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# Trends in Per Capita Carbon Dioxide Emissions


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by

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ABSTRACT

This paper examines the historical trends in $CO_2$ emissions per capita. These trends are separated into regional effects where it is noted that large developed regions are seeing decreases in $CO_2$ emissions per capita, while up-and-coming countries are seeing large increases, mostly due to changes in the fuel mix. Considerations regarding future emission pathways are made. I then compare my findings with numbers presented in the media, where few discrepancies are found. Finally, I review several models from the late twentieth century that are aimed at predicting atmospheric $CO_2$ concentrations and find that the earliest models overestimate carbon dioxide in the atmosphere.

**Keywords**: $CO_2$ emissions, greenhouse gas, global warming, climate change

## 1. INTRODUCTION

The goal of this paper is to analyse historical data of $CO_2$ emissions to obtain an unbiased perspective. Due to the connection of $CO_2$ to global warming, it is important to understand and follow the movements of this greenhouse gas so that action can be taken, if necessary, to slow its increase. In the section to follow, I look at data of per capita $CO_2$ emissions acquired from British Petroleum and make observations based on any evident trends. I then examine differences in various regions to determine which countries are experiencing any major increases or decreases in $CO_2$ emissions. Using this information, I speculate on the cause of such inclinations and what factors might play a role in predicting future emission pathways.

The third section summarizes a few news and magazine reports that relate to carbon dioxide. I make comments on the accuracy of their data and any biased language. Finally, the last section examines several $CO_2$ prediction models, specifically forecasting the $CO_2$ concentration in the atmosphere. Two of these models were conducted in the 1970's, and one in 1990. They make predictions for years that have now passed (except for the 1990 one), and so their accuracy can be assessed.

## 2. ANALYZING THE DATA

Data from British Petroleum (BP) shows a slight upward trend of $CO_2$ emissions per capita for years 1965 until 2018, illustrated in Figure 1. The lowest recorded $CO_2$ emissions per capita occurs in the earliest year, 1965, at 3.36 $tCO_2$, followed by a moderately steep upward trend for about ten years. It was just prior to this year, in the 1950's, that global fossil fuel consumption began to increase dramatically, which helps explain the quick increase in $CO_2$ emissions that follows. It was also around this time that global GDP growth started to accelerate, resulting in higher energy demand. The highest recorded point occurred in 2013 at 4.53 $tCO_2$ per capita, with the most recent observation being 4.42 $tCO_2$ in 2018.

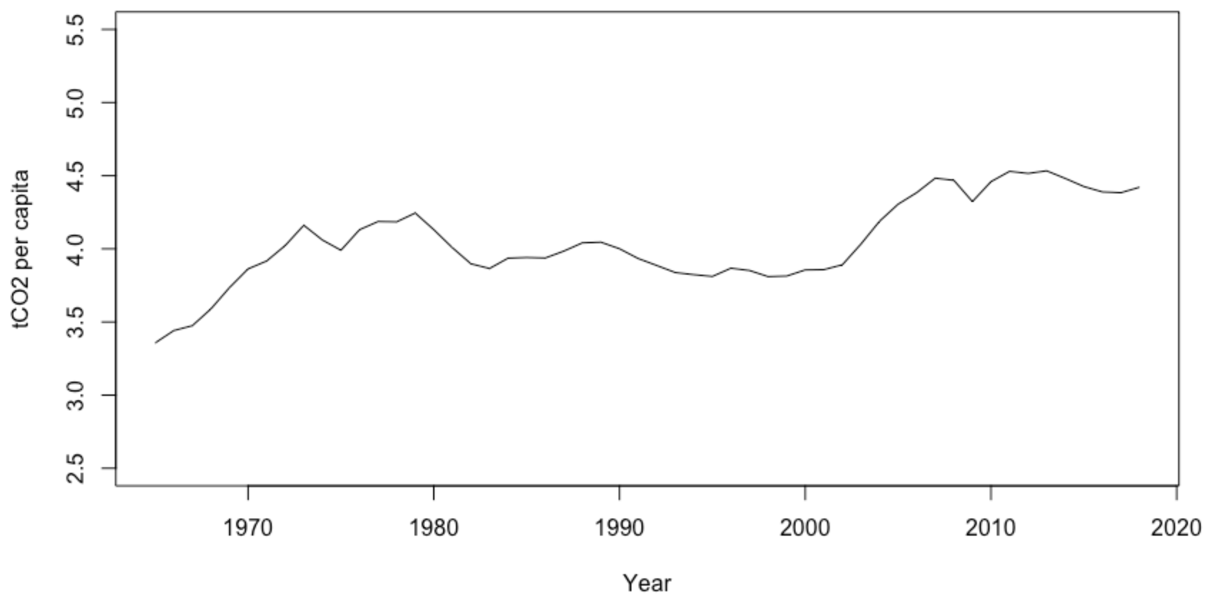


*Figure 1: Global tonnes of per capita $CO_2$ emissions from 1965 to 2018*

Indeed, the past decade or so has seen a fairly constant level of $CO_2$ emissions per capita. To extend the graph, a recent release from the International Energy Agency (IEA) notes that global energy related carbon dioxide emissions in 2018 and 2019 was constant at 33Gt, despite continued population growth. This implies decreases in per capita emissions over the two year period. This flattening can be attributed to switches from coal to natural gas, as well as the increasing role of renewable energy, such as wind and solar, and a greater reliance on nuclear power.

**Regional Trends**

The most notable decreases in $CO_2$ emissions in the past few years come from advanced countries, including the United States, European Union, United Kingdom, and Japan. The US has experienced continuous declines in $CO_2$ emissions (total and per capita) since 2000, falling from about 20.35 $tCO_2$ per capita to just over 15 $tCO_2$ in 2018, as evident in Figure 2. This equates to a

1 Gt decrease in total emissions over the same period. This decline is explained by the substitution of natural gas for coal, the former being more energy efficient and less $CO_2$ intensive.[1] Coal-fired power plants in the US experienced 15% less output in 2019 compared to 2018, which continues the trend of decreasing output since 2007. Decreasing natural gas prices resulting from advancements in hydraulic fracturing technology played a big role, which has led to increased US oil production since the turn of the century. From 2018 to 2019, gas prices decreased by almost half, as natural gas continues to become more easily accessible (IEA 2020).

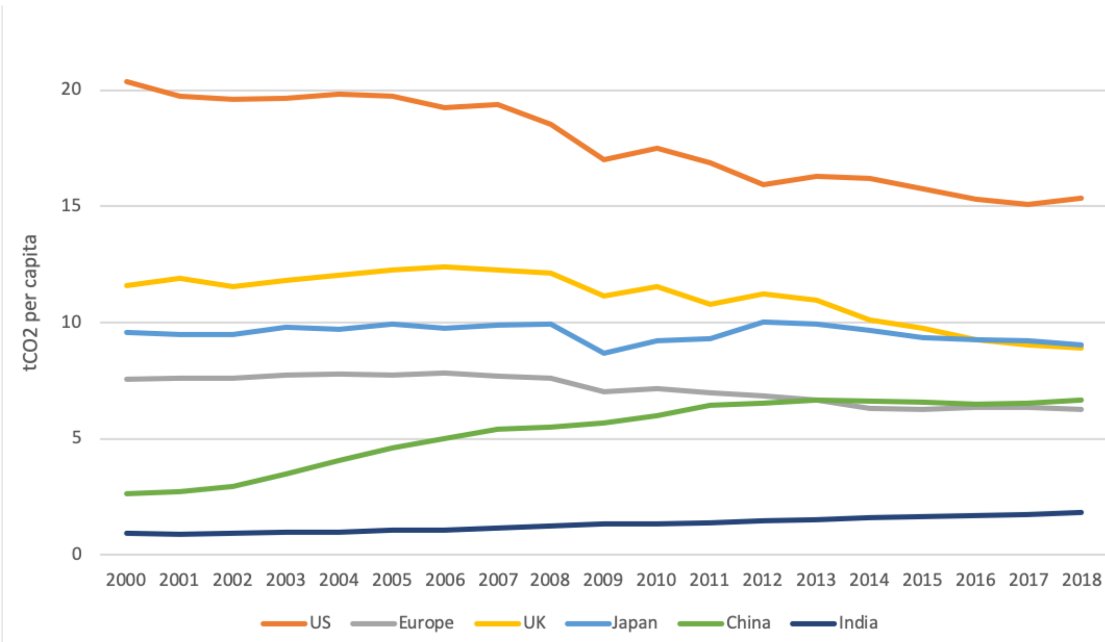


*Figure 2: Regional trends in per capita $CO_2$ emissions*[2]

In Europe, much of the recent decline in $CO_2$ emissions also came from the switch from coal to natural gas, as noted by the IEA. Their coal-fired plants saw a 25% decrease in production from 2018 to 2019, while energy from natural gas increased by 15%. Renewables also played a

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[1] Natural gas releases about 50% less carbon dioxide per unit of electricity generated (The National Academics n.d.)

[2] The UK is also included in the trend for Europe.

big role, especially in Germany, where, in 2019, renewables held a larger share of the country's total electricity output than coal. This followed an 11% increase in wind energy the previous year. In the United Kingdom, renewable sources generated more electricity than all fossil fuels combined in the third quarter of 2019. Japan saw a 40% increase in nuclear power output, which does not directly release any carbon dioxide, as idle nuclear reactors returned to operation. This contributed to a 4.3% reduction in $CO_2$ emissions from 2018 to 2019.

The downward trend of carbon dioxide emissions that we see in developed counties are largely offset by the upward trends in undeveloped counties. Throughout Asia, coal accounted for roughly 50% of energy use, with demand continuing to rise. However, renewable and other low-carbon sources of energy continue to expand throughout the region as well, which helps to offset the increases in emissions. India saw gradual increases in $CO_2$ emissions per capita. Here, overall demand for fossil fuels increased, but this was offset by increased use of renewable energy and a reduced reliance on coal. In fact, 2019 coal-fired electricity production in India saw a decrease for the first time since 1973 (IEA 2020).

## 3. FACTORS AFFECTING EMISSION PREDICTIONS

Clearly, growth in $CO_2$ emissions in the past few years has been slowing down, with increases in emissions from less developed countries being partially offset by decreases of that in advanced countries. If these trends continue, then perhaps global $CO_2$ emissions will remain relatively stable in the coming years or decades. Indeed, China and Europe have already converged to around the same level of $CO_2$ emissions per capita. In the absence of policy implementation, future emissions will depend on the relative fuel mix used to produce the world's energy, changes in energy demand, increases in energy efficiency and global population levels.

An important cause of the leveling-off of $CO_2$ emissions has been a change in the fuel mix, that is, the proportion of a given fuel source in total energy production. Figure 3 shows the carbon dioxide emissions from primary fuel sources for the US, Europe, China and India. Evidently, coal takes up larger proportions of overall energy production in China and India compared to the US or Europe. Since most developing countries continue to use large amounts of coal, $CO_2$ emissions will rise more quickly in these regions, as coal is the more carbon-intensive fossil fuel. The US and Europe are using proportionally less coal than in the past, thereby decreasing their carbon footprint. It appears that global coal production reached its maximum in 2013 or 2014, though it is too soon to say for sure (Ritchie & Rosser 2020). This would imply a decreasing trend in $CO_2$ emissions from coal into the future.

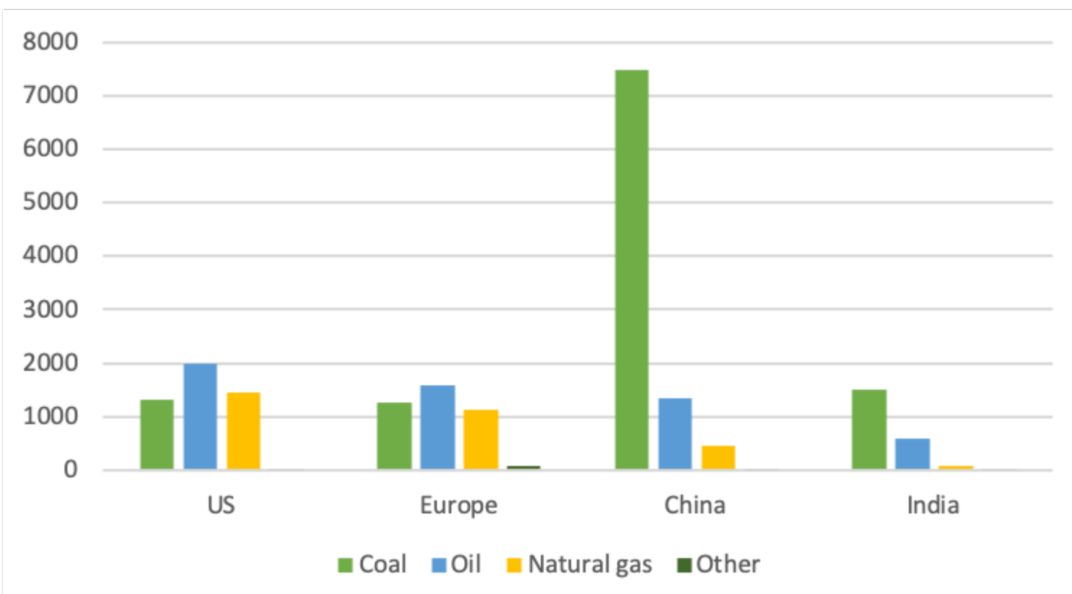


*Figure 3: $CO_2$ emissions by energy source in 2017 ($MtCO_2$)*

Energy demand will go up as standard of living (income) increases, which is assumed to occur over time. One can see this as an increase in per capita $CO_2$ emissions, all else equal. On the other hand, increases in energy efficiency results in decreases of per capita $CO_2$. Since the last decade or so has seen fairly stable global $CO_2$ emissions per capita, these forces may be increasing at the same rate. This is a sign of more stable per capita emissions in the future. If this is the case, increases in total global emissions will depend on increases in population. The United Nations (UN) provides world population projections up to the year 2100, when they expect it to reach its maximum. They assume that decreases in future fertility will occur in regions with currently large family sizes, while small increases will occur in areas with unsustainable reproduction levels (i.e., less than 2.1 children per woman on average). Projections for world population are 8.5 billion by 2030, 9.7 billion in 2050 and 11.2 billion in 2100.

It is important to consider which regions are expected to experience any prominent population changes when considering future $CO_2$ emissions. China, the most populated country at 1.44 billion people in 2019, is expected to see population decreases of around 2.2% by 2050, a reduction of 31.4 million people. This reduction in population would help offset the country's increasing energy demand and should reduce or level-off global emissions from coal-fired power plants. Over half of the world population increase by 2050 is expected to come from Africa. This will have little impact on world $CO_2$ emissions, as the continent emits only about 1 $tCO_2$ per person. It will only have a notable effect if Africa sees substantial increases in their GDP, but this is not likely to occur in the coming decades. European countries, on the other hand, are currently experiencing fertility levels below that required to maintain the population and are expected to see lower population levels in 2050. This, in combination with decreasing per capita $CO_2$ emissions across Europe, implies lower total emissions for the continent in 2050.

Population growth in the US is expected to rise at decreasing rates in the coming decades. By 2050, its population is projected to increase by 18.0% from 2019 levels, a 59.4 million increase (Vespa et al. 2020). If US $CO_2$ emissions per capita continue to decline, the higher population will not have a significant effect on total emissions coming from the US. To summarize, increases in global population may not have a large impact on future $CO_2$ release since population growth is expected to level-off by the end of the century and much of the growth is expected to come from low $CO_2$-emitting countries. Further, decreasing per capita emissions from larger economies will counteract some of the increased energy demand due to population growth.

## 4. CARBON DIOXIDE AND THE MEDIA

It is interesting to see whether what is commonly reported about $CO_2$ emissions in the media is factual. Given carbon dioxide's role in potentially causing global warming and the high level of attention that the media gives this cause, false facts can have heavy consequences. Misinforming the general public could lead to a population who under or overstates the severity of the climate crisis as it relates to $CO_2$, thereby swaying the political agenda. Here I analyse several news articles and check their claims.

In an article published by CNN on December 4, 2019, Helen Regan announces that carbon dioxide emissions in 2019 are expected to reach a record high. She states that global $CO_2$ emissions for that year are expected to reach almost 37 billion US tons (33.6 Gt). This projection turned out to be fairly accurate (although a slight overstatement), since according to the IEA, global carbon dioxide emissions for 2019 was at 33 Gt. However, as 2019 emissions were level with that in the previous year, this is no record high. According to the article, $CO_2$ emissions will likely keep increasing unless there are policies put in place to reduce them. However, most of the decreases that we've seen thus far have not been due to policies, but rather the shifting use in energy sources due to changes in supply and relative prices.

In an aggressive article published by The Environmental Magazine, Dan Lennon (2020) stresses the importance of immediate action to mitigate the effects of climate change. He claims that the US is at most to blame for global warming, due to their large share in cumulative global $CO_2$ emissions at 397 billion tons (360 Gt), compared to the second largest emitter being China, at 214 billion tons (194 Gt). While reporting cumulative emissions can provide some insight, it doesn't say anything about the actual trends occurring. Indeed, total and per capita $CO_2$ emissions are currently trending down in the US and continuing to rise in China. He reports $CO_2$ emissions per capita to be 16.5 tons for the US (about 15 tonnes), which is similar to the actual data. While he does acknowledge the major decreases in carbon dioxide emissions the US has seen since 1973, he still deems the US as unfavourable compared to the rest of the world. He claims they have the highest per capita emissions of any large country, although Canada and Australia are very close. In fact, Australia emitted about 1.5 $tCO_2$ per capita more than the US in 2018.

An article published by USA Today presents some good news. Using the latest report from the IEA, Doyle Rice (2020) reports that global emissions of $CO_2$ from fossil fuels in 2019 were similar to that in 2018 at 33 Gt, which I mentioned in previous sections. This occurred despite a 3% growth in the global economy. Similar findings are reported by James Temple (2020), in an article published by MIT Technology Review. Temple provides that the flattening emission trends come from regions like the US and EU, who are beginning to rely on more renewable energy like solar and wind, as well as increasing their use of natural gas. Also, countries like Japan and Korea are using more nuclear power which releases less $CO_2$. This is consistent with my evidence. He ends the article by countering that, despite the leveling-off of carbon dioxide emissions, we are far from where we need to be to combat global warming. He argues that a 25% reduction in global $CO_2$ emissions is required by the end of the decade, and that the world needs to be net zero by 2070.

These articles provide a brief overview of people's perceptions of $CO_2$ trends. Most outlets approach any good news with caution, as short-term emission reductions doesn't necessarily imply similar trends in the long run. Most articles I came across had headlines reporting record high $CO_2$ emissions, while few talked about the decreases occurring in many of the largest economies.

## 5. HISTORICAL ACCURACY OF $CO_2$ PREDICTION MODELS

Climate scientists have been making predictions about future carbon dioxide emissions for the past five decades. The accuracy of these predictions vary, and it is interesting to look at humanity's previous forecasts to see how well they predict the conditions we are experiencing today. Seeing as researchers continue to make forecasts today that affect government policy initiatives, studying the accuracy of past models allows the public and politicians to reassess how they interpret any new predictions. The following studies make predictions of future atmospheric carbon dioxide levels in order to predict future warming, although I simply focus on their forecasts of $CO_2$.

A study done in 1972 by John Sawyer was aimed at predicting temperature and atmospheric concentration of $CO_2$ for the year 2000. He used an approximation of climate sensitively of 2.4, which was estimated by Manabe and Wetherald (1967). This means that a doubling of atmospheric $CO_2$ levels was estimated to increase global average temperatures by 2.4 degrees Celsius. Sawyer predicted that $CO_2$ concentrations would increase by 25% from 1969 to the end of the twentieth century, which translates into a forecast of 406 ppm of carbon dioxide for 2000. This is far from the actual value of 370 ppm that occurred in that year, which is only a 14% increase from 1969 levels. In fact, the levels of $CO_2$ that Sawyer predicted for 2000 did not occur until around 2016. The trends from 1959 are shown in Figure 4, using data from the National Oceanic and Atmospheric Administration (NOAA), from measurements taken in Mauna Loa, Hawaii. It might be worth noting that Sawyer did, however, produce a reasonable estimate of global temperature increase over the same time frame, which was 0.6 degrees Celsius (Hausfather 2017).

Another model published in 1990 uses population predictions from the UN and data on fossil fuel use per capita to predict carbon dioxide atmospheric concentrations in 2025. Anastasi, Hudson and Simpson forecast levels between 415 and 421 ppm for 2025, which we indeed seem on track to reach. $CO_2$ in the atmosphere in 2019 was 411 ppm, which makes their estimate for five years from now not unreasonable, given historical patterns. It is perhaps the simplicity of their model and the insensitivity of the forecasts to changing parameters that results in an accurate estimate.

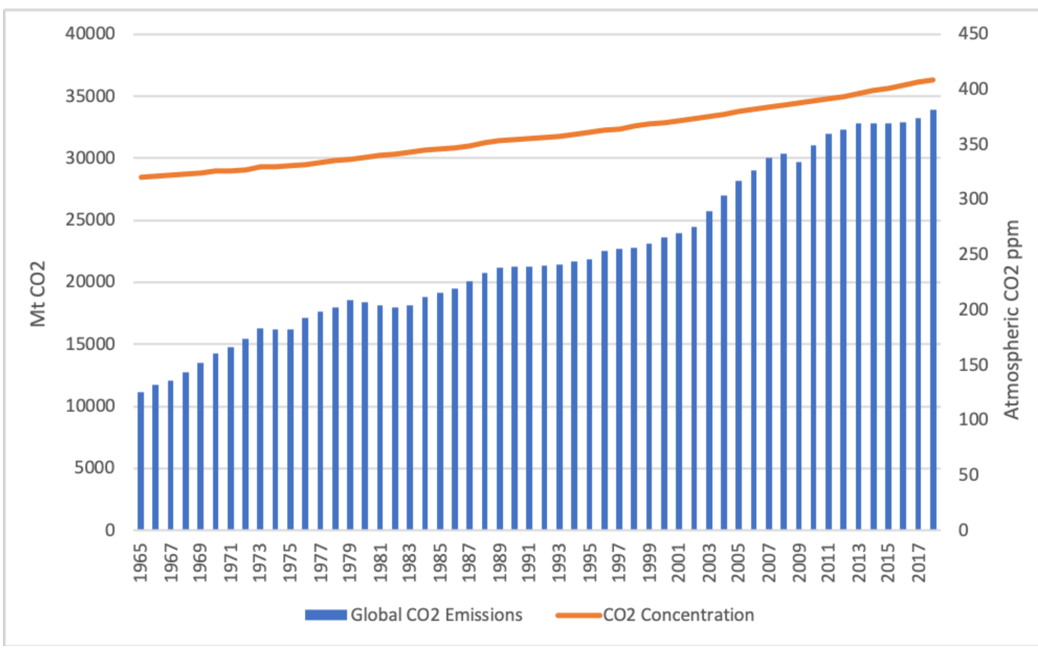


*Figure 4: Carbon dioxide in the atmosphere and global emissions*

Wallace Broecker (1975) presents a model predicting large amounts of global warming due to increases in carbon dioxide emissions in the future, despite the apparent cooling trends occurring at that time. He suggests that the warming due to the rise in $CO_2$ emissions was being offset by natural cooling effects and that exponential increases of atmospheric $CO_2$ in future decades, combined with the start of a natural warming trend, would not allow this equalizing effect to last. Due to his hypothesis of exponential growth in future $CO_2$ concentrations, despite the more linear trends that have occurred (as evident in Figure 4), he over-predicted levels seen in recent years by about 20 ppm, but was more accurate for earlier years, up until about 2000 (Hausfather 2017).

Clearly, two of the models presented had overestimates for atmospheric $CO_2$ concentration, while the other, although too soon to tell, is fairly accurate. It is interesting to note how the atmospheric $CO_2$ level hasn't increased linearly with global $CO_2$ emissions, which could be a driver behind these overestimations. It should also be mentioned that as modelling techniques improve, forecasts should become more accurate, although any model based on historical data will have a large margin of error.

## 6. CONCLUSIONS AND DISCUSSION

Carbon dioxide emissions per capita have been relatively constant for a little over a decade. Larger developed countries including the United States, most of Europe and Japan have provided the most prominent decreases. Some up-and-coming countries, such as China, have contributed to large increases in $CO_2$ per capita. If these recent patterns continue, perhaps global $CO_2$ emissions will level-off in the near future. This is hard to predict, however, given the many uncertain factors that come into play. The several news articles discussed suggest that while accurate data is used, the environmental problems associated with rising $CO_2$ levels are not solved yet, no matter any signs of slowing emissions growth.

The relevance of $CO_2$, and therefore this discussion, is directly determined by its impact on climate change and other environmental concerns. Before taking any extreme measures to reduce anthropogenic emissions, it should be known with a high degree of certainty the impact

$CO_2$ has on the environment and its inhabitants. We don't know if the living standards associated with a $CO_2$-degraded environment are worse than the living standards associated with decreased consumption and higher abatement costs. This should be considered before costly decisions are made.

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