Perspective

Environment & Earth

Is Carbon Dioxide the Real Reason of Global Warming?

Satohiro Hokari*
Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai, Miyagi 980-8577, Japan
*: All correspondence should be sent to: Dr. Satohiro Hokari
Author's Contact: Dr. Satohiro Hokari, Ph.D., E-mail: Satohiro.okari@grp.tohoku.ac.jp
DOI: https://doi.org/10.15354/si.25.pe231
Funding: No funding source declared.
COI: The author declares no competing interest.
AI Declaration: The author affirms that artificial intelligence did not contribute to the process of preparing the work.

Global warming has emerged as one of the most pressing challenges of the 21st century, with carbon dioxide (CO_2) often identified as the primary driver due to its heat-trapping capabilities. However, the dominance of carbon-centric narratives has overshadowed other potentially significant contributors such as methane, nitrous oxide, water vapor, aerosols, land-use change, and systemic feedback loops. This hypothesis article explores whether carbon is truly the main culprit behind global warming or if it is a proxy for a more complex web of factors. Through a multidisciplinary lens, it assesses scientific evidence, policy influence, climate modeling, and emerging research to question carbon's centrality. The article does not deny carbon's role but posits that focusing too narrowly on CO_2 may hinder comprehensive climate action. By re-evaluating the relative contributions of different forcings and amplifiers of warming, this analysis seeks to refine our understanding of climate dynamics and inform more holistic mitigation strategies that reflect the interconnected nature of Earth's systems.

Keywords: Carbon Dioxide; Global Warming; Earth; Greenhouse; Pollution

Science Insights, June 30, 2025; Vol. 46, No. 6, pp.1851-1855.

Introduction

CARBON dioxide has long stood at the center of climate change discourse. Since the industrial revolution, human activities—especially the burning of coal, oil, and natural gas—have dramatically increased atmospheric CO_2 levels, rising from about 280 parts per million (ppm) in pre-industrial times to over 420 ppm today (Babin et al., 2021). CO_2 is considered a well-mixed greenhouse gas, meaning it spreads uniformly in the atmosphere, trapping heat and increasing Earth's surface temperature. The Intergovernmental Panel on Climate Change (IPCC) and related scientific bodies have consistently reinforced CO_2's role through comprehensive assessment reports and climate models (Kweku et al., 2018).

International agreements such as the Kyoto Protocol and the Paris Agreement have further cemented CO_2's role as the cornerstone of mitigation strategies (Friedlingstein et al., 2022). These agreements primarily target reductions in CO_2 emissions, often measured through national inventories and carbon budgets. CO_2's prominence is partly due to the feasibility of quantifying and regulating it in economic and legal frameworks (Krueger et al., 2023). However, this approach, while practical, raises the question: Is carbon truly the main culprit, or is it a convenient metric for complex climate dynamics? Understanding the underlying assumptions behind policy decisions can illuminate the limitations of a carbon-dominated framework.

Greenhouse Gases: Beyond Carbon Dioxide

Although CO_2 is the most abundant anthropogenic greenhouse gas by volume, other gases such as methane (CH_4), nitrous oxide (N_2O), and fluorinated gases have a significantly higher global warming potential (GWP) (Kweku et al., 2018). Methane, for instance, is approximately 84 times more potent than CO_2 over a 20-year period and 28–36 times over a 100-year horizon. This makes methane critically important in the short-term fight against climate change.

Methane emissions come from diverse sources including agriculture (mainly ruminant livestock like cows), landfills, natural gas leaks, and thawing permafrost (Papakonstantinou et al., 2024). Nitrous oxide, another potent GHG with a 100-year GWP of about 298 times that of CO_2, primarily arises from the use of nitrogen-based fertilizers in industrial agriculture and fossil fuel combustion (Fagodiya et al., 2017). Fluorinated gases—used in refrigeration, air conditioning, and manufacturing—may have GWPs in the thousands and linger in the atmosphere for centuries.

Despite these gases' potency, global climate policy has disproportionately emphasized CO_2 (Cohen-Shields et al., 2023). This focus may skew the perception of which interventions are most impactful, particularly in sectors like agriculture and waste management, where methane and N_2O dominate. By broadening the scope to include all major greenhouse gases, policymakers can design more effective and equitable mitigation strategies.

The Role of Water Vapor and Feedback Loops

Water vapor is the most abundant greenhouse gas in the atmosphere, contributing significantly more to the natural greenhouse effect than CO_2 (Ricaud et al., 2013). However, it is typically treated as feedback rather than forcing in climate science. As global temperatures rise—often attributed to CO_2—more water evaporates, increasing atmospheric water vapor, which then amplifies warming through a positive feedback loop.

This dynamic complicates attribution. If CO_2 is the trigger that increases water vapor, which in turn amplifies the effect, then isolating CO_2's sole impact becomes challenging (Chung et al., 2014). Additionally, regional variations in humidity, cloud formation, and precipitation patterns further obscure the feedback effects. Some studies suggest that cloud feedbacks alone could account for a wide range of uncertainties in projected warming. Ignoring or minimizing water vapor's role may exaggerate carbon's singular importance and fail to capture the full scope of climate forcings.

Aerosols and Albedo: The Cooling Counter-forces

Aerosols are tiny particles or droplets suspended in the atmosphere, many of which originate from industrial pollution, volcanic eruptions, or biomass burning (Fahey et al., 2017). Unlike greenhouse gases, aerosols have a net cooling effect on the Earth's climate by increasing the reflection (albedo) of solar radiation back into space. Sulfate aerosols, in particular, are known to form reflective clouds that reduce incoming solar radiation (Chlek & Coakley, 1974).

The mid-20th century experienced a global temperature plateau or even cooling trend despite rising CO_2 levels, partly due to increased aerosol emissions from post-war industrialization (Zhang, 2020). This phenomenon highlights the importance of considering multiple concurrent climate forcings. When policies like the Clean Air Act reduced aerosol pollution, the masking effect lessened, allowing greenhouse warming to become more pronounced.

Aerosol-cloud interactions are still not fully understood and represent one of the largest uncertainties in climate modeling (Bauer et al., 2022). Yet, their ability to temporarily offset warming underscores the danger of attributing all observed temperature changes solely to carbon. Some geoengineering proposals even consider the deliberate introduction of aerosols to counteract warming, though these raise ethical and environmental concerns.

Land-Use Change and Deforestation

Land-use changes—including deforestation, reforestation, urbanization, and agricultural expansion—have both direct and indirect effects on climate. Deforestation releases stored carbon in biomass and soils, contributing to atmospheric CO_2 levels (Taylor, 1997). However, the climatic effects of land-use change extend beyond carbon emissions.

Changing land cover alters surface albedo (reflectivity), evapotranspiration rates, and soil moisture levels. Urban areas, with their dark, heat-absorbing surfaces, tend to create local heat islands (Pitman & Noblet‐Ducoudré, 2011). Conversely, deforestation in tropical regions reduces rainfall and cloud cover, potentially shifting climate zones. These biophysical effects may rival or exceed the impact of carbon emissions in certain contexts. Yet, land-use change is often relegated to a secondary role in climate discourse. Reforestation and agroforestry can act as potent carbon sinks while improving biodiversity and water retention, offering a multidimensional solution.

Ocean Dynamics and the Carbon Cycle

The world's oceans are a central component of the global climate system, absorbing approximately 25–30% of anthropogenic CO_2 emissions annually (Stammer et al., 2019). This process mitigates atmospheric warming but has limits. Oceanic absorption efficiency decreases with temperature, salinity, and acidification. As surface waters warm, stratification increases, reducing mixing and CO_2 uptake from deeper, colder waters.

Furthermore, the oceans store and redistribute heat through currents such as the Atlantic Meridional Overturning Circulation (AMOC) (DeVries et al., 2017). Disruptions to AMOC or El Niño-Southern Oscillation (ENSO) cycles can lead to abrupt regional or global climate shifts. Ocean outgassing of CO_2 during warming periods may further amplify atmospheric concentrations (Lynch‐Stieglitz, 2016). Ocean acidification, driven by CO_2 absorption, also affects marine life and biochemical cycles, introducing feedback loops that reinforce climate change. Therefore, understanding ocean dynamics is crucial for any realistic appraisal of carbon's role.

Climate Modeling and Attribution Science

Climate models are mathematical simulations used to understand and predict the Earth's climate system (Manabe, 2019). These models typically incorporate radiative forcings like CO_2 concentration, solar radiation, volcanic activity, and land-use change. While CO_2 is a reliable and quantifiable input, the inclusion of other variables—like aerosols, water vapor, and ocean feedbacks—remains limited or uncertain.

Model calibration often involves fitting historical temperature data using known forcings, which can introduce circular reasoning if CO_2 is disproportionately emphasized (Vasiliades & Mastraftsis, 2023). For example, some models underperform when forced with only CO_2 but perform well when other variables are added, suggesting that carbon's explanatory power may be overstated (Held & Soden, 2000). Advances in attribution science now aim to disentangle overlapping signals from multiple forcings, but the uncertainties remain high. Incorporating emerging data from satellite measurements and machine learning may improve the granularity and accuracy of models.

The Influence of Policy and Economic Interests

Carbon' s prominence in the climate narrative aligns with global regulatory and market systems. The concept of a "carbon budget" simplifies complex climate dynamics into an economic metric (Paterson & P - Laberge, 2018). This approach has enabled the development of tools such as carbon pricing, emissions trading systems (ETS), and cap-and-trade schemes. These mechanisms provide clear economic incentives but may also narrow the scope of climate action.

Major industries, including fossil fuels and finance, have adapted to the carbon-centric model by investing in offsets, carbon capture technologies, and greenwashing strategies (Stavins, 2008). This commodification creates a political and financial ecosystem resistant to alternative narratives. A broader recognition of other climate drivers could disrupt these established systems, creating resistance even within the scientific community. Public narratives also shape funding priorities and research agendas, which can perpetuate the carbon-dominant paradigm.

Emerging Research and Paradigm Shifts

New research increasingly points to a multifactorial climate system. Studies have examined solar variability, cosmic ray flux, geomagnetic activity, and tectonic influences on long-term climate trends (Cronin et al., 2018). While none of these factors fully explain current warming patterns, their inclusion complicates the idea of a linear, carbon-dominated narrative.

Interdisciplinary approaches that combine atmospheric science, oceanography, ecology, and biogeochemistry are beginning to paint a more holistic picture. For instance, Earth system models now attempt to integrate feedbacks from permafrost melting, methane clathrates, and forest-climate interactions (Bonan & Doney, 2018). These approaches point out the importance of systems thinking rather than reductionist models focused solely on carbon. The role of emergent technologies—like advanced satellite monitoring and high-resolution climate modeling—may accelerate paradigm shifts in climate science.

Conclusion: Rethinking Carbon's Centrality

Carbon dioxide is undeniably a key player in anthropogenic climate change. However, its elevation to the status of primary villain may oversimplify a multifactorial phenomenon. The hypothesis proposed here is not to exonerate carbon but to question whether its dominance in climate discourse and policy truly reflects its proportional impact. By expanding our analytical frameworks and embracing a broader spectrum of climate forcings—such as methane, nitrous oxide, aerosols, land-use change, and ocean dynamics—we can develop more nuanced and effective mitigation strategies. A diversified understanding of global warming—one that sees carbon not as the sole cause but as part of a complex systemic interaction—may better equip humanity to navigate the uncertain future of a changing planet. Embracing scientific humility and integrative thinking will be essential in developing policies and technologies that are both adaptive and resilient in the face of climate complexity.■

Received: March 20, 2025 | Revised: April 20, 2025 | Accepted: April 25, 2025

References

Babin, A., Vaneeckhaute, C., & Iliuta, M. C. (2021). Potential and challenges of bioenergy with carbon capture and storage as a carbon-negative energy source: A review. Biomass and Bioenergy, 146, 105968. DOI: https://doi.org/10.1016/j.biombioe.2021.105968

Bauer, S. E., Tsigaridis, K., Faluvegi, G., Nazarenko, L., Miller, R. L., Kelley, M., & Schmidt, G. (2022). The turning point of the aerosol era. Journal of Advances in Modeling Earth Systems, 14(12). DOI: https://doi.org/10.1029/2022ms003070

Bonan, G. B., & Doney, S. C. (2018). Climate, ecosystems, and planetary futures: The challenge to predict life in Earth system models. Science, 359(6375). DOI: https://doi.org/10.1126/science.aam8328

Chlek, P., & Coakley, J. A. (1974). Aerosols and climate. Science, 183(4120), 75–77. DOI: https://doi.org/10.1126/science.183.4120.75

Chung, E., Soden, B., Sohn, B. J., & Shi, L. (2014). Upper-tropospheric moistening in response to anthropogenic warming. Proceedings of the National Academy of Sciences, 111(32), 11636–11641. DOI: https://doi.org/10.1073/pnas.1409659111

Cohen-Shields, N., Sun, T., Hamburg, S. P., & Ocko, I. B. (2023). Distortion of sectoral roles in climate change threatens climate goals. Frontiers in Climate, 5. DOI: https://doi.org/10.3389/fclim.2023.1163557

Cronin, J., Anandarajah, G., & Dessens, O. (2018). Climate change impacts on the energy system: a review of trends and gaps. Climatic Change, 151(2), 79–93. DOI: https://doi.org/10.1007/s10584-018-2265-4

DeVries, T., Holzer, M., & Primeau, F. (2017). Recent increase in oceanic carbon uptake driven by weaker upper-ocean overturning. Nature, 542(7640), 215–218. DOI: https://doi.org/10.1038/nature21068

Fagodiya, R. K., Pathak, H., Kumar, A., Bhatia, A., & Jain, N. (2017). Global temperature change potential of nitrogen use in agriculture: A 50-year assessment. Scientific Reports, 7(1). DOI: https://doi.org/10.1038/srep44928

Fahey, D., Doherty, S. J., Hibbard, K. A., Romanou, A., & Taylor, P. C. (2017). Physical drivers of climate change. U.S. Department of Commerce. https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1572&context=usdeptcommercepub

Friedlingstein, P., O'Sullivan, M., Jones, M. W., Andrew, R. M., Gregor, L., Hauck, J., Quéré, C. L., Luijkx, I. T., Olsen, A., Peters, G. P., Peters, W., Pongratz, J., Schwingshackl, C., Sitch, S., Canadell, J. G., Ciais, P., Jackson, R. B., Alin, S. R., Alkama, R., . . . Zheng, B. (2022). Global Carbon Budget 2022. Earth System Science Data, 14(11), 4811–4900. DOI: https://doi.org/10.5194/essd-14-4811-2022

Held, I. M., & Soden, B. J. (2000). Water vapor feedback and global warming. Annual Review of Energy and the Environment, 25(1), 441–475. DOI: https://doi.org/10.1146/annurev.energy.25.1.441

Krueger, L. A., Koester, L. R., Jones, D. F., & Spangler, D. A. (2023). Carbon dioxide equivalent emissions from corn silage fermentation. Frontiers in Microbiology, 13. DOI: https://doi.org/10.3389/fmicb.2022.1092315

Kweku, D., Bismark, O., Maxwell, A., Desmond, K., Danso, K., Oti-Mensah, E., Quachie, A., & Adormaa, B. (2018). Greenhouse Effect: Greenhouse gases and their impact on global warming. Journal of Scientific Research and Reports, 17(6), 1–9. DOI: https://doi.org/10.9734/jsrr/2017/39630

Lynch-Stieglitz, J. (2016). The Atlantic Meridional overturning circulation and abrupt climate change. Annual Review of Marine Science, 9(1), 83–104. DOI: https://doi.org/10.1146/annurev-marine-010816-060415

Manabe, S. (2019). Role of greenhouse gas in climate change. Tellus a Dynamic Meteorology and Oceanography, 71(1), 1620078. DOI: https://doi.org/10.1080/16000870.2019.1620078

Papakonstantinou, G. I., Voulgarakis, N., Terzidou, G., Fotos, L., Giamouri, E., & Papatsiros, V. G. (2024). Precision Livestock farming Technology: Applications and challenges of animal welfare and climate change. Agriculture, 14(4), 620. DOI: https://doi.org/10.3390/agriculture14040620

Paterson, M., & P‐Laberge, X. (2018). Political economies of climate change. Wiley Interdisciplinary Reviews Climate Change, 9(2). DOI: https://doi.org/10.1002/wcc.506

Pitman, A., & De Noblet-Ducoudré, N. (2011). Human effects on climate through Land-Use-Induced Land-Cover change. In Elsevier eBooks (pp. 77–95). DOI: https://doi.org/10.1016/b978-0-12-386917-3.00004-x

Ricaud, P., Carminati, F., Courcoux, Y., Pellegrini, A., Attié, J., Amraoui, L. E., Abida, R., Genthon, C., August, T., & Warner, J. (2013). Statistical analyses and correlation between tropospheric temperature and humidity at Dome C, Antarctica. Antarctic Science, 26(3), 290–308. DOI: https://doi.org/10.1017/s0954102013000564

Stammer, D., Bracco, A., AchutaRao, K., Beal, L., Bindoff, N. L., Braconnot, P., Cai, W., Chen, D., Collins, M., Danabasoglu, G., Dewitte, B., Farneti, R., Fox-Kemper, B., Fyfe, J., Griffies, S. M., Jayne, S. R., Lazar, A., Lengaigne, M., Lin, X., . . . Vialard, J. (2019). Ocean climate observing requirements in support of climate research and climate information. Frontiers in Marine Science, 6. DOI: https://doi.org/10.3389/fmars.2019.00444

Stavins, R. N. (2008). Addressing climate change with a comprehensive US cap-and-trade system. Oxford Review of Economic Policy, 24(2), 298–321. DOI: https://doi.org/10.1093/oxrep/grn017

Taylor, D. (1997). Seeing the forests for the more than the trees. Environmental Health Perspectives, 105(11), 1186–1191. DOI: https://doi.org/10.1289/ehp.9710511 86

Vasiliades, L., & Mastraftsis, I. (2023). A Monthly Water Balance Model for Assessing Streamflow Uncertainty in Hydrologic Studies. Environmental Sciences Proceedings, 39. DOI:

https://doi.org/10.3390/ecws-7-14192

Zhang, B. (2020). The effect of aerosols to climate change and society. Journal of Geoscience and Environment Protection, 08(08), 55–78. DOI: https://doi.org/10.4236/gep.2020.88006