FRANKFURT UNIVERSITY OF APPLIED SCIENCES

Environmental Assessment

Fachbereich 2 Informatik und Ingenieurwissenschaften

Organizational matters

- office hours: Wednesday 1:30 - 2:30 pm, 8-110
- email: sebastian.schaefer@fb2.fra-uas.de

- lecture (with integrated exercises): 15 sessions until February 7
- final exam: 90 minutes

FRANKFURT UNIVERSITY OF APPLIED SCIENCES

Outline

Related literature

- Stern, N.: The Economics of Climate Change – The Stern Review, Cambridge University Press, New York, 2007.
- Endres, A., Radke, V.: Economics for Environmental Studies, 2nd ed., Springer, Berlin Heidelberg, 2018.
- Sue Wing, I., Ellerman, A.D., Song, J., 2009. Absolute versus intensity limits for CO_2 emission control: performance under uncertainty. In: The design of climate policy. MIT Press, Cambridge (Massachusetts). In: CESIfo Working Paper No. 2749.
- Schäfer, S. Decoupling the EU ETS from subsidized renewables and other demand side effects: lessons from the impact of the EU ETS on CO_2 emissions in the German electricity sector. *Energy Policy* 2019, **133**, 110858.

Environment and economics

Figure: Forest near Siegen; source: Frank Haubenschild `https://www.haubenschild.de/waldsterben/`

The Greenhouse Effect

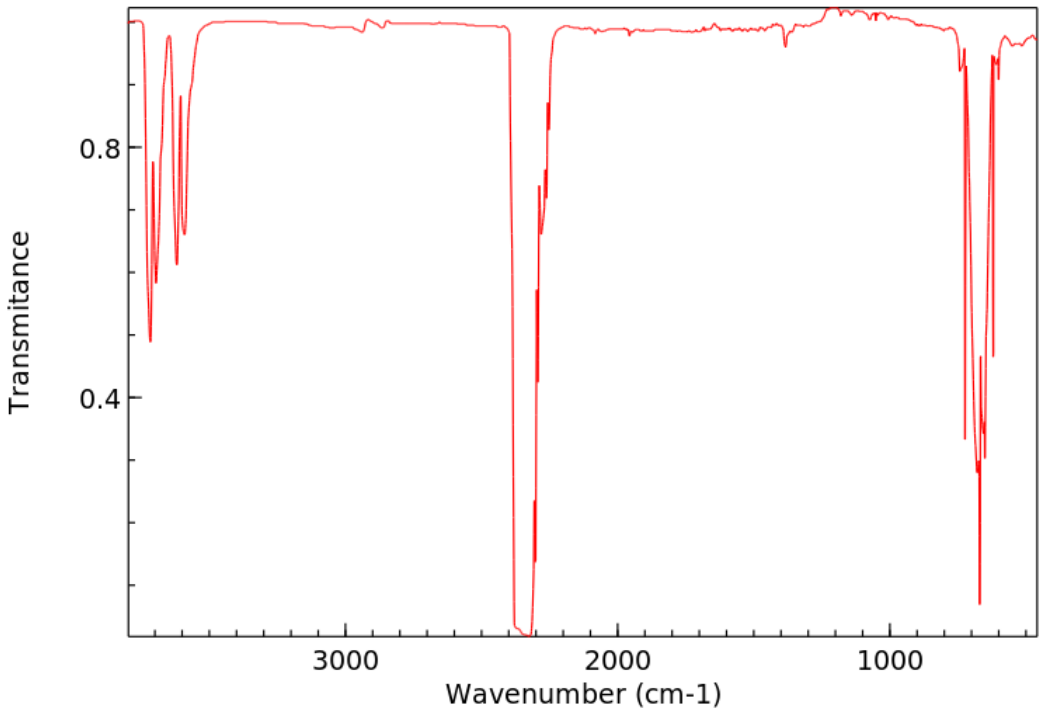


Figure: Infrared spectrum of CO_2; source: NIST Chemistry Webook `https://webbook.nist.gov/cgi/cbook.cgi?Spec=C124389&Index=1&Type=IR&Large=on`

- transmittance of radiation with low wave length
- interaction with matter leads to transformation into heat radiation (infrared)
- absorption of infrared radiation with longer wave lengths

The Greenhouse Effect

Figure: Svante August Arrhenius (1859 – 1927); source: Wikipedia

- 1827 Jean Baptiste Fourier understood the atmosphere's asymmetry with respect to incoming light and outgoing infrared.
- 1859 John Tyndall presented a *"Note on the Transmission of Radiant Heat through Gaseous Bodies"*.
- 1896 Svante Arrhenius calculated that a doubling of CO_2 in the atmosphere would induce an average surface warming of 1°C.

Climate Change in the general public

- The Intergovernmental Panel on Climate Change (IPCC) was founded on December 6, 1988 to provide policy makers with regular scientific assessments
- Core of the IPCC are its assessment reports (AR) divided into several working groups (the IPCC does not do any own research)
- The first AR was published in 1990
- The latest AR is from 2023

IPCC

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

WMO

UNEP

IPCC – First Assessment Report

"*We are certain of the following: there is a **natural greenhouse effect** which already keeps the Earth warmer than it would otherwise be; **emissions resulting from human activities** are substantially increasing the atmospheric concentrations of the greenhouse gases: carbon dioxide, methane, chlorofluorocarbons (CFCs) and nitrous oxide.*" (IPCC, 1990)

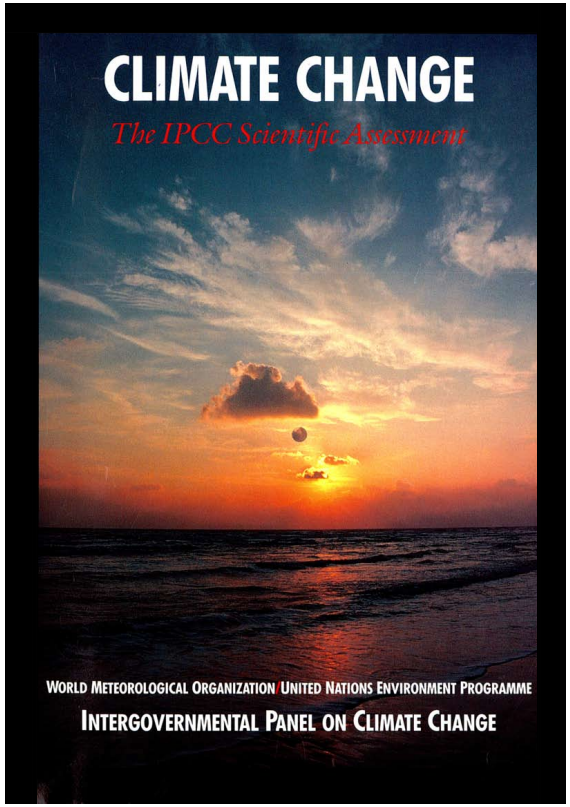


Figure: Cover of the First Assessment Report of the IPCC in 1990

IPCC – Second Assessment Report

"*The balance of evidence* ***suggests a discernible human influence*** *on global climate [...] Our ability to quantify the human influence on global climate is currently limited because the expected signal is still emerging from the noise of natural variability, and because there are uncertainties in key factors. [...] Nevertheless, the balance of evidence suggests that there is a discernible human influence on global climate.*" (IPCC, 1995)

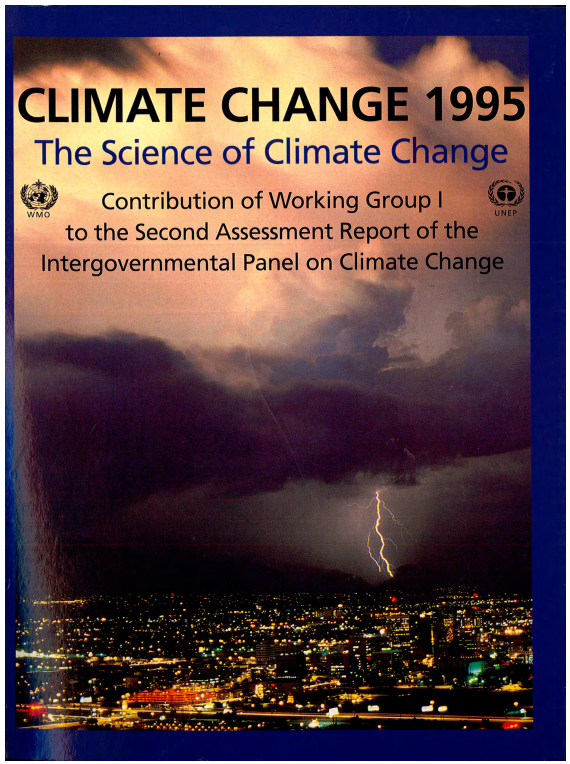


Figure: Cover of the Second Assessment Report of the IPCC in 1995

IPCC – Third Assessment Report

"*There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities. [...] In the light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is* ***likely*** *to have been due to the increase in greenhouse gas concentrations.*"
(IPCC, 2001)

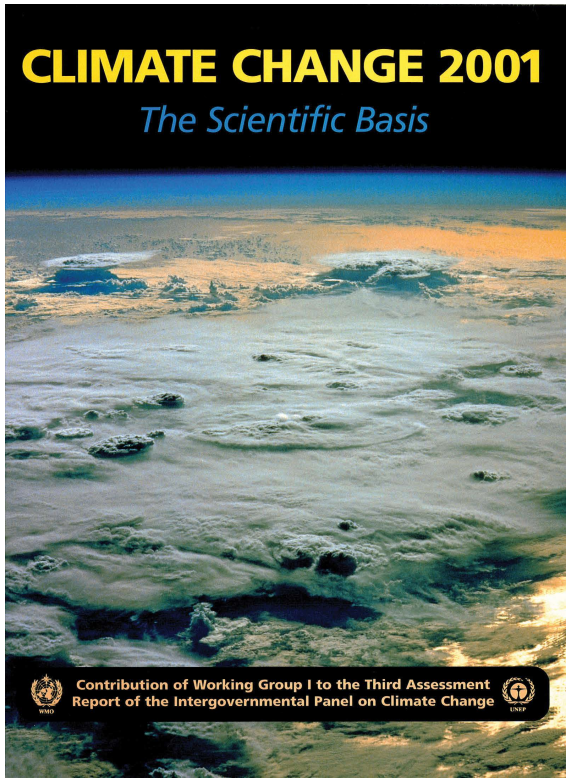


Figure: Cover of the Third Assessment Report of the IPCC in 2001

IPCC – Fourth Assessment Report

"*Most of the observed increase in global average temperatures since the mid-20th century is* ***very likely*** *due to the observed increase in anthropogenic greenhouse gas concentrations.*" (IPCC, 2007)

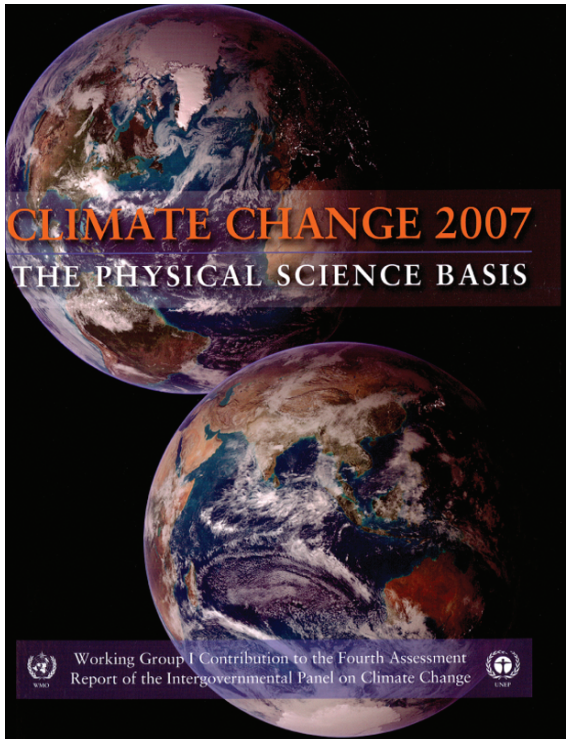


Figure: Cover of the Fourth Assessment Report of the IPCC in 2007

IPCC – Fifth Assessment Report

"*Human influence on the climate system is clear, and recent anthropogenic emissions of green-house gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems. [...] It is* ***extremely likely*** *that human influence has been the* ***dominant cause*** *of the observed warming since the mid-20th century.*" (IPCC, 2013)

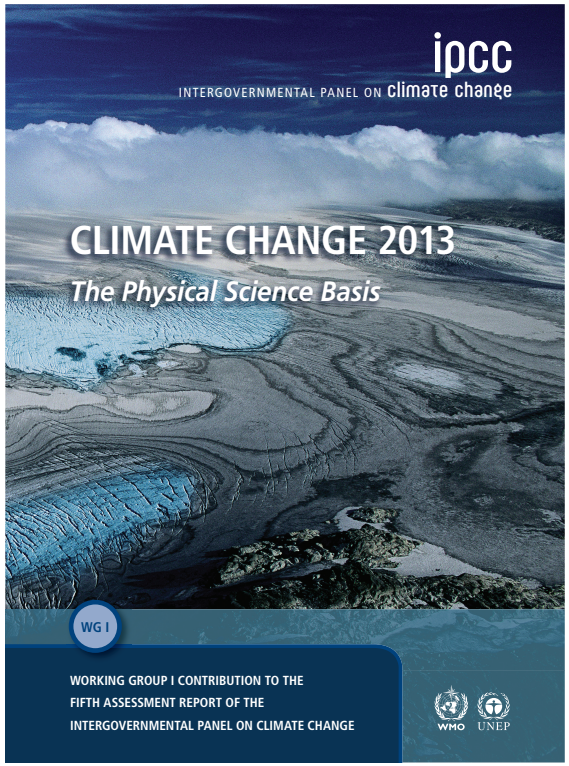


Figure: Cover of the Fifth Assessment Report of the IPCC in 2013

IPCC – Sixth Assessment Report

"*It is **unequivocal** that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred. [...] The likely range of total human-caused global surface temperature increase from 1850-1900 to 2010-2019 is 0.8°C to 1.3°C, with a best estimate of 1.07°C.*"
(IPCC, 2021)

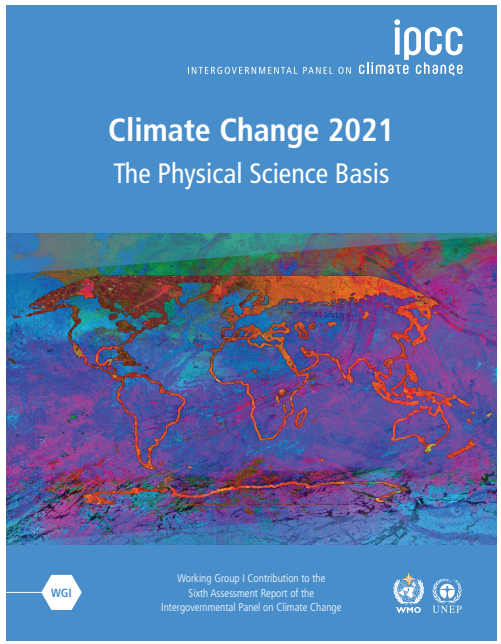


Figure: Cover of the Sixth Assessment Report of the IPCC

Natural carbon sinks

- Contact of CO_2 and the ocean

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

- Protonation of water (decreasing pH value)

$$H_2CO_3 + H_2O \rightleftharpoons HCO_3^- + H_3O^+$$

- Reduction of carbonate ions (problems for corals and shells)

$$CO_3^{2-} + H_3O^+ \rightleftharpoons HCO_3^- + H_2O$$

- Carbon weathering

$$2\,CO_2 + H_2O + CaSiO_3 \rightleftharpoons Ca^{2+} + 2\,HCO_3^- + SiO_2$$

Changes in global surface temperature relative to 1850-1900

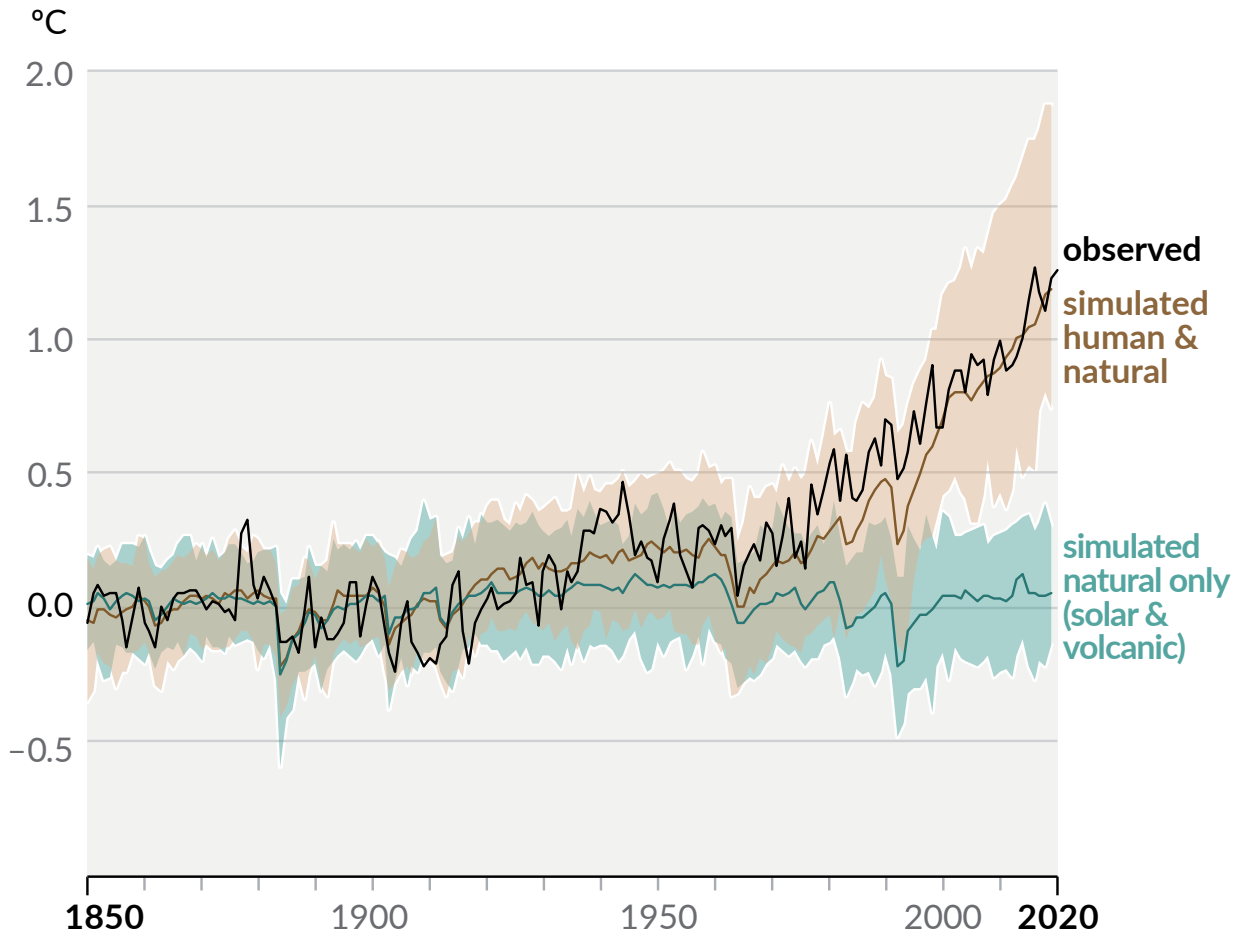


Figure: Change in global surface temperature (annual average) as observed and simulated using human and natural (brown) and only natural (mint) factors (both 1850-2020); source: IPCC (2021).

Changes in global surface temperature relative to 1850-1900

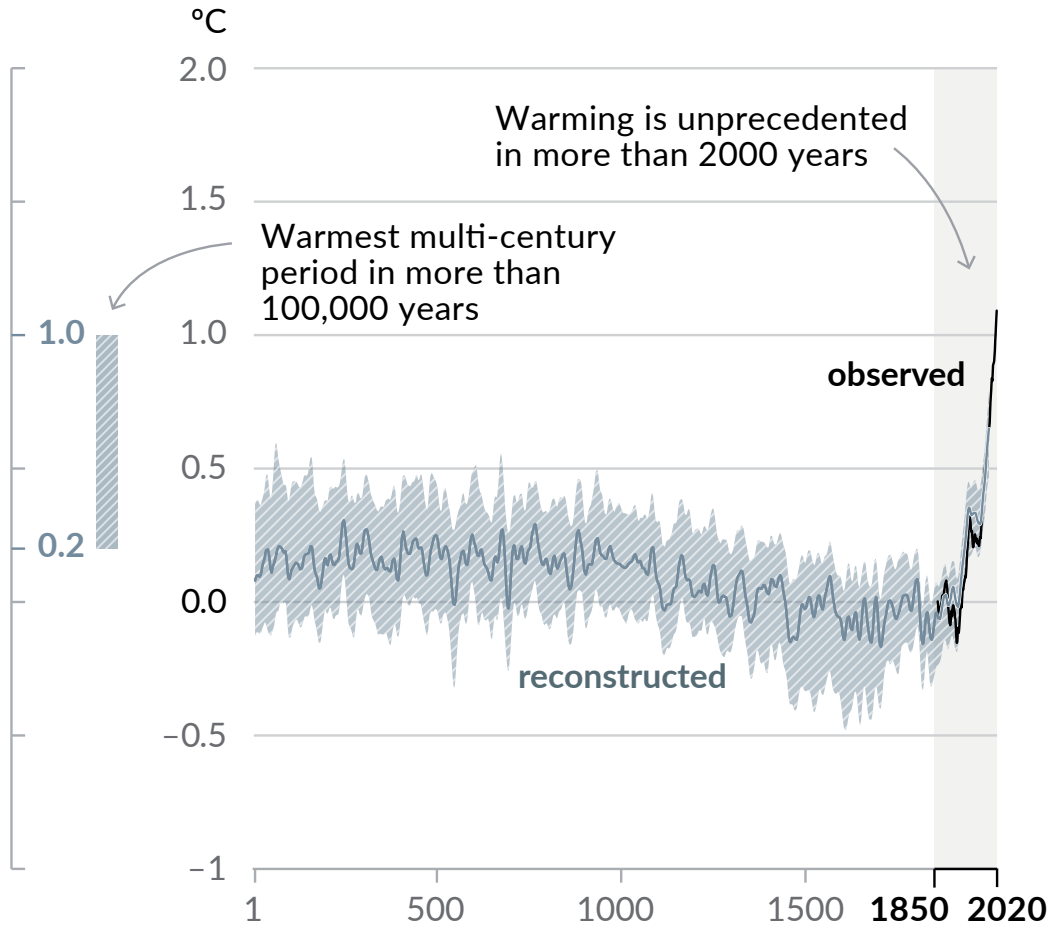
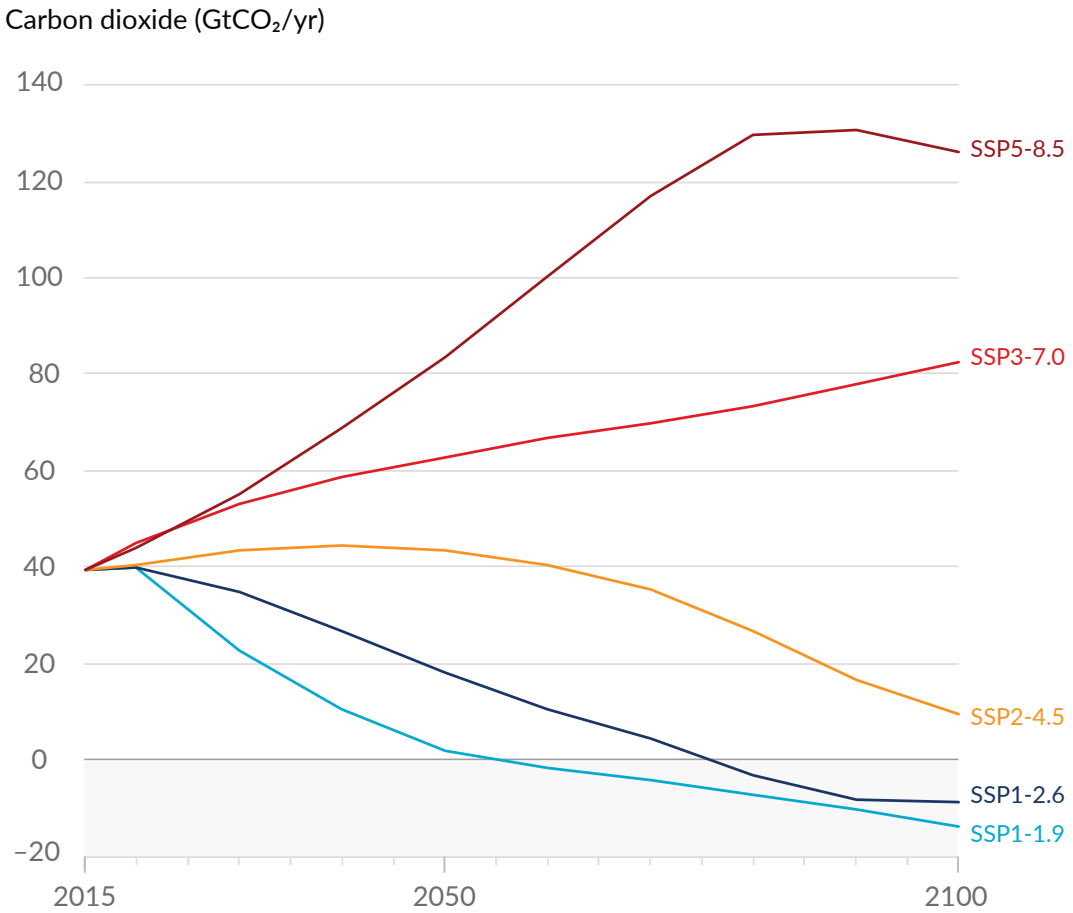


Figure: Change in global surface temperature (decadal average) as reconstructed (1-2000, grey) and observed (1850-2020, black); source: IPCC (2021).

Emission change according to scenarios



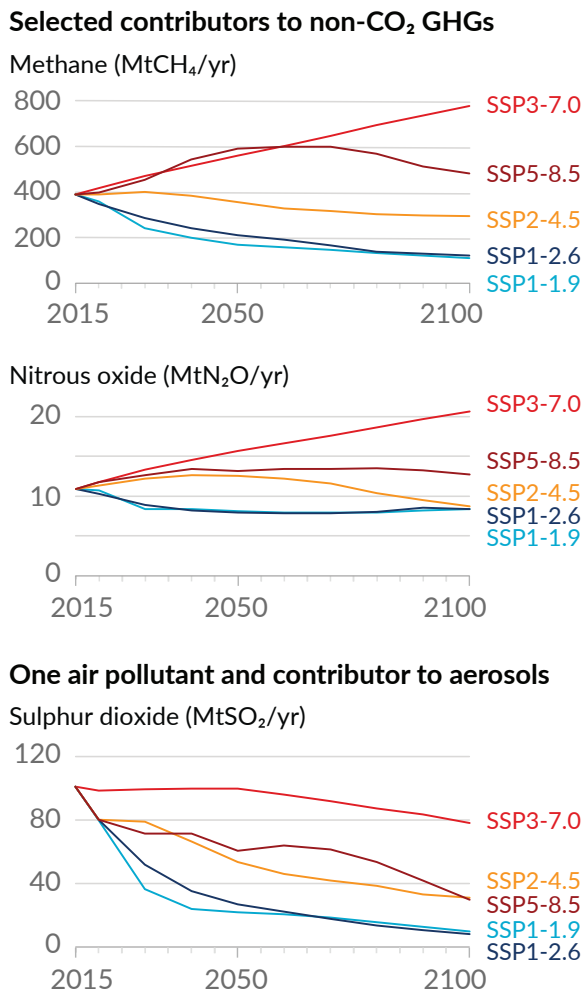


Figure: Future annual emissions of CO_2 (left) and of a subset of key non-CO_2 drivers (right), across five illustrative scenarios; source: IPCC (2021).

Changes in global surface temperatures according to scenarios

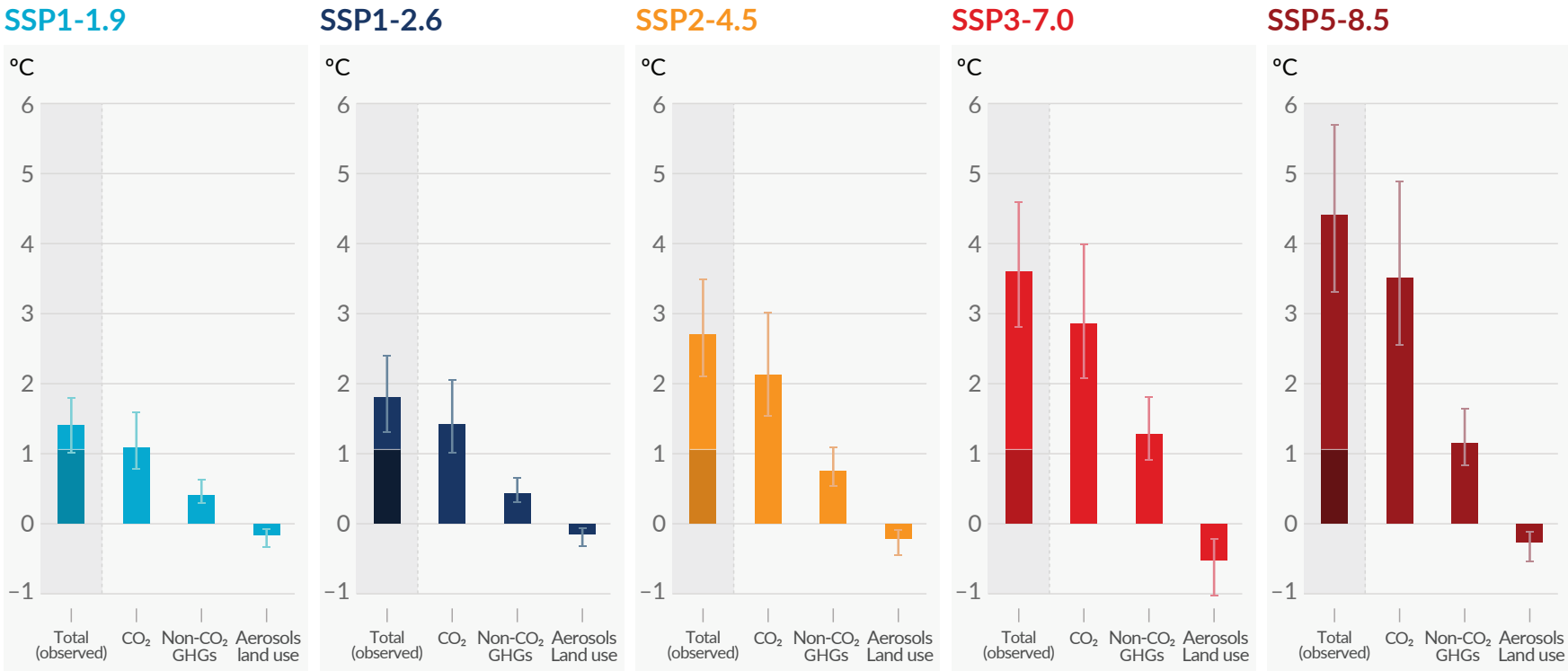


Figure: Contribution to global surface temperature increase from different emissions, with a dominant role of CO_2 emissions. Change in global surface temperature in 2081-2100 relative to 1850-1900 (°C). Total warming (observed warming to date in darker shade), warming from CO_2, warming from non-CO_2 GHGs and cooling from changes in aerosols and land use; source: IPCC (2021).

Changes in global surface temperatures according to scenarios

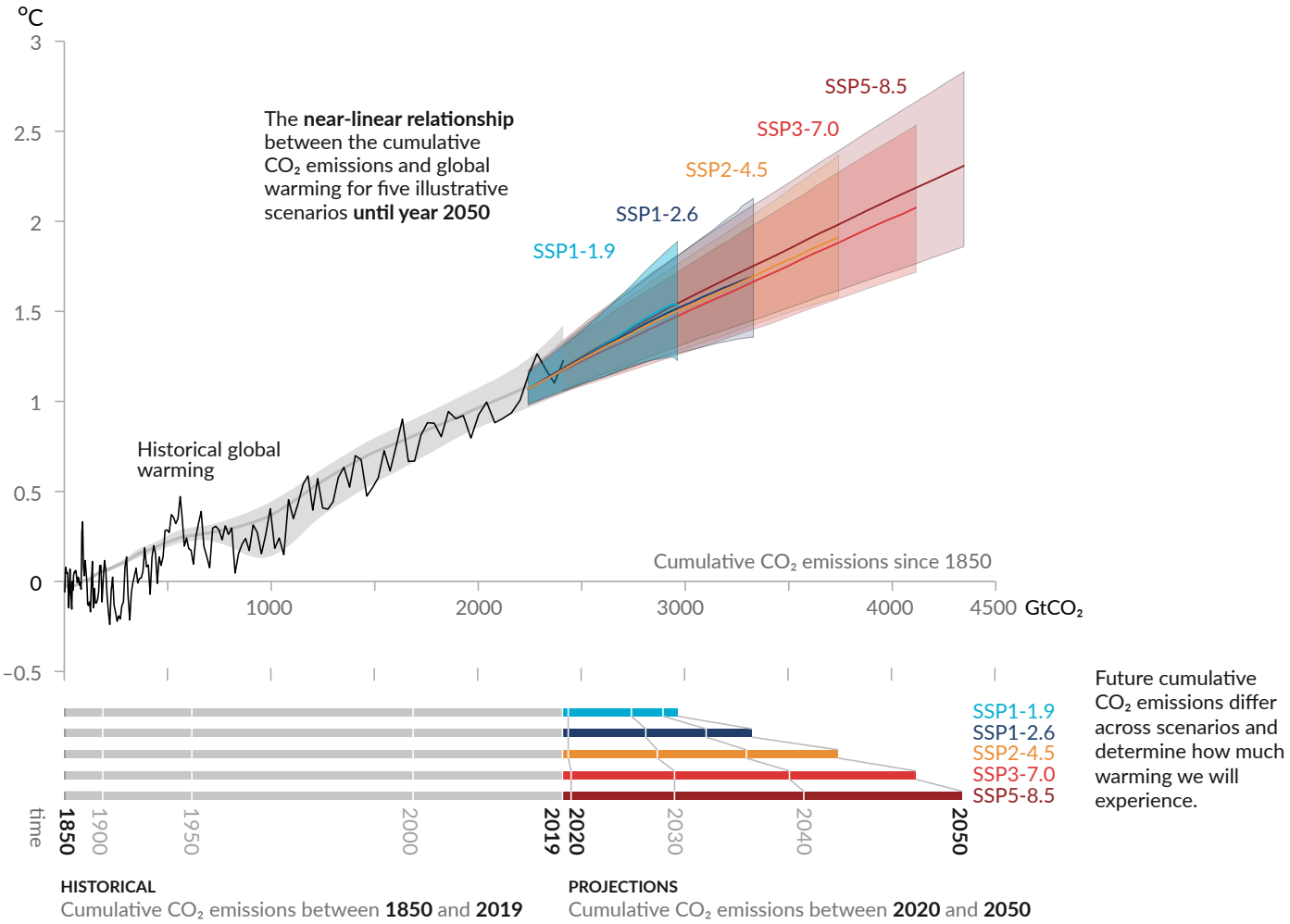


Figure: Global surface temperature increase since 1850-1900 (°C) as a function of cumulative CO_2 emissions ($GtCO_2$; source: IPCC (2021).

Scenarios for the global surface temperature

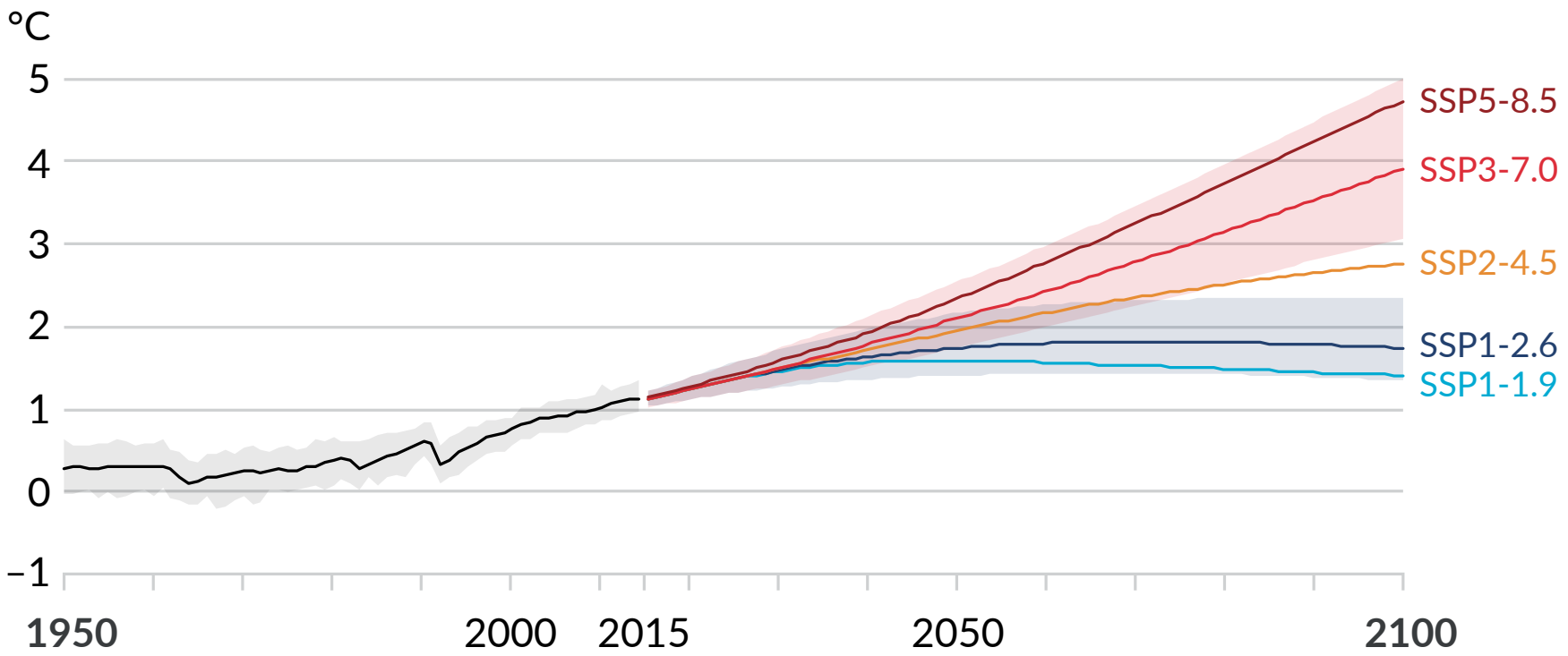


Figure: Global surface temperature change relative to 1850-1900; source: IPCC (2021).

Reconstructed historic temperature development

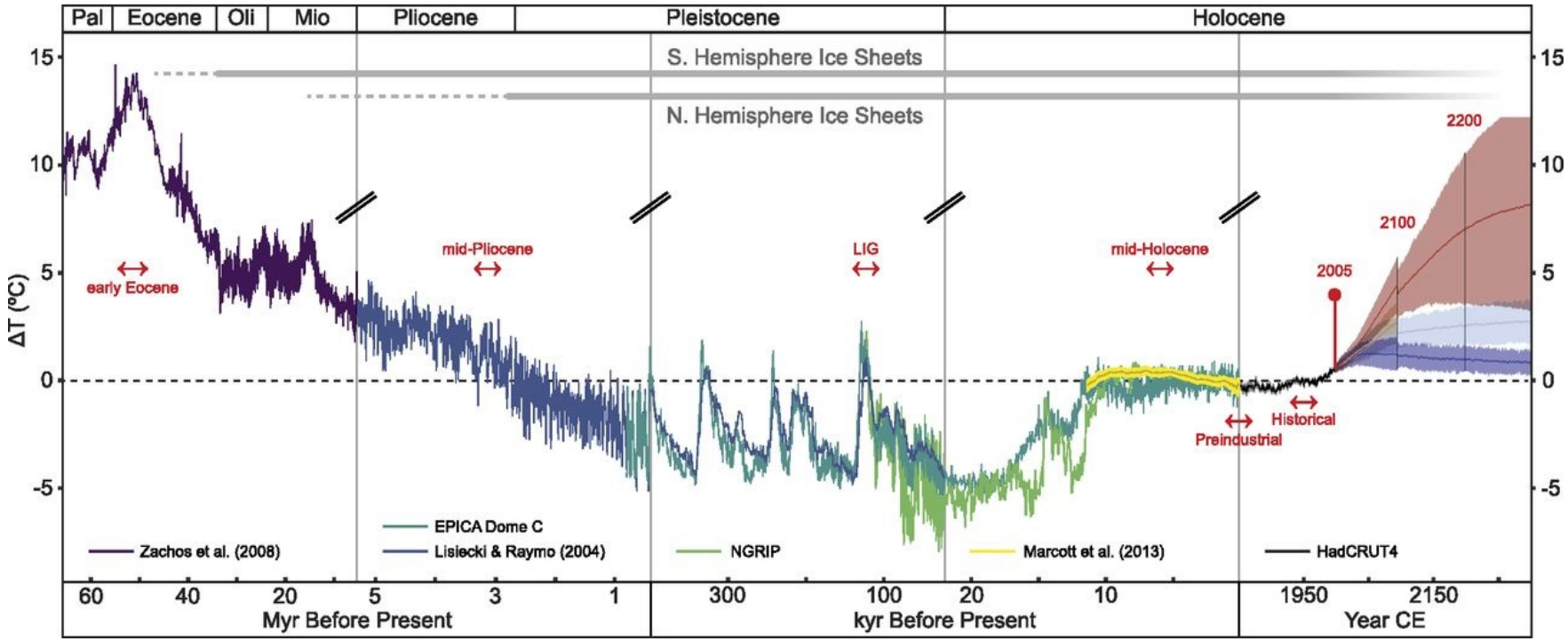


Figure: Temperature trends for the past 65 million years together with scenarios for future temperature development; source: Burke *et al.* (2018).

CO_2 in the atmosphere

"Carbon dioxide cycles between the atmosphere, oceans and land biosphere. Its removal from the atmosphere involves a range of processes with different time scales. About 50% of a CO_2 increase will be removed from the atmosphere within 30 years, and a further 30% will be removed within a few centuries. The remaining 20% may stay in the atmosphere for many thousands of years" (Denman *et al.*, 2007).

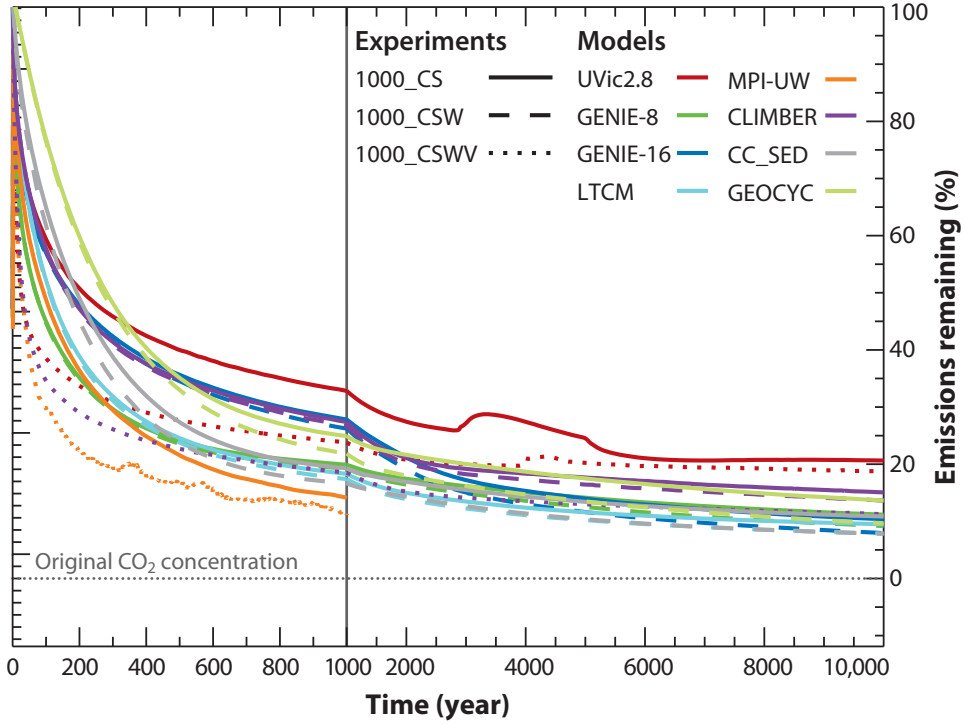


Figure: Atmospheric CO_2 trajectories for the 10,000-year duration of certain climate model simulations (Archer *et al.*, 2009)

Projected changes in extremes

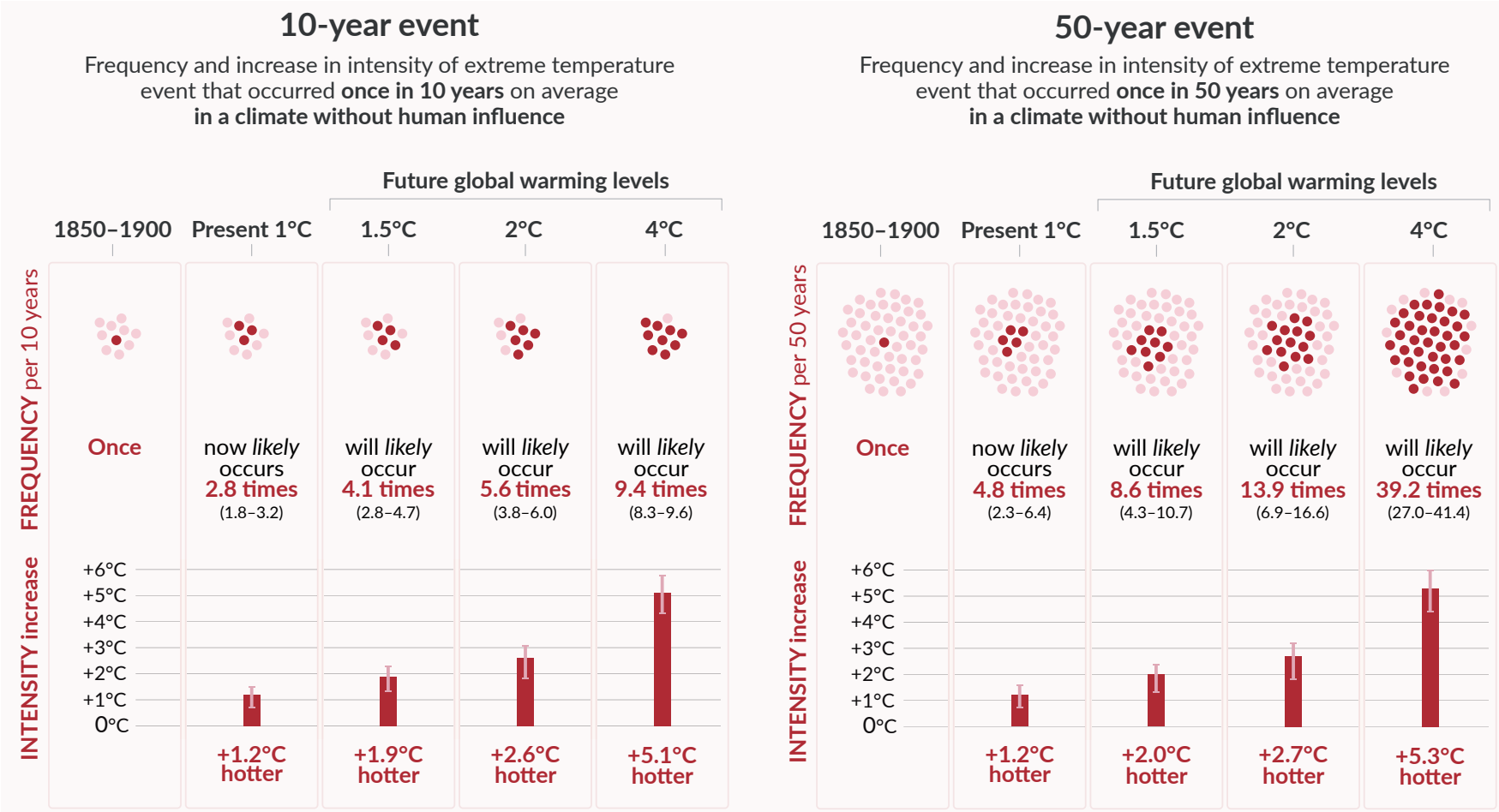


Figure: Hot temperature extremes over land; source: IPCC (2021).

Projected changes in extremes

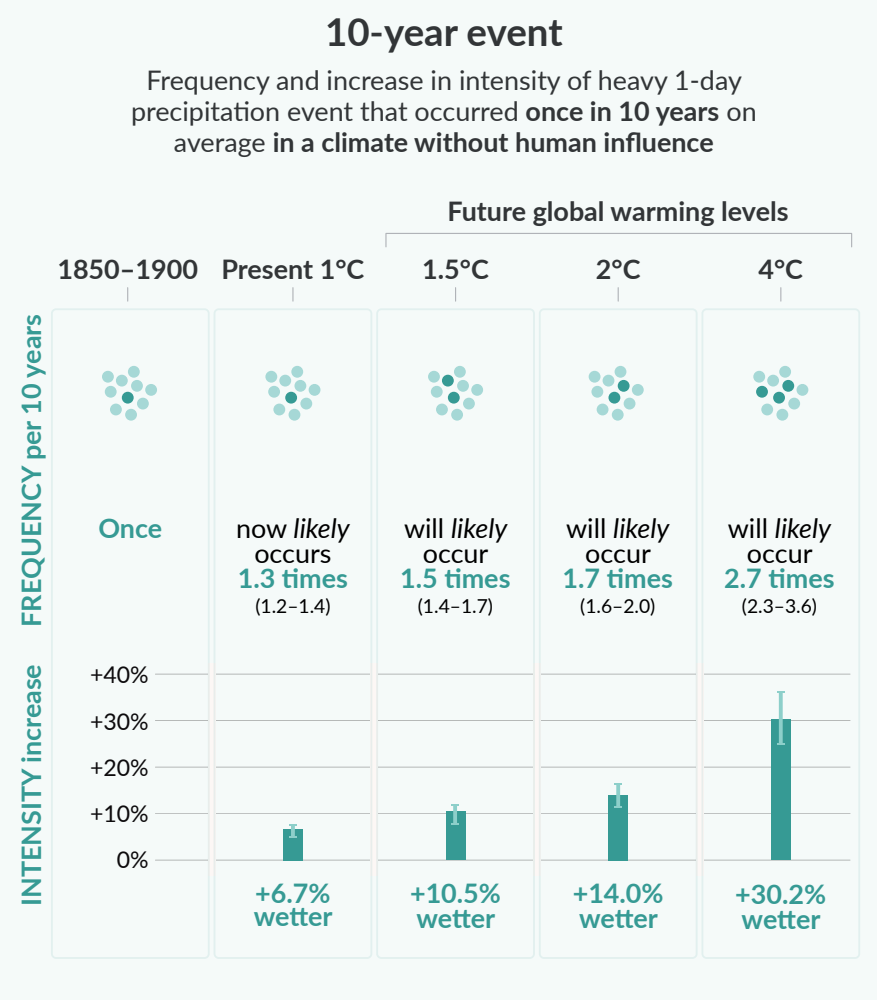


Figure: Heavy precipitation over land; source: IPCC (2021).

Projected changes in extremes

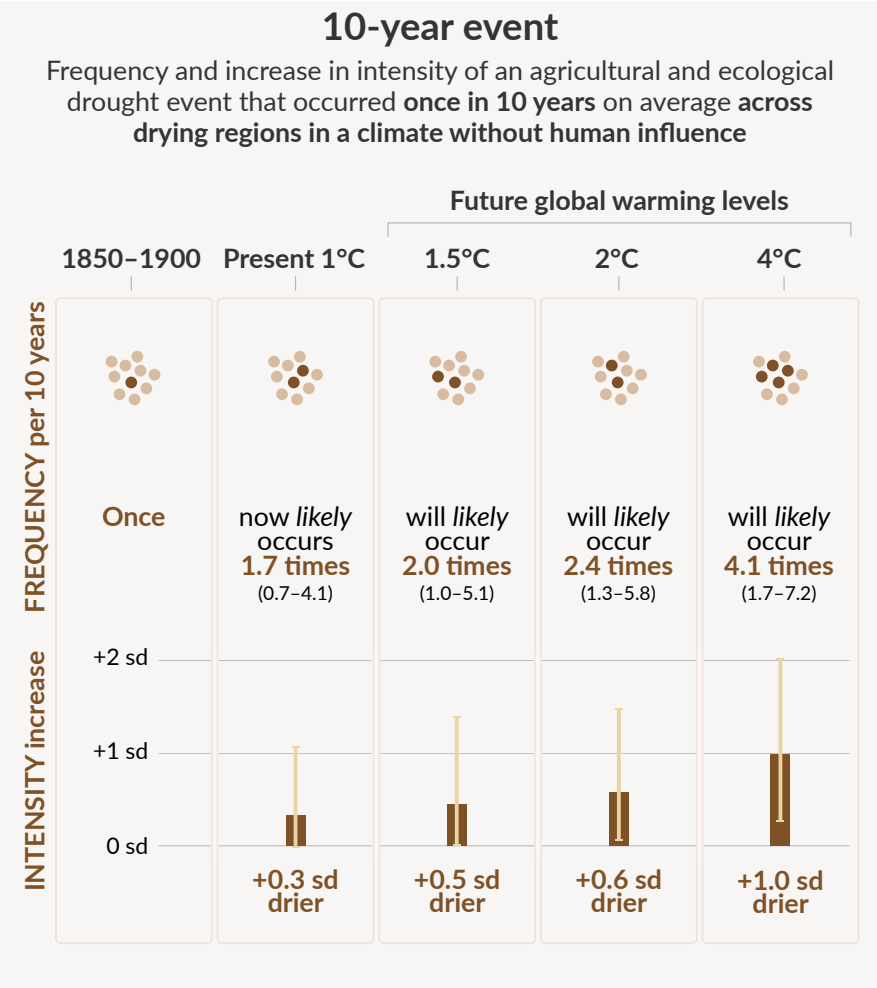
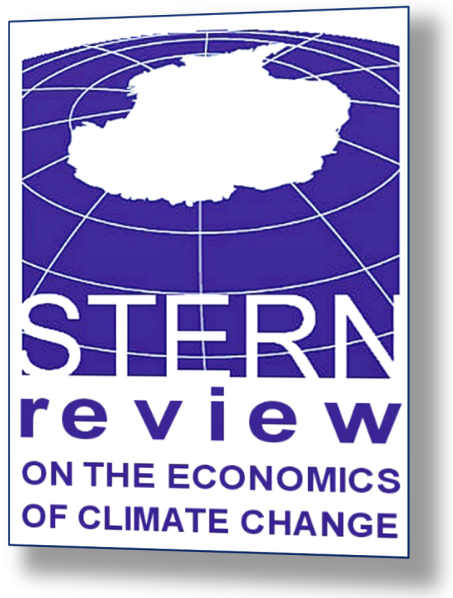


Figure: Agricultural and ecological droughts in drying regions; source: IPCC (2021).

The Stern Review

- "*The benefits of strong and early action far outweigh the economic costs of not acting [...] So prompt and strong action is clearly warranted.*" (Stern, 2007)
- "*Climate change is the greatest market failure the world has ever seen, and it interacts with other market imperfections [...] A range of options exists to cut emissions; strong, deliberate policy action is required to motivate their take-up.*" (Stern, 2007)
- broad discussion of the discount factor...



Development of CO_2 emissions

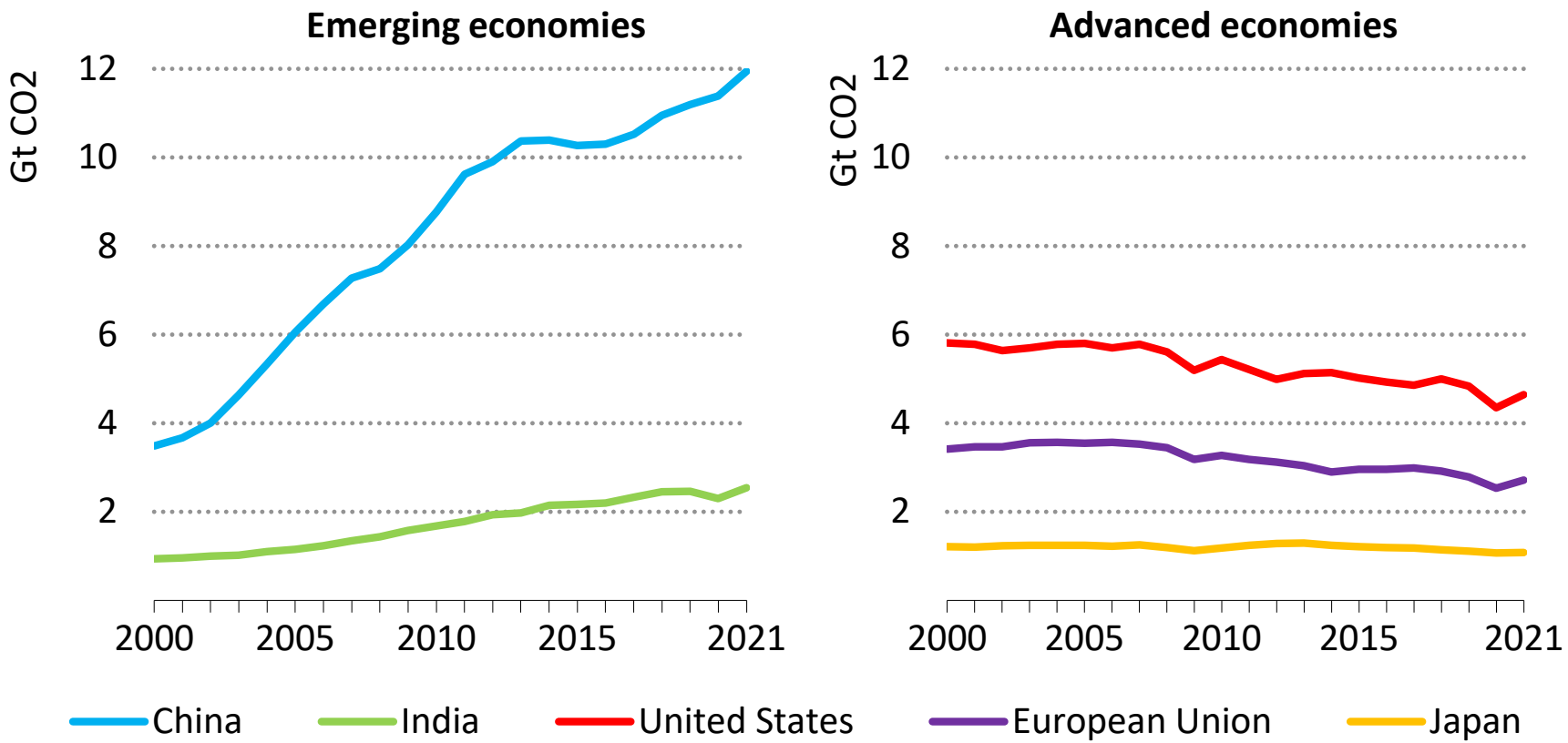


Figure: CO_2 emissions in selected emerging and advanced economies, 2000-2021; source: IEA (2022).

Cumulative CO_2 emissions worldwide

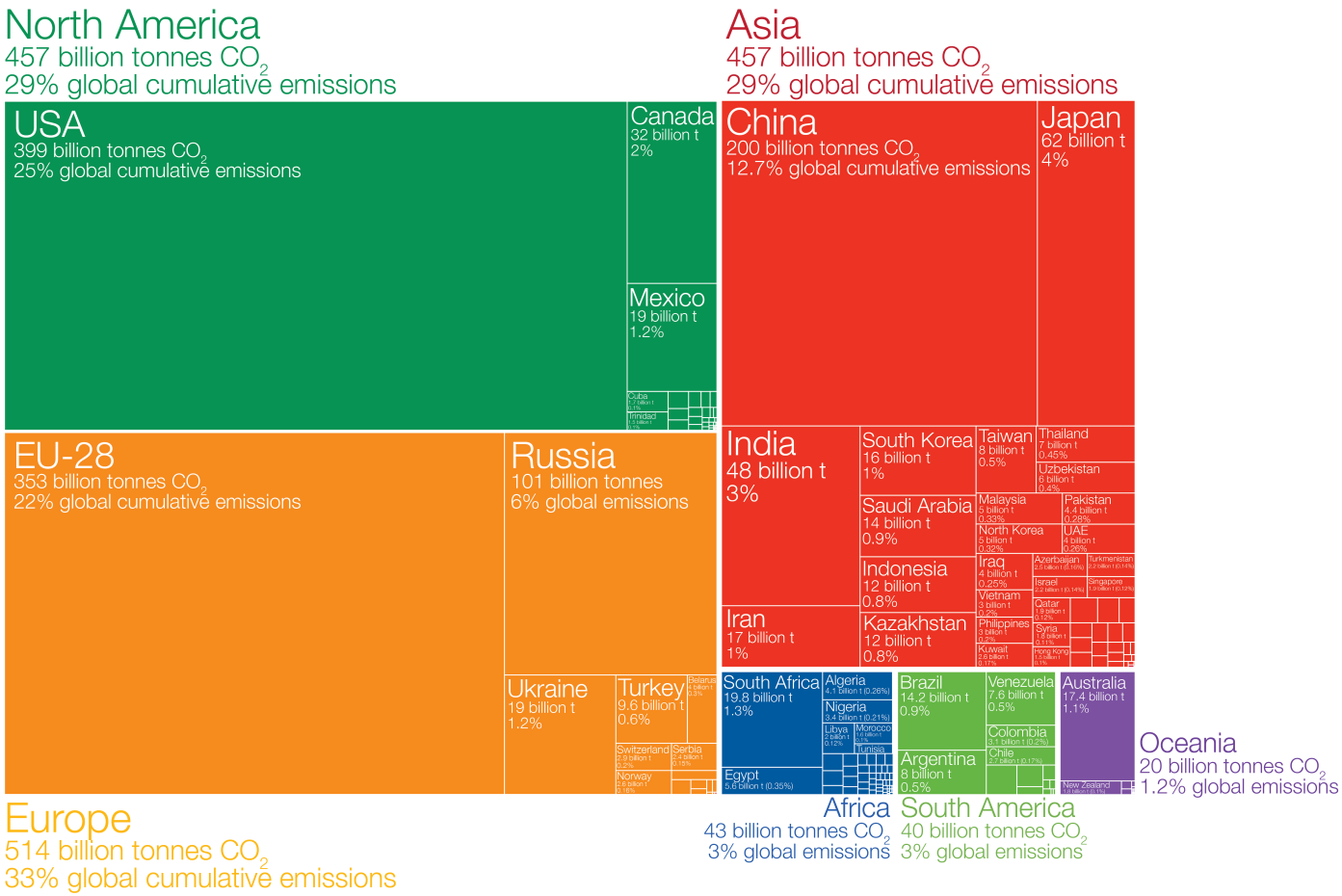


Figure: Cumulative CO_2 emissions over the period from 1751 to 2017. Figures are based on production-based emissions which measure CO_2 produced domestically from fossil fuel combustion and cement and do not correct for embedded in trade (i.e. consumption-based). Emissions from international travel are not included; source: OurWorldinData.org `https://ourworldindata.org/contributed-most-global-co2`.

Development of per capita CO_2 emissions

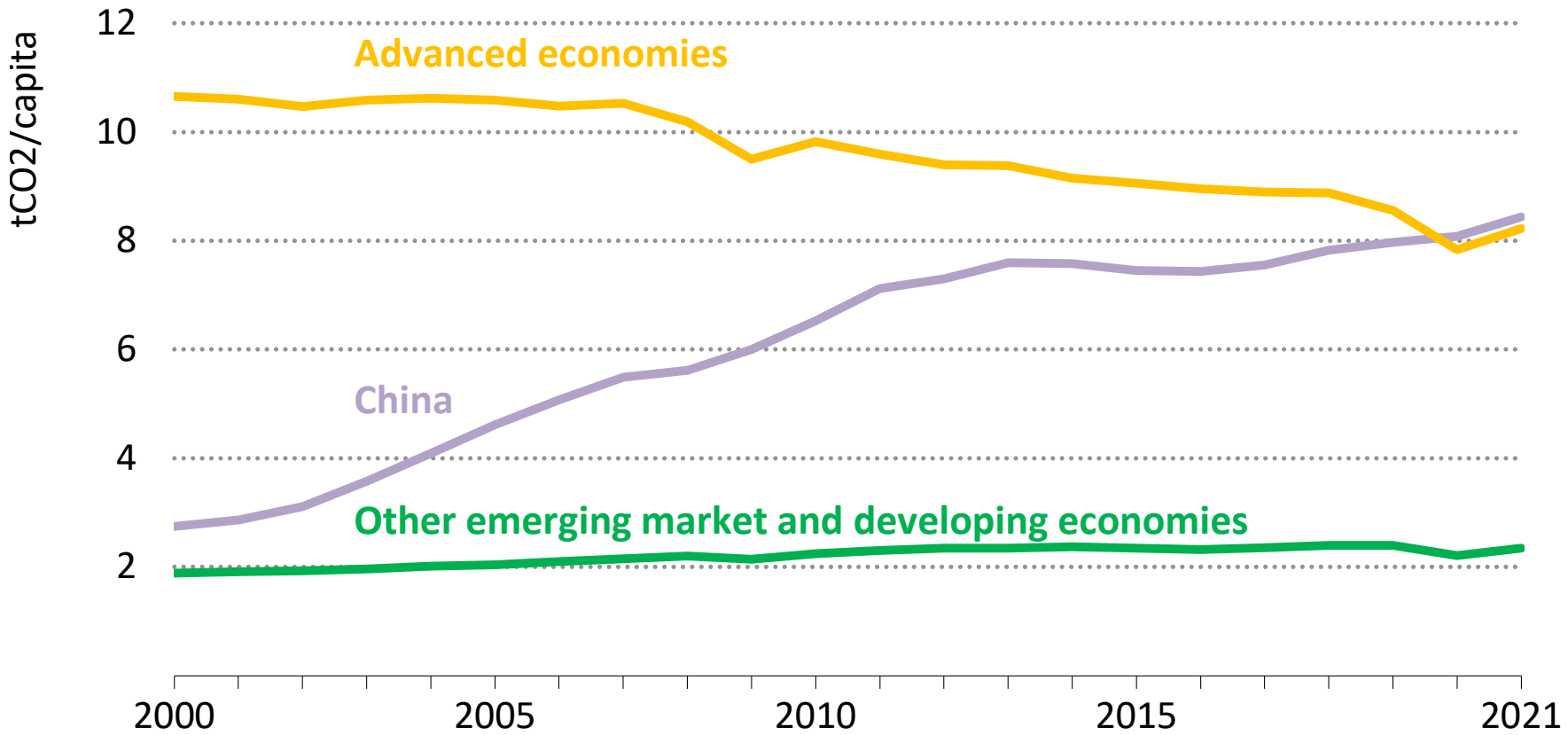


Figure: CO_2 emissions per capita by region, 2000-2021; source: IEA (2022).

Development of CO_2 emissions per output

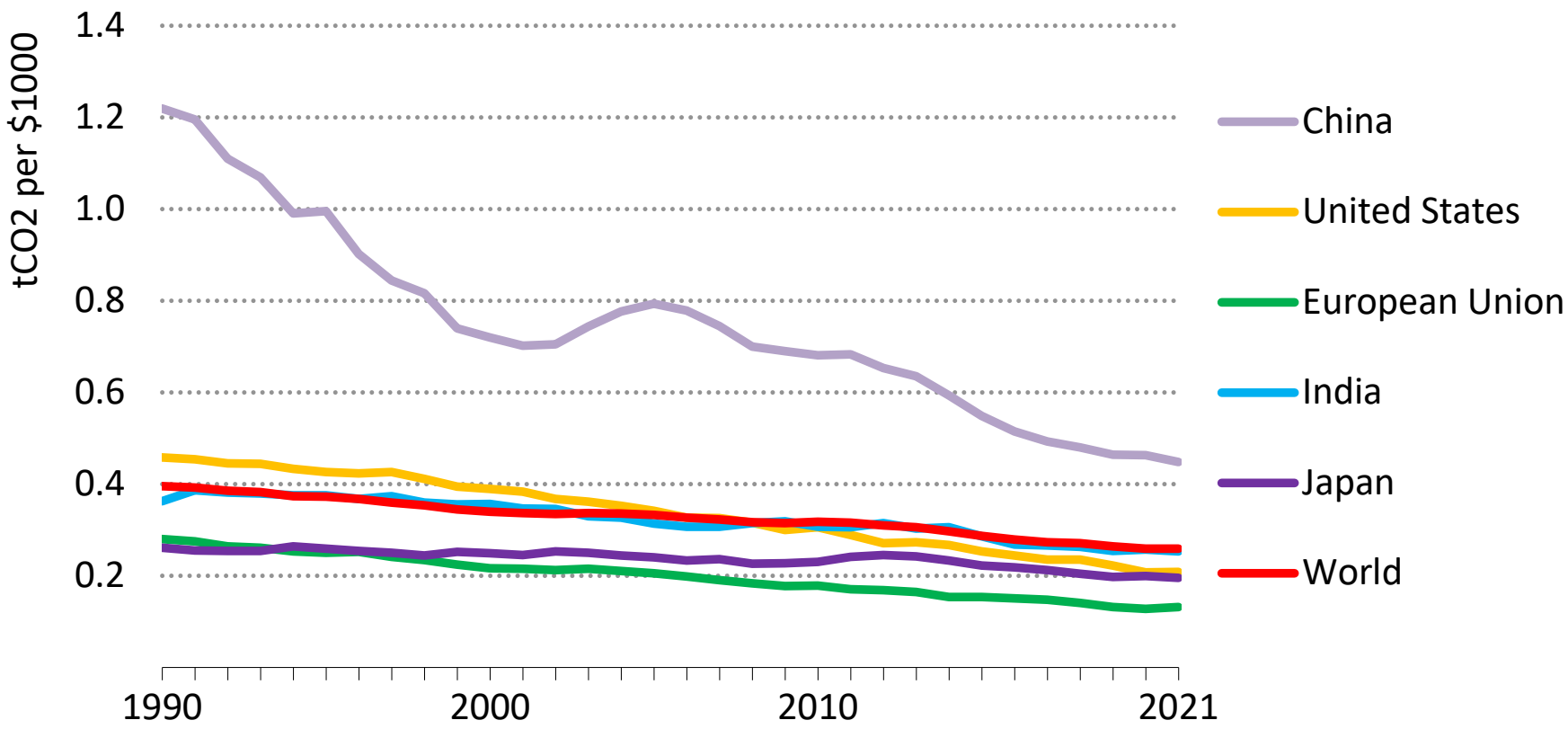


Figure: CO_2 emissions intensity of GDP, 1990-2021; source: IEA (2022).

Legal framework in Germany

- Climate Protection Law (CPL) 2019 of the Federal Government

→ Reduction of CO_2 emissions compared to 1990: 55 % until 2030

→ sectoral objectives

⇒ "obligation"

- descision of the Federal Constitutional Court from March 24, 2021

→ objectives for the time period past 2030 necessary

amendment of the CPL (2021)

→ CO_2 reduction compared to 1990: 65 % until 2030, 88 % until 2040, 100 % until 2045

CO_2 emissions in Germany

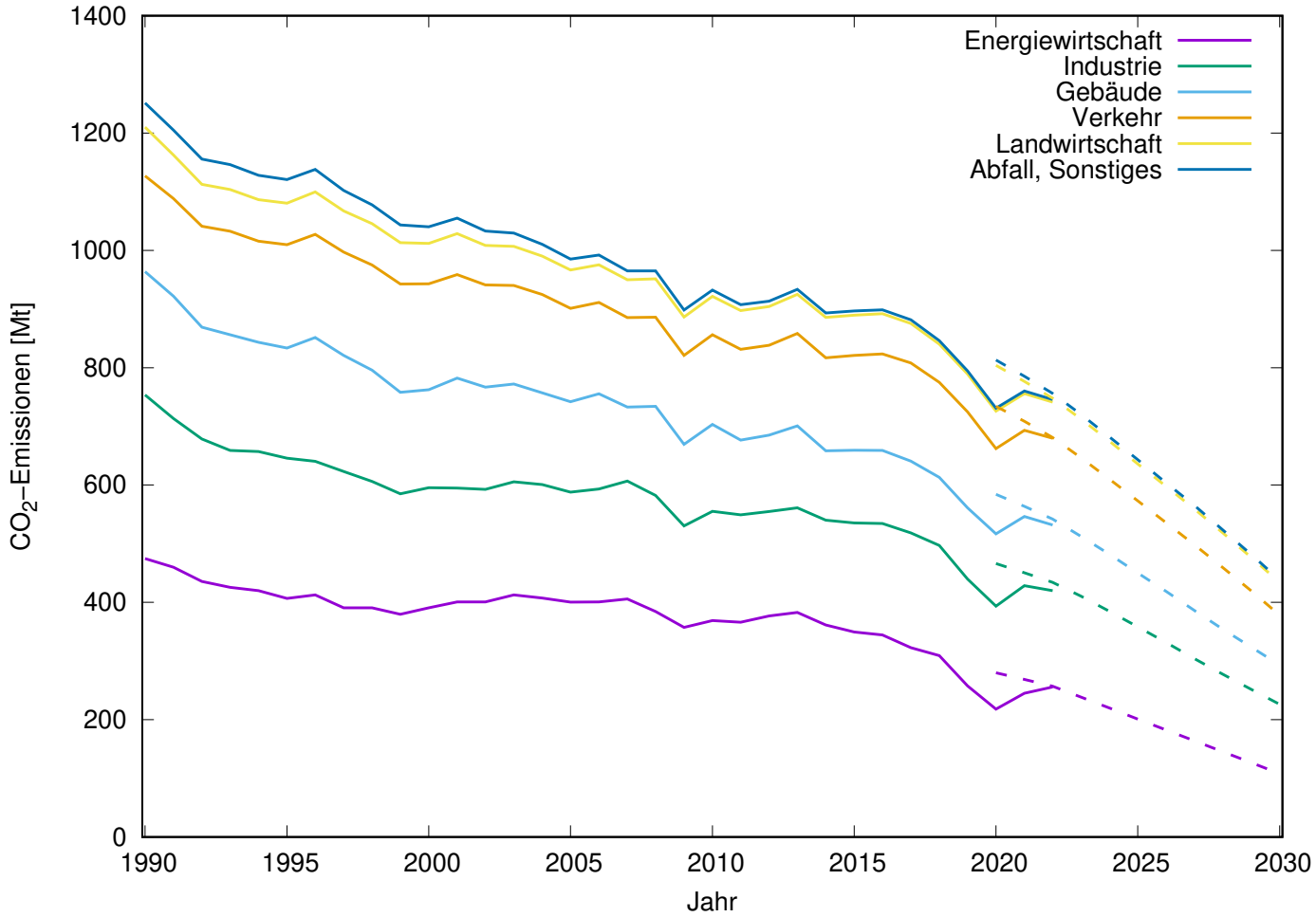


Figure: Development of CO_2 emissions in Germany from 1990-2022 (2022 preliminary) and reduction objectives according to CPL until 2030; own illustration (stacked line chart) based on data from Umweltbundesamt (2023).

CO_2 emissions in Germany

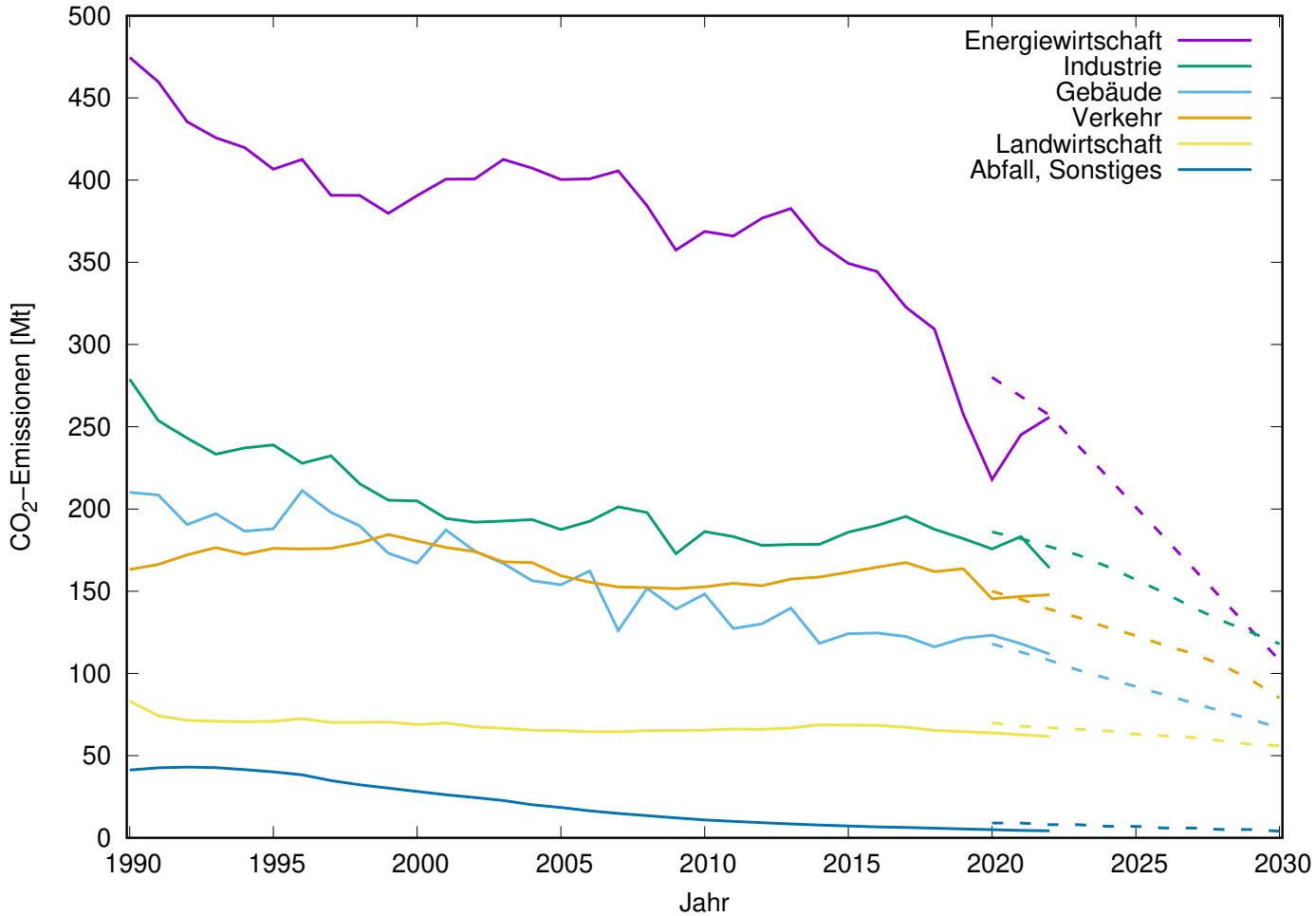


Figure: Development of CO_2 emissions in Germany from 1990-2022 (2022 preliminary) and reduction objectives according to CPL until 2030; own illustration (line chart) based on data from Umweltbundesamt (2023).

References I

Archer, D., Ebyand, M., Brovkinand, V., Ridgwelland, A., Cao, L., nd Ken Caldeira, U. M., Matsumoto, K., Montenegro, G. M. A., and Tokos, K. (2009). Atmospheric lifetime of fossil fuel carbon dioxide. *Annual Review of Earth and Planetary Sciences*, **37**, 117–134.

Burke, K. D., Williams, J. W., Chandler, M. A., Haywood, A. M., Lunt, D. J. and Otto-Bliesner, B. L. (2018). Pliocene and eocene provide best analogs for near-future climates. *Proceedings of the National Academy of Sciences*, **115** (52), 13288–13293.

Denman, K. L., Brasseur, G., Chidthaisong, A., Ciais, P., Cox, P., Dickinson, R., Hauglustaine, D., Heinze, C., Holland, E., Jacob, D., Lohmann, U., Ramachandran, S., da Silva Dias, P., Wofsy, S. and Zhang, X. (2007). Couplings between changes in the climate system and biogeochemistry. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. Averyt, M.Tignor and H. L. Miller (eds.), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment*, Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

IEA (2022). Global energy review: CO_2 emissions in 2021. Available at: `https://www.iea.org/reports/global-energy-review-co2-emissions-in-2021-2`, accessed October 17, 2022.

IPCC (1990). Policymaker summary of working group I (scientific assessment of climate change). In J. T. Houghton, G. J. Jenkins and J. J. Ephraums (eds.), *Climate Change: The IPCC Scientific Assessment*, New York: Cambridge University Press.

IPCC (1995). Summary for policymakers. In J. Houghton, L. Meira Filho, B. Callander, N. Harris, A. Kattenberg and K. Maskell (eds.), *Climate Change 1995: The Science of Climate Change*, New York: Cambridge University Press.

IPCC (2001). Summary for policymakers. In j. T. Houghton, Y. Ding, D. J. Griggs, M. Nouger, P. J. van der Linden, X. Dai, K. Maskell and C. A. Johnson (eds.), *Climate Change 2001: The Scientific Basis*, New York: Cambridge University Press.

References II

IPCC (2007). Summary for polcymakers. In S. D. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. Averyt, M.Tignor and H. Miller (eds.), *Climate Change 2007: The Scientific Basis. Contribution of WorkingGroup I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

IPCC (2013). Summary for policymakers. In T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. Midgley (eds.), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

IPCC (2021). Summary for policymakers. In V. Masson-Delmotte, P. Zhai, A. Pirani, S.L.Connors, C. Pean, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. Matthews, T.K.Maycock, T. Waterfield, O. Yelekci, R. Yu, and B. Zho (eds.), *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, , Cambridge, United Kingdom and NewYork, NY, USA: Cambridge University Pres.

Stern, N. (2007). *The Economics of Climate Change: The Stern Review*. Cambridge, New York: Cambridge University Press.

Umweltbundesamt (2023). Emissionsübersichten nach Sektoren des Bundesnaturschutzgesetzes. Verfügbar über `https://www.umweltbundesamt.de/sites/default/files/medien/361/dokumente/2023_03_15_em_entwicklung_in_d_ksg-sektoren_pm.xlsx`, aufgerufen am 29. Mai 2023.