MARCH 2025

THE HISTORY AND FUTURE OF ATMOSPHERIC CO_2

Trends, Impacts, and Projections

Research Report

Author: Ebadat Ur Rehman

Author/s

Ebadat Ur Rehman | Carbo-X (Private) Limited

Acknowledgement

Carbo-X sincerely thank **Mr. Nameer Urfi** and **Mr. Mashhood Urfi** for their valuable time and effort in reviewing this report. Their insightful feedback and constructive suggestions have greatly enhanced the clarity and quality of our work.

Cite as

Carbo-X. (2025). *The history and future of atmospheric CO_2: Trends, impacts, and projections* (Research Report). Carbo-X (Private) Limited. https://carboxconsulting.com/

Executive Summary

This paper addresses the critical role of carbon dioxide (CO_2) in shaping Earth's climate, examining historical trends, modern data, and future projections. CO_2, the most abundant greenhouse gas, has fluctuated naturally over millions of years but has been rapidly increasing since the Industrial Revolution due to human activities such as fossil fuel burning and deforestation. This increase has disrupted the natural carbon balance, contributing to global warming, ocean acidification, and ecosystem disruptions.

The paper highlights key periods in Earth's history where elevated CO_2 levels coincided with evolutionary milestones, such as the Great Ordovician Biodiversification Event. It explores how high CO_2 levels from volcanic activity 300 million years ago led to an unstable climate, resulting in glaciation. The rapid rise in CO_2 since the Industrial Revolution parallels the development of human civilization, with current concentrations exceeding 400 ppm—levels not seen for millions of years. The COVID-19 pandemic briefly reduced emissions but did not significantly lower atmospheric CO_2, demonstrating its persistence.

Looking to the future, climate models predict varying CO_2 trajectories based on different emission scenarios. The optimistic RCP 2.6 scenario assumes immediate cessation of emissions, while RCP 4.5 and 6.0 reflect moderate reductions, and RCP 8.5 suggests catastrophic consequences due to continued fossil fuel dependence. The paper emphasizes the urgency of transitioning to sustainable practices to avoid the worst-case scenario.

In conclusion, the paper underscores the importance of immediate and aggressive emission reductions to mitigate climate change impacts. It advocates for decisive global actions, enhanced climate policies, technological advancements, and widespread public awareness to stabilize CO_2 levels and prevent irreversible damage to Earth's climate and ecosystems.


CO2
CO2

Introduction

"We're in a new era, and it's going fast. We're going to touch up against 410 pretty soon."
– Ralph Keeling, Director of the Scripps Institution of Oceanography's CO2 Program in San Diego.

Carbon dioxide (CO_2) is the most abundant greenhouse gas in Earth's atmosphere and serves as a key indicator of climate change. As a cornerstone of Earth's climate system, CO_2 plays a critical role in regulating temperature, influencing ocean chemistry, and shaping biodiversity. Throughout Earth's history, CO_2 levels have fluctuated naturally over millions of years due to processes such as volcanic activity, oceanic absorption, and biological evolution. A common misconception suggests that because CO_2 concentrations were higher in the distant past, today's increase is merely part of a natural cycle. While it is true that historical CO_2 levels have been significantly elevated at certain points in Earth's past, the current rise is distinct in both its cause and pace. Human activities since the Industrial Revolution, primarily the burning of fossil fuels, large-scale deforestation, and industrial emissions, have driven CO_2 concentrations to levels not seen in at least 3 million years. This rapid acceleration has disrupted the natural carbon balance, contributing to global warming, ocean acidification, and ecosystem disruptions.

This paper synthesizes paleoclimate data, modern observations, and climate models to contextualize the current CO_2 crisis and highlight the urgency of mitigation. By analyzing past atmospheric CO_2 variations, we can better understand the scale and implications of today's unprecedented increase. We will also examine the trajectory of future CO_2 concentrations, the potential consequences for Earth's climate and ecosystems, and the pathways available to mitigate further damage. Addressing this challenge requires informed decision-making, global cooperation, and decisive action to reduce emissions and restore environmental stability.

CO_2 in the Past

The past data highlights key periods in Earth's history where CO_2 levels were significantly higher than today's values, particularly during the Ordovician period (~500 million years ago). CO_2 concentrations ranged between 3,000 and 9,000 ppm, significantly surpassing the 280 ppm pre-industrial levels. These high levels coincided with the *Great Ordovician Biodiversification Event (GOBE)*, a major evolutionary milestone that saw a burst of marine species evolution. This suggests a possible relationship between higher CO_2 levels and increased biodiversity, though it's essential to note that the specific mechanisms at play during this period are complex and likely involve factors like temperature, ocean chemistry, and atmospheric oxygen, in addition to CO_2.

The graph in **Figure 1** connects high CO_2 levels to rapid speciation, reinforcing the idea that periods of high atmospheric CO_2 may have played a role in shaping the evolutionary trajectory of life on Earth. However, it's important to consider that other factors, such as tectonic activity, ocean circulation, and biological feedback loops, also contributed to these events.

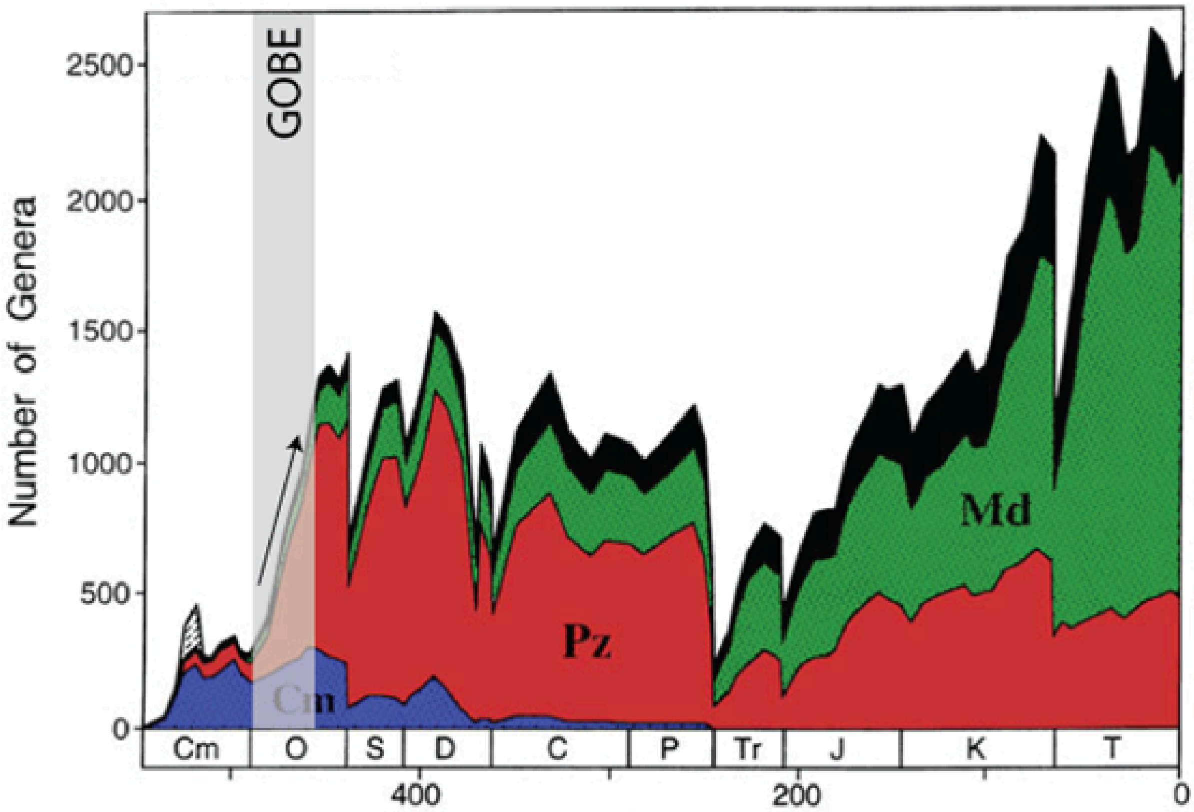

Figure 1: Animal diversity curve highlighting the Ordovician Biodiversification Event (grey line). The black arrow denotes rapid speciation during this period.

Reconstructing CO_2 and Temperature Trends

Modern scientific tools such as ice cores and sediment records have provided invaluable insight into past CO_2 and temperature variations. For example, **Figure 2**, derived from the University of Copenhagen, demonstrates a strong correlation between CO_2 levels and Antarctic temperature over the last 800,000 years, with red peaks corresponding to warm interglacial periods and blue troughs marking colder glacial phases. This clear relationship highlights the role of CO_2 in driving Earth's climate cycles, with higher CO_2 levels generally correlating with warmer global temperatures.

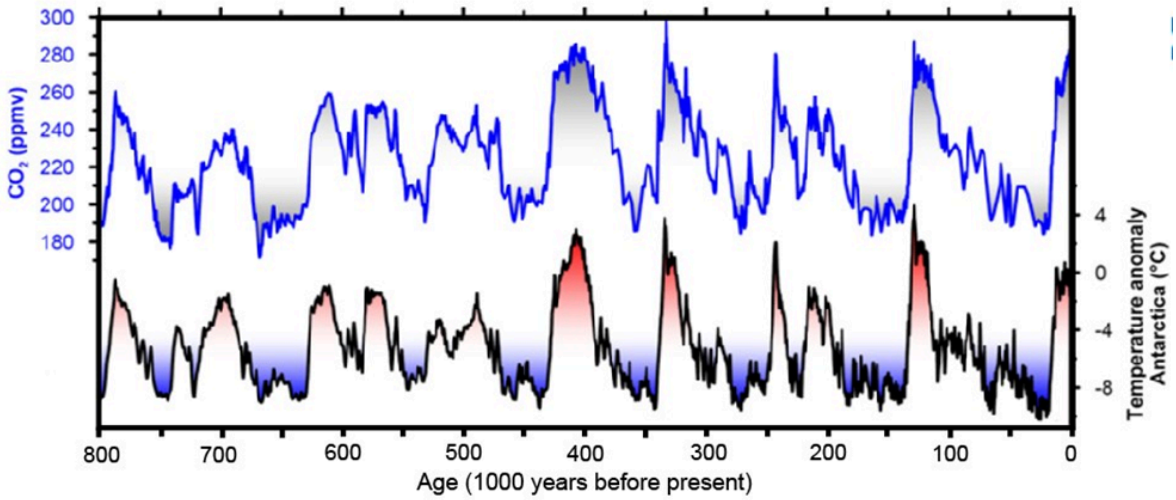

Figure 2: CO_2 (blue) and Antarctic temperature (black) over 800,000 years. Interglacial (red) and glacial (blue) phases are highlighted.

A closer examination of the past 18,000 years, shown in **Figure 3**, reveals a rapid rise in CO_2 levels following the last ice age. This surge aligns with human civilization's development and industrialization, pointing to the significant anthropogenic influence on current climate trends.

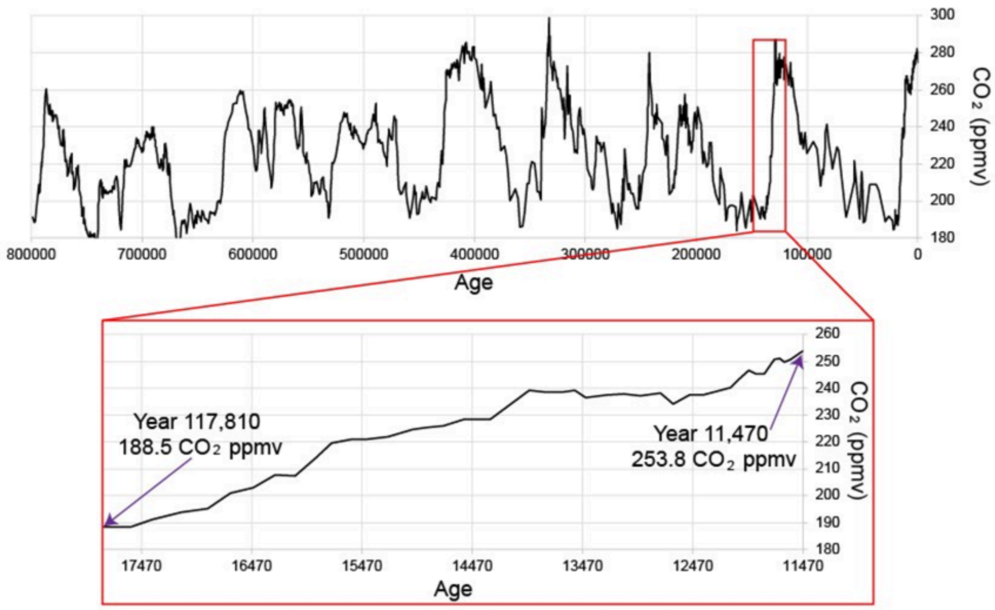

Figure 3: CO_2 fluctuations over 800,000 years (top) and a detailed view of the post-glacial surge (bottom).

Volcanic Activity and Carbon Imbalances

The analysis further delves into a period of carbon imbalance around 300 million years ago, which led to glaciation. This was followed by volcanic eruptions that doubled CO_2 concentrations to ~1,000 ppm, creating an unstable climate. Despite a reduction in CO_2 levels after this peak, the Oligocene epoch (~34–23 million years ago) maintained CO_2 levels comparable to today, but global temperatures were 4–6°C higher (**Figure 4**). This underscores the power of CO_2 in shaping long-term climate trends and suggests that even moderate increases in CO_2 can drive significant warming, with profound implications for ecosystems and human societies.

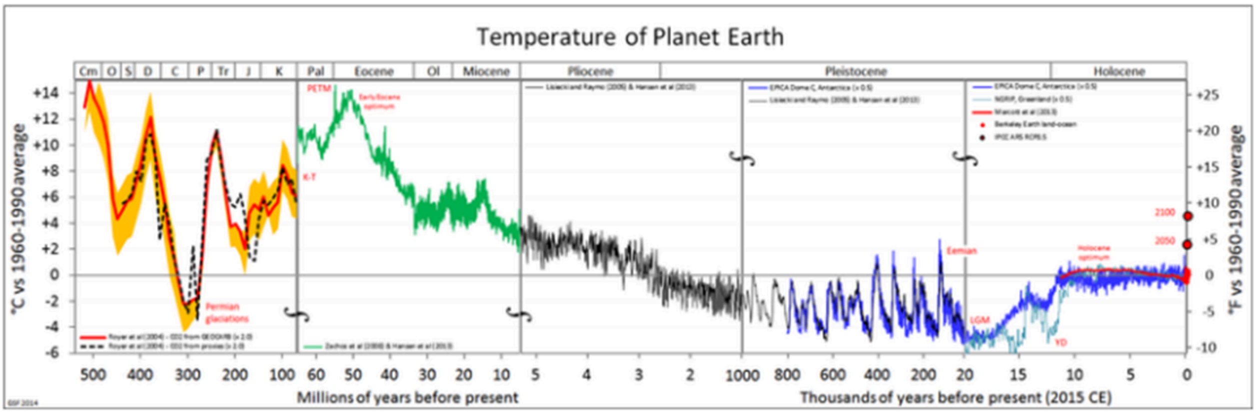

Figure 4: Temperature estimates over 500 million years (Glen Fergus)

CO_2 in the Present: The Industrial Revolution and Beyond

The industrial revolution marked a sharp increase in CO_2 emissions, with levels rising sharply after 1750, as depicted in **Figure 5**. Prior to this, CO_2 concentrations hovered around 280 ppm, but with the advent of fossil fuel use and deforestation, levels exceeded 400 ppm by 2015. The rise of CO_2 levels is closely mirrored by temperature increases, highlighting the impact of human activities on the climate. **Figure 6** illustrates how current CO_2 levels (around 417 ppm in May 2020) have surpassed natural variability as indicated by ice core data, suggesting that we are entering uncharted territory in terms of atmospheric CO_2 concentrations.

The COVID-19 pandemic caused a brief dip in emissions, but 2020 CO_2 levels remained at record highs, underscoring the inertia of CO_2 in the atmosphere (**Figure 7**). Even with temporary reductions in emissions, the long-term effects of accumulated CO_2 persist.

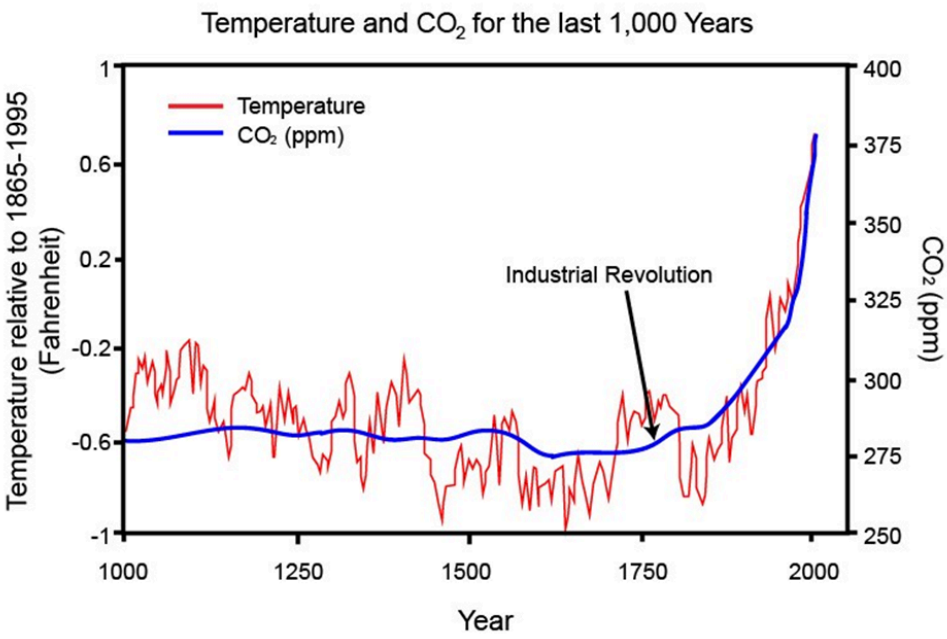

Figure 5: CO_2 (blue) and temperature (red) from 1000–1978. Data sources: Vostok and Law Dome ice cores, Mauna Loa Observatory.

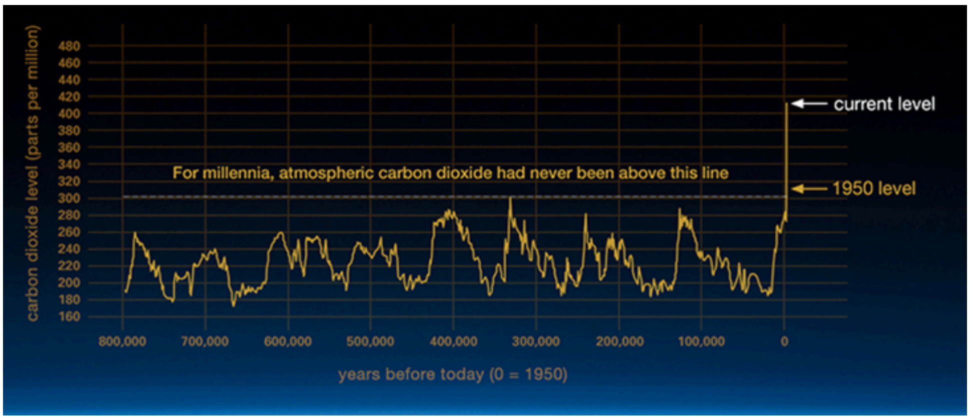

Figure 6: Ice core-derived CO_2 records (climate.nasa.gov).

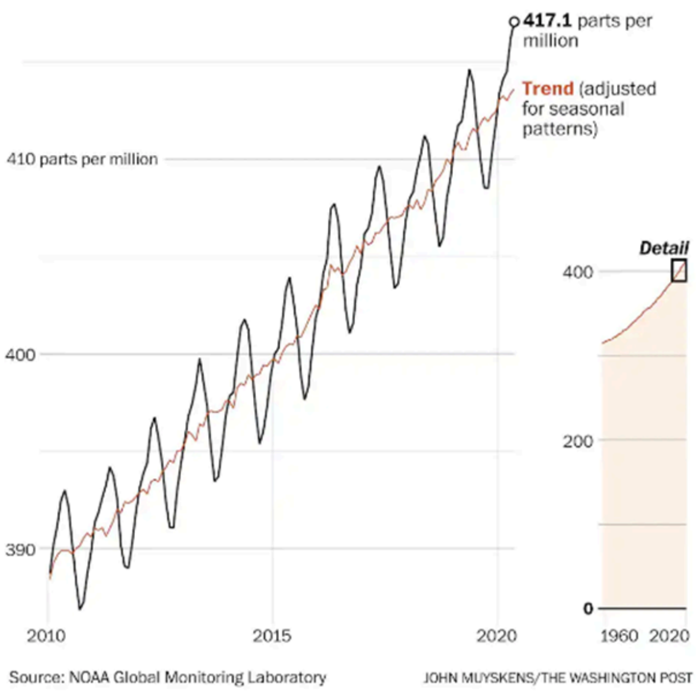

Figure 7: CO_2 and Covid-19 Pandemic

CO_2 in the Future

Looking ahead, climate models project a range of possible CO_2 trajectories, depending on future emissions scenarios. The Figure 8 presents four different scenarios and their projected outcomes. The y-axis represents atmospheric CO_2 levels, while the x-axis shows years into the future. These scenarios are known as *Representative Concentration Pathways (RCPs)*, which are standardized climate projections developed by scientists worldwide. RCPs are widely accepted and non-controversial.

- ***RCP 2.6 (green):*** This scenario assumes immediate cessation of emissions, leading to a decline in CO_2 levels by mid-century. While optimistic, it requires urgent and unprecedented global action.
- ***RCP 4.5 (purple) and RCP 6.0 (gold):*** These scenarios reflect moderate emission cuts, leading to slower increases in CO_2 but still result in significant warming. The gray bands represent uncertainties in these projections, highlighting the challenge of accurately predicting future climate dynamics.
- ***RCP 8.5 (red):*** This "business-as-usual" scenario, characterized by continued fossil fuel dependence, could push CO_2 concentrations above 1,000 ppm by 2100, with catastrophic consequences for global temperatures and ecosystems. This represents the worst-case scenario and underscores the urgency of transitioning to sustainable practices.

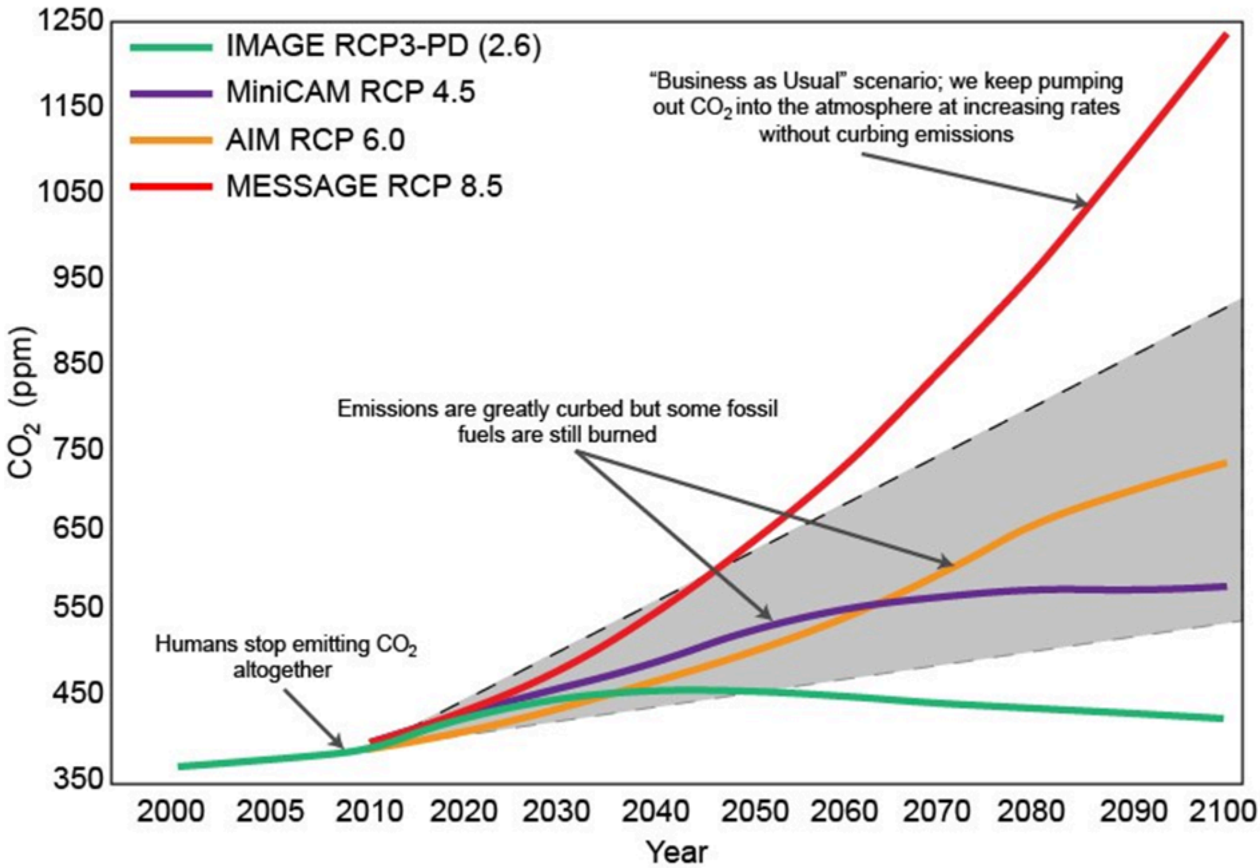

Figure 7: Projected CO_2 under RCP scenarios.

Conclusion

The analysis of past, present, and future CO_2 trends demonstrates the pivotal role of carbon in shaping Earth's climate. High CO_2 levels in ancient periods have been linked to significant evolutionary events, but the rapid increase in CO_2 since the Industrial Revolution, driven by human activities, poses an unprecedented challenge. The data makes it clear that the path we take in the coming decades will determine the severity of climate change impacts. Immediate and aggressive emission reductions, as proposed in RCP 2.6, offer the best hope for mitigating catastrophic warming, but current trends indicate that scenarios closer to RCP 4.5–6.0 are more likely unless substantial policy and technological changes are made. The resilience of CO_2 in the atmosphere, as evidenced by post-pandemic data, further emphasizes the long-term commitment required to stabilize the climate.

Recommendations

Based on the analysis of CO_2 trends, urgent action is needed to address the challenges posed by rising carbon levels. To mitigate climate change impacts, key recommendations include:

- Governments and industries must prioritize rapid emission reductions by transitioning to renewable energy, increasing energy efficiency, and adopting carbon-neutral technologies to steer global CO_2 levels toward the RCP 2.6 pathway and avoid catastrophic climate outcomes.
- Global climate policies should be strengthened, ensuring that countries adhere to stricter emissions standards and collaborate on shared climate goals. International agreements, such as the Paris Agreement, should be expanded and enforced with more rigorous accountability mechanisms.
- Research and investment in Carbon Capture and Storage (CCS) technologies should be accelerated to mitigate current CO_2 levels while allowing continued industrial activities.
- Comprehensive climate monitoring systems should be established by governments and research institutions to track CO_2 emissions and temperature changes more effectively. Enhancing predictive climate models with paleoclimate data can help anticipate future climate impacts and guide adaptive strategies.
- Public awareness campaigns should be launched to emphasize the significance of CO_2 levels and their long-term effects on climate stability. Encouraging sustainable lifestyles, reducing consumption, and promoting carbon-neutral choices at the individual and societal levels can support emission reduction efforts.

References

- Earth.org. (2020). *A brief history of CO_2*. Retrieved March 15, 2025, from https://earth.org/data_visualization/a-brief-history-of-co2/#:~:text=As%20a%20point%20of%20reference,period%2C%20500%20million%20years%20ago.
- Penn State University. (n.d.). *Earth 103: Earth in the Future.* Retrieved March 15, 2025, from https://www.e-education.psu.edu/earth103/node/1018
- NOAA. (2019). *Carbon dioxide levels hit record peak in May.* National Oceanic and Atmospheric Administration. Retrieved March 15, 2025, from https://research.noaa.gov/carbon-dioxide-levels-hit-record-peak-in-may/
- Timescavengers. (n.d.). *CO_2: Past, present, and future.* Retrieved March 15, 2025, from https://timescavengers.blog/climate-change/co2-past-present-future/
- Luthi, D., et al. (2008); Etheridge, D. M., et al. (2010); Vostok ice core data/J. R. Petit et al.; NOAA Mauna Loa CO_2 record. Some description adapted from the Scripps CO_2 Program website, *Keeling Curve Lessons.*

Carbo-X (Private) Limited

290, Capital Street, H-13 Sector, Islamabad, 44000, Pakistan
info@carboxconsulting.com | +92 333 6669630