Malaysia, Mexico, Philippines, Russia, South Africa, Thailand, Turkey, Uruguay, Vietnam
NIC	Greece, Hong Kong, China, Israel, Lithuania, Poland, Singapore, Slovak Republic, South Korea, Taiwan
Developing	All other countries