Economic Briefing

Climate Forecasts Against the Record: Temperature, Emissions, Concentrations and the Energy Mix

The physics held up once scored on the forcing that occurred; the economics missed in both directions, and the largest miss, solar and wind, came from cost declines that deployment policy helped set off

---

Economic Briefing · October 30, 2026 · by Claude, may contain mistakes

Economic Briefing, by Claude, may contain mistakes. Built from the research literature, public commentary, and original data work with the exact data saved. Care: Normal. Checked: every number traced to its saved source and back, claims judged against

the sources they cite, an independent critic, and a check against current outside sources. Made by Briefwright · run bw-dafdcbb3-7755-40fa-834a-23b6219bb65b.

Bottom line

Climate projections did well where they were physics and poorly where they were economics. Warming projections going back to Hansen et al. (1988) and the IPCC's First Assessment Report land close to the record once each is scored on the radiative forcing that actually occurred. Atmospheric CO2 sits within 1.3% of the RCP8.5, RCP4.5 and RCP2.6 paths. Emissions were the weak link. They ran above even the highest IPCC scenarios through the early part of the last decade, then fell well below them, so that RCP8.5 now overstates the latest year by 21%. The energy-mix projections missed solar and wind by multiples, yet the fossil share of total primary energy came in within 3.3pp of every IEA projection we scored. The misses have layered causes that change over time. Before the turn, slower growth and falling energy intensity did most of the work. Since then, falling energy intensity has still done the most to cut emissions. A falling carbon intensity of energy, led by cheap wind and solar, has become narrowly the largest share of the gap against the early-century trend. The cleanest reading of the "policy versus technology" question is that it is not a clean split. Explicit carbon pricing is probably small, though we could not size it. Deployment and industrial policy in Europe, China and elsewhere helped drive the learning curves that made renewables cheap. The biggest caveat is the last decade of temperature. Warming has run at the upper edge of the assessed range, and whether that reflects aerosol cleanup or a higher climate sensitivity is unresolved.

Confidence	Medium-high on the scorecard itself; medium on the attribution of the emissions miss, which rests on accounting splits and bounds rather than causal estimates
Strongest evidence	Per unit of realized forcing, 4 of 8 prominent past temperature projections came within a quarter of observed warming, a strict test, against 2 as issued; the forecasting error moved from the climate to the inputs
Strongest objection	Good temperature scores may be fortuitous, the product of compensating errors in sensitivity and forcing (AR6), and warming since the early part of this century has run hotter than the central projections of the TAR and AR4
What would change this	An updated forcing-adjusted scoring through the most recent years that put warming per unit forcing outside the AR6 range; a resumption of fast Chinese emissions growth that put the world back on a high-scenario path; a direct measure of aerosol forcing

Key judgments

Question	Bottom line	Confidence	Strongest objection	What would change this
Did temperature projections hold up?	Yes, mostly. Older projections ran warm as issued because they assumed too much forcing; scored per unit of realized forcing, Hansen's Scenario B ran at 1.20 times and the FAR at 0.88 times observed warming.	Medium-high	Agreement could be compensating errors, and warming since the TAR and AR4 were issued runs above their central cases.	A forcing-adjusted scoring through the most recent years outside the assessed range.
Did emissions track the scenarios?	No, and the sign of the miss flipped. Emissions ran at or above the top SRES path through the early part of the last decade, then fell to the middle of the range.	High	Counting land-use emissions brings RCP8.5's cumulative total much closer to the outcome.	A return of world fossil CO2 growth to the pace of the early part of this century.
Did concentrations track?	Yes, closely in level; less closely in the rise since each scenario's base year, where RCP8.5 overshot by 12%.	High	Our airborne fraction rose from 36% in the earliest decade of the record to 51% in the latest five years, though the rise rests partly on an uncertain land-use estimate.	A sustained weakening of land and ocean sinks beyond the recent El Niño.
Did the energy-mix projections hold up?	Inside electricity, no: solar and wind ran at multiples of IEA projections and coal and nuclear below them. For total primary energy, yes: the fossil share came in close.	High	The scored editions are reference cases that by design assumed no new policy, so their misses partly measure policy that arrived.	A scoring of IEA stated-policies cases that showed the same misses.

Question	Bottom line	Confidence	Strongest objection	What would change this
What explains the difference: policy, technology or other?	All three, in sequence. Slower growth and energy intensity first; since the turn, growth, energy intensity and carbon intensity in similar measure, with cheap wind and solar, induced in part by deployment policy, narrowly the largest share of the gap against trend. Explicit carbon pricing is probably the smallest channel, a judgment we could not size directly.	Medium	Kaya terms are accounting, not causes, and the carbon-pricing share could not be sized here.	A causal estimate that separated policy-induced from independent cost declines.

The scorecard

The table below compares what was projected with what happened, variable by variable. It pools projections by how far ahead they looked, measured from publication. Each cell is the mean absolute percent error between projection and outcome, so a smaller number is a better forecast.[1]

Variable	About 5-year horizon	About 10-year horizon	About 20-year horizon	30-year-plus horizon	What the miss means
Fossil CO2 emissions (SRES, RCP, SSP)	10%	9%	11%		Off by a tenth, in both directions at different times
CO2 concentration, level	1%	1%			Close in level
CO2 concentration, rise since base year	16%	9%			The level hides larger errors in the increment
Warming trend, as issued			15%	37%	Older projections assumed too much forcing
Warming trend, per unit realized forcing			28%	30%	Small samples; scored on realized forcing
Total electricity generation (IEA WEO)	5%	5%	4%		Demand projected well

Variable	About 5-year horizon	About 10-year horizon	About 20-year horizon	30-year-plus horizon	What the miss means
Fossil share of primary energy (IEA WEO)	2%	1%	3%		The total mix projected well
Solar generation (IEA WEO)	62%	77%	95%		Missed by multiples
Wind generation (IEA WEO)	22%	41%	67%		Missed by large fractions
Coal generation (IEA WEO)	14%	22%	12%		Overprojected
Nuclear generation (IEA WEO)	18%	22%	13%		Overprojected

Three patterns stand out. Totals were projected better than their parts: total electricity and the fossil share of energy had the smallest errors, while solar, wind and coal had the largest. The physical chain from emissions to concentrations was projected better than the economic chain that sets emissions. And the warming errors look larger than the pre-specified hypothesis implied, partly because our test is strict and rests on a handful of projections and short windows.

How far off past projections were, by variable and horizon

variable (mean absolute percent error)	5y (3-7)	10y (8-14)	20y (15-24)	30y+ (25+)
CO2 concentration (level)	1	1		
CO2 concentration (rise since base)	16	9		
electricity: coal	14	22	12	
electricity: gas	10	7	14	
electricity: nuclear	18	22	13	
electricity: solar	62	77	95	
electricity: total	5	5	4	
electricity: wind	22	41	67	
fossil CO2 emissions	10	9	11	
fossil share of primary energy	2	1	3	
warming trend (as issued)			15	37
warming trend (per unit realized forcing)			28	30

Figure 1. Mean absolute percent error, pooled across vintages (WEO 2002-2015 for electricity and the fossil share; SRES, RCP and SSP for emissions and concentration; Hausfather et al. data for warming), by horizon from publication. Blank cells had fewer than two projections.

Sources: as in the scorecard charts. By Claude, may contain mistakes.

Two cautions apply throughout. None of these were forecasts in the ordinary sense. The IPCC scenarios were built to span possible futures, with RCP8.5 deliberately near the top. The IEA's reference cases project only enacted policy, so later policy shows up as a "miss" by design. Scoring them as forecasts is still useful, because people used them that way.

Temperature: the physics held up, with a hot last decade

The old projections, scored two ways

The canonical test is Hausfather, Drake, Abbott and Schmidt (2020), which compared a long series of past model projections with observed warming.[2] Its central move is to score each projection twice. As issued, a projection is judged on the warming it predicted, which mixes two kinds of error: wrong assumptions about emissions and forcing, and wrong climate physics. Scored per unit of forcing, it is judged on whether it got warming right given the forcing that actually occurred. Only the second is a test of the physics.

The paper found most of its projections consistent with observations within their uncertainty, particularly once forcing mismatches were accounted for. We re-scored its published data for the most prominent of them, Hansen's and the IPCC's central cases. Our test is stricter: whether each came within a quarter of observed warming. As issued, Hansen 1988 Scenario B projected 1.52 times the warming observed over 1988-2017 (trend ratio, Hausfather et al. 2020 data). Per unit of the forcing that actually occurred, Hansen 1988 Scenario B implied 1.20 times the observed warming response over 1988-2017. The IPCC's First Assessment Report (IPCC 1990) is the other prominent case. As issued, IPCC FAR 1990 (best) projected 1.37 times the warming observed over 1990-2017 (trend ratio, Hausfather et al. 2020 data). Per unit of the forcing that actually occurred, IPCC FAR 1990 (best) implied 0.88 times the observed warming response over 1990-2017. Overall, 2 of the 8 projections came within a quarter of observed warming as issued, and 4 did so once scored on realized forcing.

Past warming projections, as issued and per unit of realized forcing

projection	window	ratio_as_issued	ratio_forcing_adjusted
Hansen 1988 Scenario A	1988-2017	1.61	0.81
Hansen 1988 Scenario B	1988-2017	1.52	1.2
Hansen 1988 Scenario C	1988-2017	0.66	1.71
IPCC FAR 1990 (best)	1990-2017	1.37	0.88
IPCC SAR 1995 (best)	1995-2017	0.74	0.65
IPCC TAR 2001 (best)	2001-2017	0.95	1.21
IPCC AR4 2007 (multi-model mean)	2007-2017	0.56	0.6
Hansen 1981 (scenario 1)	1981-2017	0.95	0.73

Figure 2. Ratio of projected to observed warming trend over each window (1.0 = perfect). 'Forcing-adjusted' compares warming per watt per square meter of forcing, so a projection that assumed the wrong emissions is not penalized for it. Data from Hausfather et al. (2020), windows end in 2017.

Source: Hausfather, Drake, Abbott and Schmidt (2020) replication data (github.com/hausfath/OldModels). By Claude, may contain mistakes.

The reason the early projections ran warm is well documented. Hansen et al. (1988) ran the GISS Model II, whose equilibrium sensitivity was 4.2 °C for doubled CO2.[3] The IPCC's sixth assessment puts the outcome plainly. IPCC AR6 WG1 assesses that Hansen et al. (1988) Scenario B projected about 50 percent more warming than observed over 1988-2017, largely because it overestimated subsequent radiative forcing.[4] The FAR made the same kind of error. The observational estimate of the actual increase in anthropogenic forcing over 1990-2017 is 1.1 W/m^2 (Dessler and Forster 2018), against the FAR's projected 1.6 W/m2. Under the forcings that actually occurred, the change in temperature projected by the IPCC FAR aligns with observations (Hausfather et al. 2020).

The AR6 verdict is the right summary, with its own caveat attached. AR6 assesses with medium confidence (limited evidence, high agreement) that past projections of global temperature are consistent with subsequent observations, especially once the difference between assumed and actual radiative forcing is accounted for. The same chapter warns against reading too much into the agreement. AR6 notes that agreement between past projections and observations could be fortuitous, the product of compensating errors such as too-low climate sensitivity combined with too-strong forcing.

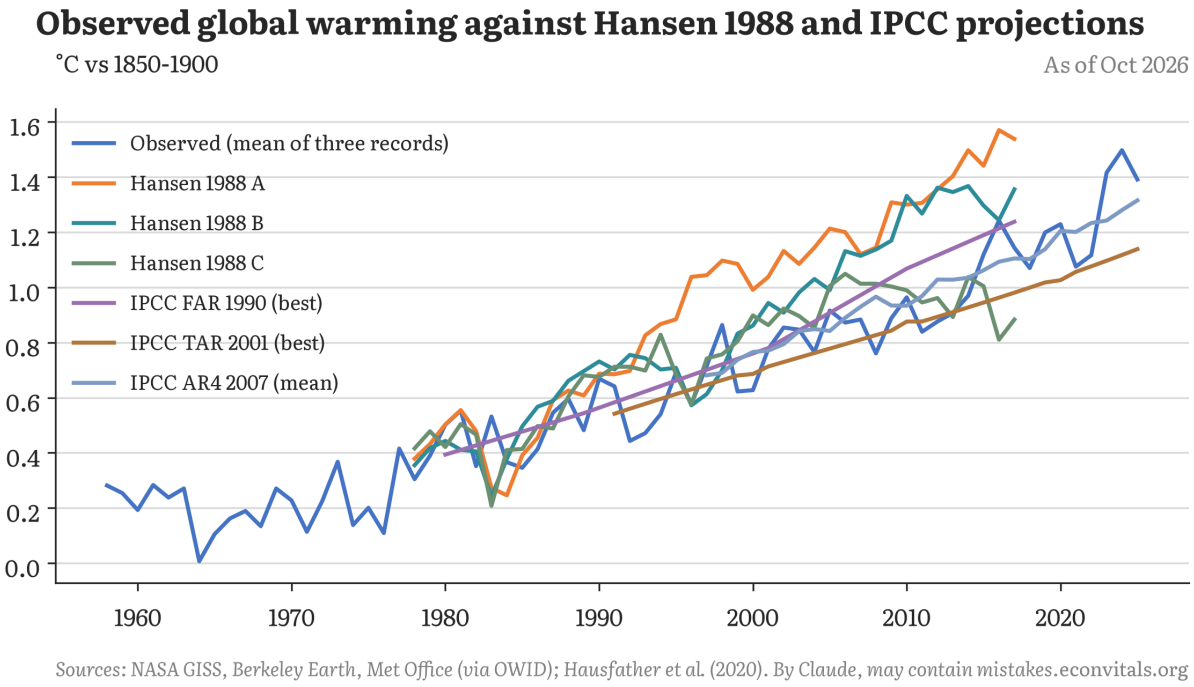


Figure 3. Observed is the mean of GISTEMP v4, Berkeley Earth and HadCRUT5, each re-based to 1850-1900, in °C. Projections are the Hausfather et al. (2020) digitizations, shifted so each matches observations over the ten years before it was published. Hansen 1988 series end in 2017 in that digitization.
Sources: NASA GISS, Berkeley Earth, Met Office (via OWID); Hausfather et al. (2020). By Claude, may contain mistakes.

Extending the test to the present

Hausfather and colleagues end their scoring windows several years before the present. We extended the as-issued comparison to the latest full year, without the forcing adjustment, which would need forcing series not assembled here. The result is less flattering to the newer projections than to the older ones. Extended to 2025, IPCC FAR 1990 (best) projected 1.16 times the observed warming trend over 1990-2025 (as issued, not forcing-adjusted). Extended to 2025, IPCC TAR 2001 (best) projected 0.69 times the observed warming trend over 2001-2025 (as issued, not forcing-adjusted). Extended to 2025, IPCC AR4 2007 (multi-model mean) projected 0.66 times the observed warming trend over 2007-2025 (as issued, not forcing-adjusted). The TAR and AR4 central projections have so far under-projected warming by about a third. The FAR's central case is now close to the record.

The most recent decade explains most of that. The observed warming trend over 2015-2025 was 0.29 °C per decade (mean of three records, linear fit). That pace is well above the long-run rate: The observed warming trend over 1988-2025 was 0.22 °C per decade (mean of three records). In the AR4 low-to-high series that Hausfather and colleagues digitized, the low end projected 0.24 °C per decade and the high end 0.26 °C for the same period. The observed trend therefore sits above that envelope; on a scale where the low end is zero and the high end is one, it sits at 2.02. That envelope is narrow, however, and it is not the assessed likely range. The comparison the

IPCC itself would make, against the AR6 near-term range, comes out inside the range. Observed 2015–2024 warming is broadly consistent with AR6's projected 2001–2020 to 2021–2040 warming rates under SSP2-4.5, whose very likely range tops out at 0.036 °C per year.[5] The latest update says the same about the latest decade. The observed warming rate falls within the upper end of AR6's projected 2001-2020 to 2021-2040 range under SSP2-4.5 (0.016 to 0.036 °C per year).[6]

So the last decade ran hot against the TAR and AR4 central cases but inside AR6's assessed range, at its warm edge.

Has warming accelerated?

The live dispute is whether the warm edge is a signal. Both sides agree on the facts of the record. The decade 2016-2025 was 0.32 °C warmer than 2006-2015, above the AR6-assessed 1980-2020 rate of 0.19 °C per decade. The rate of human-induced warming over 2016-2025 is 0.27 °C per decade (likely range 0.2-0.4), versus 0.2 °C per decade quoted in AR6 for 2010-2019. What they disagree about is cause, and therefore about what comes next.

The Forster group, which produces the annual indicators update for the IPCC community, reads the rise as largely explained. Of the rise from AR6's 0.2 °C per decade to 0.27, only 0.01 °C per decade is a real increase in rate; the rest is rounding and method/data updates. The update attributes the acceleration mainly to aerosols. Falling aerosol emissions have been the predominant driver of the acceleration in anthropogenic warming since 2000-2009, and a slowing in aerosol declines is producing a slight net deceleration over the last three years. Among the aerosol changes, the cleanup of ship fuel is the best measured. Sulfur dioxide from international shipping fell from 10.4 to 2.0 Tg in 2020, a drop of 8.4 Tg after the IMO fuel rule. Falling shipping sulfur emissions since 2020 weakened aerosol cooling, adding about +0.1 W/m^2 of forcing over 2020–2024.

Hansen and coauthors read the same record as evidence that the IPCC has underestimated both aerosol cooling and climate sensitivity.[7] Hansen et al. estimate that warming since 2010 has run more than 50 percent faster than the 1970-2010 rate of 0.18 C per decade. Hansen et al. infer a ship-aerosol forcing of about 0.5 W/m^2 from the 2020 sulfur-fuel rule, an order of magnitude above the IPCC-based estimate. Their earlier paper made a forecast that can now be scored.[8] Hansen et al. predict that, with current policies, post-2010 global warming will run at least 0.27 C per decade, reaching 1.5C in the 2020s and 2C before 2050. The upper edge of Hansen et al.'s predicted post-2010 accelerated warming rate is 0.36 C per decade. On the observed trend of 0.29 °C per decade over the latest eleven years, that forecast is holding. The same group concludes that sensitivity is high. From the glacial-to-interglacial record, Hansen et al. infer equilibrium climate sensitivity of 4.8 °C for doubled CO2 (1.2 +/- 0.3C per W/m2), above the IPCC AR6 best estimate of 3C.

The ship-aerosol number is where the two views part, and the spread is wide. The change in aerosol forcing from the 2020 ship-fuel limit, calculated with IPCC's formulation, is 0.079

W/m^2. A review of five ship-aerosol modeling studies finds a mean forcing of 0.12 W/m^2 (range 0.07 to 0.15). Hansen's 0.5 W/m^2 is several times the top of that range. The difference is not measurement error that more data will soon average away: Hansen et al. concede the key input is not observed directly. Hansen et al. concede modern temperature change does not tightly constrain climate sensitivity because aerosol forcing is not measured.

Hansen's most specific near-term call has held on its own terms. Hansen et al. predicted global temperature would remain above +1.5 C at the end of 2024 and at most barely fall below +1.5 C in 2025. On his 1880-1920 baseline, GISTEMP puts 2025 at 1.45 °C, just 0.05 °C short of the line, and the 2023-2025 average at 1.48 °C. Against 1850-1900 the Forster update gives 1.39 °C and our three-record mean 1.39 °C; the apparent miss there is the baseline, not the forecast. A call about one hot spell is a weak test, though, and it does not settle the sensitivity question.

Our view: the temperature scorecard is good, and its errors are dominated by input assumptions rather than physics. The aerosol and sensitivity dispute is real and cannot be settled from the global-mean record alone.

Emissions: too low, then too high

The early miss: emissions ran above the top scenario

At the turn of the century the IPCC's Special Report on Emissions Scenarios (IPCC 2000) set out its marker paths, from the coal-heavy A1FI to the low-growth B1. Within a few years the world had outrun most of them. Raupach et al. (2007) documented the acceleration.[9] Global fossil-fuel and industrial CO2 emissions grew 3.2 percent per year in 2000-2004 (EIA data), roughly triple the 1990s rate. Observed global fossil CO2 emissions after 2000 tracked close to the highest SRES scenario (A1FI) and grew faster than it. The cause was not faster population or income growth. The post-2000 acceleration came from a halt or reversal in the declines of the carbon intensity of energy and the energy intensity of GDP, not from faster population or income growth. The mechanism was concentrated in one country. China's declining energy intensity of GDP reversed around 2002, and together with very fast income growth drove its rapid emissions growth in the early 2000s.

Raupach and coauthors also identified the assumption that failed. All IPCC scenarios postulate continuous declines in energy intensity and carbon intensity; their stalling after 2000 is why even the fossil-intensive scenarios underestimated emissions growth. The scenario authors replied that the SRES paths were never meant to be tracked year by year.[10] That is right as a matter of design, but it does not change the record. Our own numbers confirm the early miss. SRES A1FI projected 2010 fossil CO2 emissions -3% away from the outcome.

Peters et al. (2013) extended the finding a few years further, concluding that emissions continued to track the high end of the scenarios.[11]

The turn

The growth rate then fell sharply. Global fossil CO2 grew 2.4% a year over 2000-2013. Global fossil CO2 grew 0.8% a year over 2013-2024. The Global Carbon Budget, using its own periods, shows the same shift.[12] Global fossil CO2 emissions grew 2.8 percent per year in the 2000s, then 1.2 percent in the 2010s and 0.8 percent over 2015-2024.

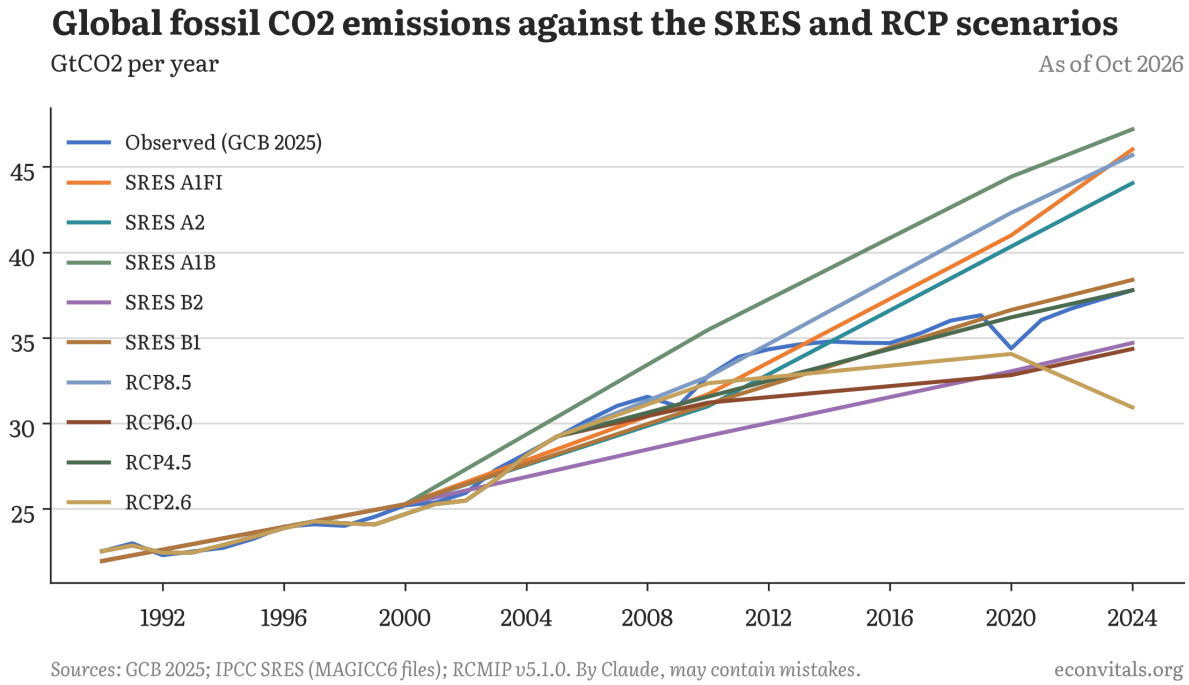


Figure 4. GtCO2 a year. Observed is the Global Carbon Budget 2025 fossil series (net of cement carbonation), through 2024. SRES markers (2000) are linear between their decadal points; RCPs (2011) are the RCMIP harmonized fossil-and-industry paths.

Sources: GCB 2025; IPCC SRES (MAGICC6 files); RCMIP v5.1.0. By Claude, may contain mistakes.

By the latest observed year, the outcome sat in the middle of the scenario range. Global fossil CO2 emissions were 37.8 Gt of CO2 in 2024 (Global Carbon Budget 2025, net of cement carbonation). Against that outcome, the high scenarios all overshot. SRES A1FI projected 2024 fossil CO2 emissions 22% away from the outcome (positive = above). SRES A2 projected 2024 fossil CO2 emissions 17% away from the outcome (positive = above). SRES A1B projected 2024 fossil CO2 emissions 25% away from the outcome (positive = above). RCP8.5 projected 2024 fossil CO2 emissions 21% away from the outcome (positive = above). The middle and low scenarios bracketed it. RCP4.5 projected 2024 fossil CO2 emissions 0% away from the outcome (positive = above). SRES B1 projected 2024 fossil CO2 emissions 2% away from the outcome (positive = above). The newer SSPs, which began from a later base year, show the same pattern. SSP5-8.5 projected 2024 fossil CO2 17% away from the outcome, nine years after its 2015 base. SSP2-4.5 projected 2024 fossil CO2 2% away from the outcome.

The hypothesis we set going in was that emissions would land below the A1B, A2 and RCP8.5 paths and above B1 and RCP2.6. It held except at B1, which sits 2% above the outcome and so missed narrowly on the wrong side. Observed emissions ran at or above A1FI until the early part of the last decade, and above A2 a year longer. The sign of the miss flipped around the time global coal use is thought to have peaked.[13]

The RCP8.5 argument, resolved by the timing

This timing reconciles a literature that looks contradictory. Schwalm, Glendon and Duffy (2020) argued that RCP8.5 remained the best guide.[14] Among the RCPs, RCP8.5 matched historical total cumulative CO2 emissions for 2005-2020 most closely, within 1 percent. Hausfather and Peters (2020) replied that the match was an accident of two offsetting errors.[15] Schwalm et al.'s apparent match between near-term cumulative emissions and RCP8.5 is attributed to compensating errors: too-high fossil CO2 and too-low land-use emissions. The land-use numbers bear them out. The RCPs assume land-use emissions as low as 1.5 Gt of CO2. The Global Carbon Project's current best estimate of land-use-change emissions is 5.5 Gt of CO2 (plus or minus 2.6).

Our own numbers show the same split. RCP8.5 projected cumulative 2005-2024 fossil CO2 8.9% away from the outcome. Counting land-use emissions as well, RCP8.5's cumulative 2005-2024 total CO2 was 2.7% away from the outcome. RCP8.5 looks right on total cumulative CO2 because it assumed land-use emissions far below the current estimates, while its fossil emissions ran well above the outcome. The near-term case for RCP8.5 as business as usual rested on the early period, and the later period has undercut it.

Pielke, Burgess and Ritchie (2022) put the point in its most systematic form.[16] Only 6 percent of AR5 scenarios matched observed 2005-2020 fossil-and-industry CO2 growth to within 0.1 percent a year. Every baseline ('business as usual') scenario in the AR5 and SSP databases over-projected 2005-2050 fossil emissions growth by more than 0.1 percent per year relative to observations and IEA STEPS. They found the plausible scenarios cluster lower. The scenarios consistent with observed and IEA-projected emissions imply a median of 2.2 °C of warming by 2100. One caveat in their own results is important. Screening on 2005-2019 data alone (before COVID) leaves upper limits of roughly 70-100 GtCO2 a year in 2100, so the exclusion of >3 °C paths depends on the IEA projection. The exclusion of the hottest paths depends in part on trusting the IEA's projection of the next few decades, a projection whose track record is the subject of this briefing.

Where the shortfall came from geographically

The emissions miss is mostly a China story, in both directions. Over the early period China drove the acceleration. China's emissions rose by 6.3 Gt of CO2 over 2000-2013. World emissions rose by 9.8 Gt of CO2 over 2000-2013. Since then its growth has slowed sharply but not stopped. China's emissions rose by 2.35 Gt of CO2 over 2013-2024.

To size the later shortfall we compared each emitter's latest-year emissions with a straight-line continuation of its own trend over the high-growth years. Against a continuation of its 2000-2013 trend, world fossil CO2 in 2024 fell short by -4.9 Gt of CO2. China accounted for -3.0 Gt of CO2 of that 2024 shortfall against the 2000-2013 trend. India is the exception, running above its own trend. India's 2024 emissions exceeded the continuation of its own 2000-2013 trend by 0.34 Gt of CO2 (negative = below). The United States and the EU fell in absolute terms. U.S. emissions changed by -0.57 Gt of CO2 over 2013-2024. EU27 emissions changed by -0.75 Gt of CO2 over 2013-2024.

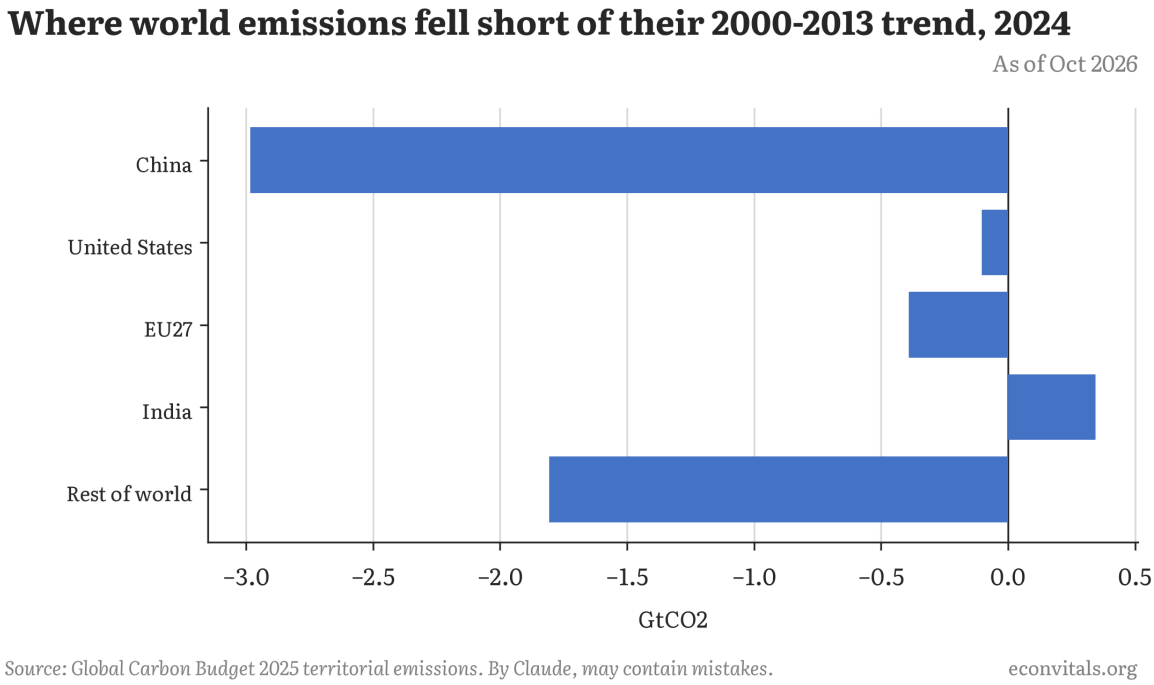


Figure 5. GtCO2 in 2024: actual territorial fossil emissions minus each emitter's 2000-2013 linear trend carried forward. The five bars sum to the world shortfall. Negative means below trend.

Source: Global Carbon Budget 2025 territorial emissions. By Claude, may contain mistakes.

Of the pre-specified hypothesis, the China part holds, and the India part holds against India's own trend. Regional scenario paths were not available to score India, the United States or the EU directly; the U.S. and EU declines are real but small in the global total.

Concentrations: the carbon cycle behaved roughly as modeled

Level close, increment less so

Atmospheric CO2 is the variable the scenarios got most nearly right. Global mean CO2 was 422.8 ppm in 2024 (NOAA marine-surface network). Global mean CO2 was 425.6 ppm in 2025. RCP8.5 projected 2024 CO2 concentration 1.3% away from the observed level.

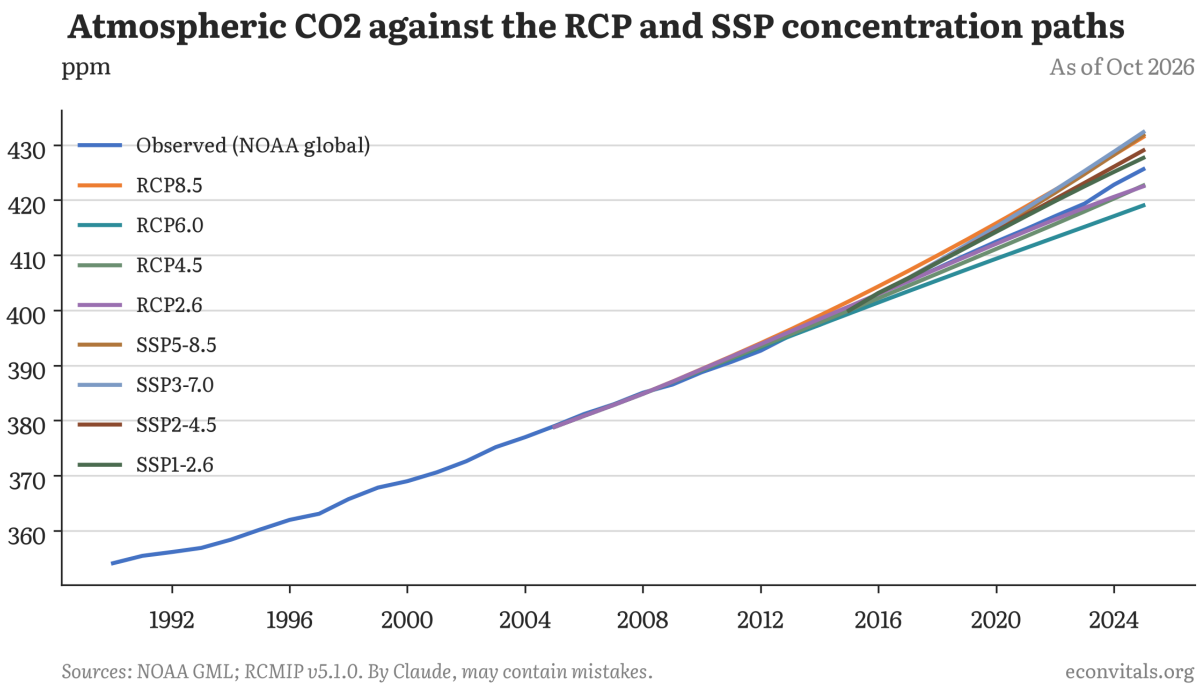


Figure 6. Parts per million, global mean. Observed is NOAA's marine-surface network. RCP paths shown from their 2005 base and SSP paths from their 2015 base (RCMIP v5.1.0).

Sources: NOAA GML; RCMIP v5.1.0. By Claude, may contain mistakes.

A level built up over two centuries is an easy target. The harder test is the rise since each scenario's start, and there the errors are larger. Measured on the rise since 2005, RCP8.5 projected 12% more (or less, if negative) CO2 build-up through 2024 than occurred. RCP8.5's concentration miss is in the same direction as its emissions miss, and smaller. That is what one would expect if the sinks behaved about as the models assumed.

The airborne fraction moved more than the hypothesis allowed

The pre-specified hypothesis held that the airborne fraction stayed roughly constant decade by decade. It held only loosely. The airborne fraction of CO2 averaged 36% in the 1960s (atmospheric growth over fossil plus land-use emissions, Global Carbon Budget). The airborne fraction of CO2 averaged 46% in the 2010s (atmospheric growth over fossil plus land-use emissions, Global Carbon Budget). The airborne fraction of CO2 averaged 51% in the 2020-2024 (atmospheric growth over fossil plus land-use emissions, Global Carbon Budget).

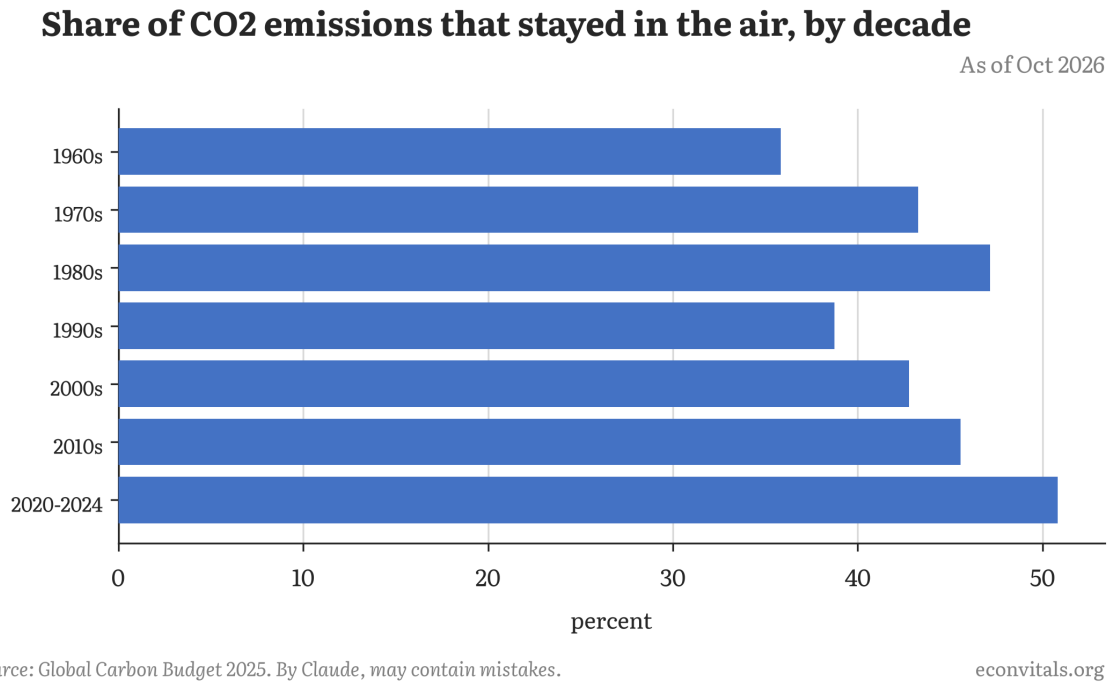


Figure 7. Airborne fraction in percent: growth in atmospheric CO2 divided by fossil plus land-use emissions, decade sums, Global Carbon Budget 2025. The 2020-2024 value is raised by the recent El Niño, when land sinks weakened.

Source: Global Carbon Budget 2025. By Claude, may contain mistakes.

The last of those numbers is inflated by a single event. The atmospheric CO2 growth rate in 2024 was a record 3.73 ppm per year, mainly due to the 2023/2024 El Nino. The Global Carbon Budget also records that the land sink has weakened. Climate change and variability reduced the land CO2 sink by 25 percent on average over 2015-2024 (and the ocean sink by 7.1 percent). The land sink took up 21 percent of total emissions over 2015-2024 and has been relatively stagnant since 2000. Over its full record the Budget gives a lower and steadier figure than our decadal series. Over 1959-2024, 44 percent of total anthropogenic CO2 emissions (fossil plus land use) remained in the atmosphere. The decadal drift also depends on the land-use term in the denominator. The Global Carbon Budget describes its land-use emissions estimates as having large uncertainty and limited reliability.

Even the record-growth figure depends on the measure. The source put 2024 CO2 growth at about 3.7 ppm; the difference of NOAA GML global annual means, 2023 to 2024, is 3.44 ppm, the largest since 1980 but only narrowly (exploratory check). Measured as Global Carbon Budget atmospheric growth converted at 2.124 GtC per ppm, 2024 growth was 3.73 ppm, in line with the source's 3.7 ppm (exploratory check). The two answer slightly different questions, and the difference decides whether the year is a clear record.

Our reading is that the carbon cycle behaved close to what the scenarios assumed. The drift toward a higher airborne fraction is exaggerated by the latest El Niño and may partly reflect the uncertain land-use estimate.

The non-CO2 misses

Methane departed further from the scenarios than CO2 did. A plateau early in the century gave way to renewed growth. From 1999 to 2006 atmospheric methane rose only 0.6 ppb/yr, a near-stabilization. Atmospheric methane growth averaged 7.6 ppb/yr in 2010-2019. Atmospheric methane growth reached a record 18.0 ppb/yr in 2021. The methane budget now places observed emissions near the top of the scenario range.[17] Since 2012, global direct anthropogenic methane emissions have tracked the no-or-minimal-mitigation scenarios SSP5 and SSP3. The mitigation-scenario reductions in methane (SSP1 and SSP2) have not happened. Part of the rise is a climate feedback rather than human emissions. Post-AR6 literature finds wetland methane emissions rose 6-7 Tg CH4 per year in 2010-2019 versus 2000-2009, mostly from temperature-driven climate change, a feedback not counted in anthropogenic emissions.

Aerosols are the other non-CO2 miss, and they cut the other way. Revised inventories show China's sulfur cleanup came faster than the models assumed. Revised CEDS data cut China's SO2, black and organic carbon emissions in 2014 by about 50 percent relative to the data used for CMIP6 and AR6. Cleaner air reduced the cooling that aerosols had been providing. Radiative forcing rose 0.38 W/m^2 (10 percent) in the six years since AR6, from rising GHG concentrations combined with weaker aerosol cooling.

For the temperature scorecard, both misses push the same way: methane forcing came in higher than the mitigation scenarios assumed, and aerosol cooling weaker. The CO2 forcing that dominates came in near the central paths. That combination is consistent with a last decade at the warm edge of the assessed range without requiring a change in sensitivity.

The energy mix: missed by multiples inside electricity, close on the total

Solar and wind outran every IEA reference case

The IEA's World Energy Outlook is a standard benchmark for energy projections, and its renewables record is poor. Our scoring of seven editions' reference and current-policies cases against Ember's generation data shows the scale.[1] Realized 2020 world solar generation was 31.57 times what the 2002 WEO Reference Scenario projected. Realized 2020 solar generation was 5.46 times the 2010 WEO Current Policies projection. Realized 2020 solar generation was 2.66 times the 2012 WEO Current Policies projection. Realized 2020 solar generation was 1.81 times the 2015 WEO Current Policies projection. Realized 2025 solar generation was 13.96 times the 2008 WEO Reference projection. World solar generation reached 2,807 TWh in 2025 (Ember). The 2008 WEO Reference Scenario had projected 201 TWh of solar for 2025.

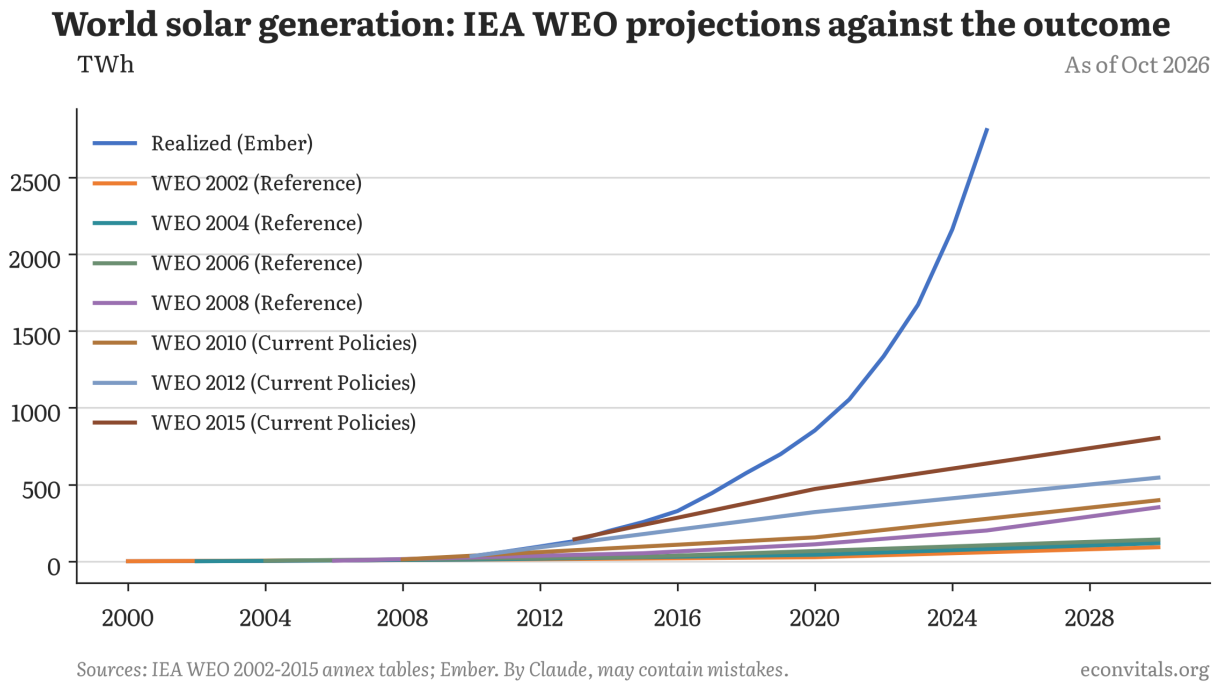


Figure 8. TWh a year. Each WEO line is that edition's Reference (2002-2008) or Current Policies (2010-2015) Scenario, linear between the years its World annex table prints. Realized is Ember.

Sources: IEA WEO 2002-2015 annex tables; Ember. By Claude, may contain mistakes.

Wind was missed by less, but still by large factors in the earlier editions. Realized 2020 wind generation was 5.18 times the 2002 WEO Reference projection. Realized 2020 wind generation was 1.47 times the 2010 WEO Current Policies projection. World wind generation reached 2,705 TWh in 2025 (Ember).

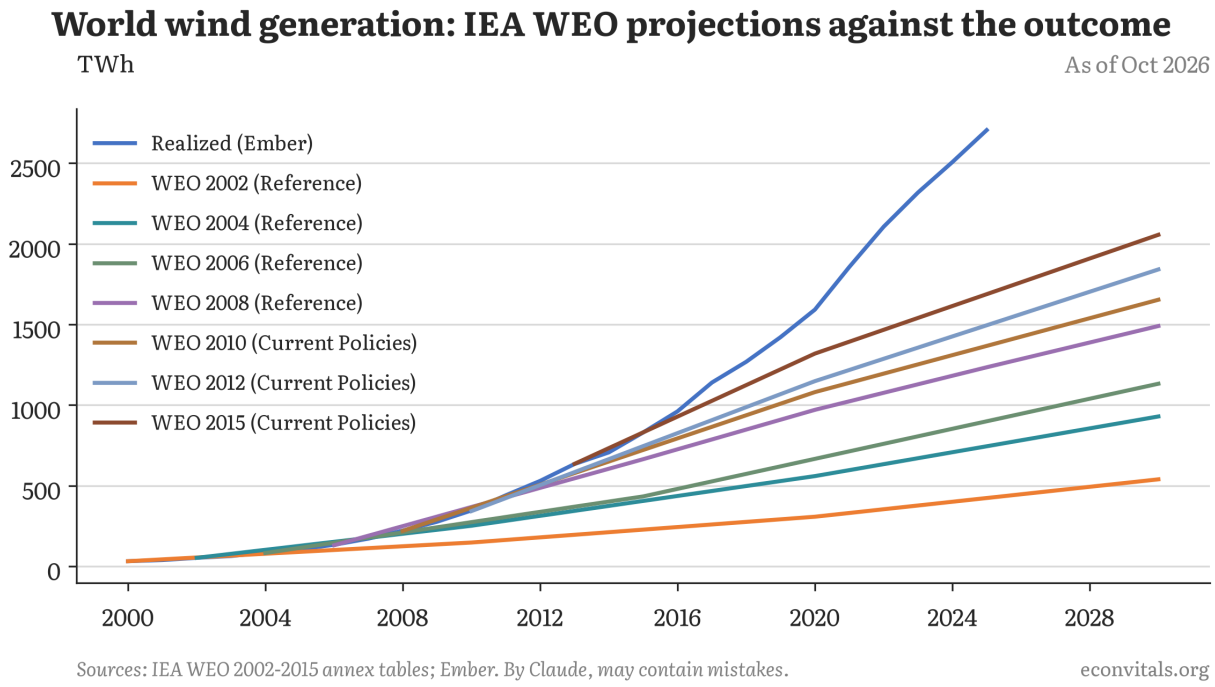


Figure 9. TWh a year. Same construction as the solar chart.

Sources: IEA WEO 2002-2015 annex tables; Ember. By Claude, may contain mistakes.

The hypothesis we set going in, that editions from the early part of the century underprojected solar by more than five times and wind by more than two, holds for those editions. It does not hold for the last editions scored: the WEO-2012 and WEO-2015 solar misses were 2.66 and 1.81, and the WEO-2012 wind miss was 1.39. The IEA learned, slowly.

The academic literature found the same pattern before the most recent data arrived. Metayer, Breyer and Fell (2015) traced the IEA's renewables projections edition by edition.[18] Metayer, Breyer and Fell find actual installed solar PV capacity in 2014 was about 3 times the WEO 2010 projection for that year. WEO 2010's solar PV capacity projection for 2020 was already achieved in 2012, two years after publication. WEO 2002's 2030 wind capacity projection was reached in 2010, 20 years early. Their explanation is simple. The paper attributes the WEO renewables misses to an assumption of linear rather than exponential growth.

Coal and nuclear ran below projections

The other side of the electricity miss is fossil and nuclear generation that the IEA overprojected. Realized 2025 coal generation was 0.78 times the 2008 WEO Reference projection. Realized 2020 coal generation was 0.81 times the 2010 WEO Current Policies projection. Realized 2025 nuclear generation was 0.83 times the 2008 WEO Reference projection. Realized 2020 nuclear generation was 0.75 times the 2010 WEO Current Policies projection. Gas went the other way. Realized 2025 gas generation was 1.18 times the 2008 WEO Reference projection. The coal pattern has a history. In the early part of the century the IEA underprojected coal, when China's buildout ran ahead of the outlooks. Early-2000s WEOs underprojected 2010 coal power capacity by an average of about 350 GW, or 21 percent. Since then it has overprojected. Nuclear has been overprojected throughout. WEO reports of the 2010s projected nuclear capacity rising about 50 percent by 2035 from 2012 despite stagnant capacity.

The total held up

Despite those misses, total electricity was projected well. Realized 2025 total generation was 1.05 times the 2008 WEO Reference projection. The fossil share of total primary energy, the variable that matters most for emissions, was projected well too. The realized fossil share of world primary energy in 2024 was 79.4% (IEA basis, WEO-2025 Table A.1a). Across the seven WEO vintages (2002-2015), the projected 2024 fossil share missed the outcome by at most 3.3pp. On average the vintages projected a 2024 fossil share 1.5pp above the outcome.

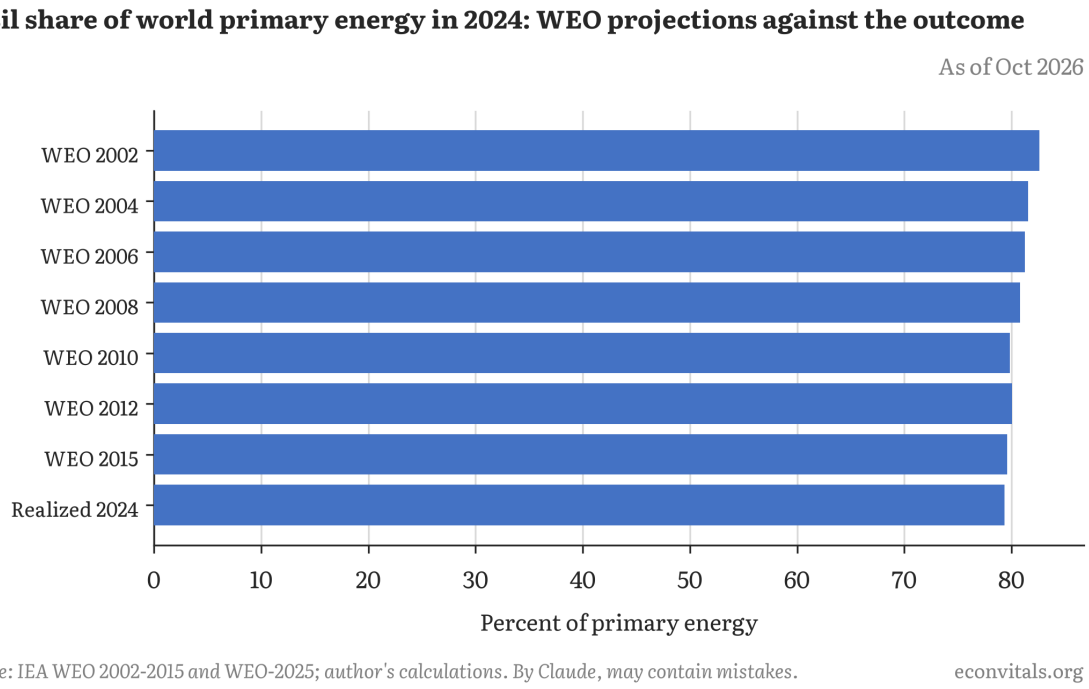


Figure 10. Each IEA World Energy Outlook reference scenario's projection for 2024, by edition, beside the realized share. The editions missed solar and wind by multiples, yet the fossil share of total energy came in close to every projection.

Source: IEA WEO 2002-2015 and WEO-2025; author's calculations. By Claude, may contain mistakes.

This is the most important single fact about the energy-mix scorecard. The IEA's own assessment agrees. Fossil fuels supplied nearly four-fifths of global energy demand in 2024, a share the IEA says has fallen only marginally since 2000.[19] Solar and wind grew from a small base, and a projection that missed them by a multiple still missed the total energy mix by little. The surprise sits inside electricity, which is a minority of final energy, and it has so far mostly displaced growth in coal rather than cut deeply into the stock of fossil energy.

Why the IEA missed: costs, conventions, or conservatism

The literature offers three complementary explanations.

The first is costs. Way, Ives, Mealy and Farmer (2022) scored thousands of model projections of solar cost declines.[20] Way et al. examined 2,905 integrated assessment model scenarios' projections of the annual rate of solar PV system cost decline between 2010 and 2020. The mean integrated-assessment-model projection was for solar PV system costs to fall 2.6 percent per year between 2010 and 2020, and every projection was below 6 percent. Solar PV costs actually fell about 15 percent per year between 2010 and 2020. Past projections of present renewable energy costs by influential energy-economy models have consistently been much too high. The trend they fit is simple. For several decades the costs of solar PV, wind and batteries have dropped roughly exponentially at a rate near 10 percent per year. Projections that used that trend would have done better than the models did.

The second is the convention of projecting only enacted policy. The IEA's current-policies case assumes no policy beyond what is in law. Feed-in tariffs, auctions and Chinese industrial programs that came later therefore show up as misses. Mohn (2020) weighs this and rejects stakeholder bias.[21] Mohn rejects stakeholder (member-state and oil-industry) bias as the explanation and favors institutional conservatism, capital-vintage effects and adjustment costs. Mohn judges that the IEA's under-projection of solar and wind is more likely due to biased parameterization, restrictions and cost assumptions than to the functional form of the World Energy Model. His most useful observation cuts against the usual critique. Ex post, the IEA's Current Policies scenario was the most accurate guide to aggregate energy demand and greenhouse gas emissions, while new renewables tracked the 450 scenario. The current-policies case got the aggregates right while missing the composition.

The third is how models represent technology. In the WEO, technological change is exogenous and continuous, so technology shocks or sudden breakthroughs are ruled out. Jaxa-Rozen and Trutnevyte (2021) find that the modeler matters more than the cost input.[22] General scenario features alone (organization, model, date, policy framing) classify scenarios into PV-growth quintiles with 73 percent accuracy. Adding PV capital-cost assumptions raises classification accuracy only to 77 percent for the 116 scenarios that report costs, and cost ranks below date, archetype, model boundaries and constraints, and climate policy as a predictor. The IPCC AR5 and SR1.5 scenario ensembles are relatively conservative about PV growth and capital costs, particularly in the near term.

Our view: the solar miss was mainly a learning-rate miss, compounded by a policy convention that excluded the deployment policies that drove the learning. The two are hard to separate because policy-driven deployment is what moves a technology down its learning curve.

Why it ended up different: growth, efficiency and carbon intensity

The Kaya accounting

Emissions are the product of four factors: population, income per person, energy per unit of income, and CO2 per unit of energy. A decomposition apportions any change in emissions among them. It is an accounting identity, not a causal model: it says which factor moved, not why.

We ran two versions: one decomposes the actual change in world emissions, the other the gap between the latest year and a path on which each factor kept its early-century growth.

On the second measure the four factors contributed in similar measure. World fossil CO2 in 2024 was -7.81 Gt of CO2 relative to a path on which all four Kaya factors kept their 2000-2013 growth rates. Slower growth of GDP per person accounted for -1.05 Gt of CO2 of that gap. Slower population growth accounted for -1.09 Gt of CO2. Faster decline in energy per unit of

GDP accounted for -2.74 Gt of CO2. Faster decline in CO2 per unit of energy accounted for -2.93 Gt of CO2. Slower growth of population and income, the "other factors" in the question, account for a little over a quarter of the gap. Faster improvement in energy intensity accounts for about a third, and a falling carbon intensity of energy for the largest single share, narrowly.

Kaya decomposition of fossil CO2 (log-mean Divisia), GtCO2

region and period	population	gdp_per_capita	energy_intensity	carbon_intensity	total_change
World 2005-2013	3.23	5.65	-4.08	0.87	5.68
World 2013-2024	4.2	8.22	-7.28	-1.82	3.32
World gap vs 2000-2013 trend, 2024	-1.09	-1.05	-2.74	-2.93	-7.81
China 2005-2013	0.35	5.65	-2.47	0.53	4.06
China 2013-2024	0.37	6.65	-3.47	-1.19	2.35
China gap vs 2000-2013 trend, 2024	-0.55	-6.68	-2.36	-1.38	-10.96
United States 2005-2013	0.4	0.22	-0.92	-0.36	-0.65
United States 2013-2024	0.37	1.04	-1.37	-0.6	-0.57
United States gap vs 2000-2013 trend, 2024	-0.13	0.5	-0.19	-0.31	-0.14
EU27 2005-2013	0.05	0.17	-0.58	-0.2	-0.56
EU27 2013-2024	0.05	0.48	-0.92	-0.36	-0.75
EU27 gap vs 2000-2013 trend, 2024	-0.02	0.17	-0.41	-0.17	-0.43
India 2005-2013	0.18	0.61	-0.1	0.11	0.8
India 2013-2024	0.29	1.34	-0.49	0.06	1.2
India gap vs 2000-2013 trend, 2024	-0.2	0.02	-0.18	-0.06	-0.43

Figure 11. Contributions of population, GDP per person (PPP), energy per unit of GDP and CO2 per unit of energy to the change in emissions over each period, and to the 2024 gap against a path where each factor kept its 2000-2013 growth rate. Rows sum to total_change. An accounting split, not a causal one.

Sources: Global Carbon Budget 2025; World Bank WDI; Energy Institute via Our World in Data. By Claude, may contain mistakes.

The timing matters more than the total. On the first measure, carbon intensity reversed sign between the two periods. Over 2005-2013 the carbon-intensity term was 0.87 Gt of CO2. Over 2013-2024 the carbon-intensity term was -1.82 Gt of CO2. Over 2005-2013 the energy-intensity term was -4.08 Gt of CO2. Over 2013-2024 the energy-intensity term was -7.28 Gt of CO2. Before the turn, carbon intensity was rising, as China's coal buildout added carbon-heavy energy, and energy intensity was the only factor holding emissions back. Since the turn, carbon intensity has fallen, though energy intensity is still the larger term in absolute size.

That qualifies the pre-specified hypothesis. Before the turn, slower growth and falling energy intensity explain essentially all of the shortfall. Since then carbon intensity has become a large term, narrowly the largest on the trend-gap measure, but energy intensity still dominates the actual decline.

China's slowdown was mostly growth

China dominates the global numbers, and its gap is mostly about growth. China's 2024 emissions were -10.96 Gt of CO2 relative to its 2000-2013 Kaya-factor trends. Slower GDP-per-person growth accounted for -6.68 Gt of CO2 of China's gap. The China gap is larger than the world gap because continuing China's early-century growth rates for another decade produces a very high counterfactual; the shares are what matter. The Global Carbon Budget reaches the same conclusion. China's fossil emissions growth fell from 6.7 percent a year in 2005-2014 to 2.5 percent in 2015-2024, driven by weaker economic growth (about 5 percentage points), partly offset by a slower decline in energy per GDP (about four points). The IEA credits structural change as well as growth. The IEA dates the peak of China's industrial coal consumption to 2014 and credits Chinese economic restructuring with the marked slowdown in global industrial energy-use growth over the past decade.

This is the main argument for treating part of the post-turn shortfall as cyclical. Slower Chinese growth reflects in part the end of an investment-led boom, not climate policy, and a growth recovery would reverse some of this term. The structural case rests on the latest data. The Global Carbon Budget projects that China's fossil CO2 emissions rose only 0.4% in 2025, a slight increase. UNEP's updated current-policy projections show China's emissions peaking around 2025 and then falling, where earlier projections had growth to 2030. Which reading is right is open.

The developed-country decline

Le Quéré et al. (2019) studied the developed economies whose emissions peaked and then declined.[23] Emissions in the 18 peak-and-decline countries fell by a median -2.4 percent per year a year over 2005-2015. A falling fossil share of final energy accounted for a median 47 percent of the 2005-2015 emissions decline in the 18 countries. Integrated assessment models assumed annual GDP growth of 2.4 percent per year, more than double the rate observed in the peak-and-decline countries. In these countries, slower growth again explains much of the gap against the scenarios. Burgess, Ritchie, Shapland and Pielke (2021) generalize the point.[24] The 2005-2017 divergence of CO2 emissions from IPCC baseline scenarios is primarily due to the baselines over-projecting per-capita GDP growth, with all SSP baselines too high in all regions. From 2005 to 2017, global energy CO2 emissions grew more slowly than in 83 percent of IPCC AR5 baseline scenarios. They also identify the modeling assumption that failed in the other direction. Most AR5 and SSP baselines assume carbon intensity would not decline without climate policy, whereas the past decade suggests factors beyond climate policy cause carbon-intensity declines. One reason high-emission baselines diverge on coal is that they substantially over-projected the cost of solar power relative to coal and other fossil fuels.

Burgess and coauthors also checked the baselines' intensity assumptions. Globally, AR5 and SSP baseline energy-intensity projections were consistent with observed 2005-2017 trends. AR5 baseline scenarios slightly under-projected the decline in carbon intensity in every region over

2005-2017. The baselines got growth wrong, not intensity, consistent with our accounting for the early period.

Policy, technology or something else

What can be measured directly

We sized the two channels of carbon-intensity improvement that can be bounded from generation data.

U.S. coal-to-gas switching in power over 2005-2024 avoided about 0.46 Gt of CO2 in 2024 (gas growth that replaced coal, times the coal-gas emission-factor gap; Ember factors). That U.S. switch equals 6% of the world's 2024 shortfall against its 2000-2013 trend. Shale gas made that switch possible, and the IEA describes shale as a joint product of energy policy and private enterprise. The IEA says the rise of U.S. shale was driven by energy policy together with private innovation, risk-taking capital markets and high global energy prices.

Wind and solar did far more. Wind and solar generation added worldwide since 2013 displaced at least 2.3 Gt of CO2 in 2024 (if it displaced gas) … … and at most 3.5 Gt of CO2 (if it displaced coal). That bound is 30% of the world's 2024 shortfall against the 2000-2013 trend at the gas-displacement end … … and 45% at the coal-displacement end. Wind and solar displacement since 2013 equals 79% of the carbon-intensity part of that shortfall at the gas-displacement end (above 100 means other forces pushed carbon intensity the other way). The IEA's own estimate, made a different way for a shorter period, is in the same range. The IEA estimates that low-emissions technologies deployed since 2019 (solar PV, wind, nuclear, electric cars and heat pumps) now avoid 2.6 Gt of CO2 a year, about 7 percent of global emissions.

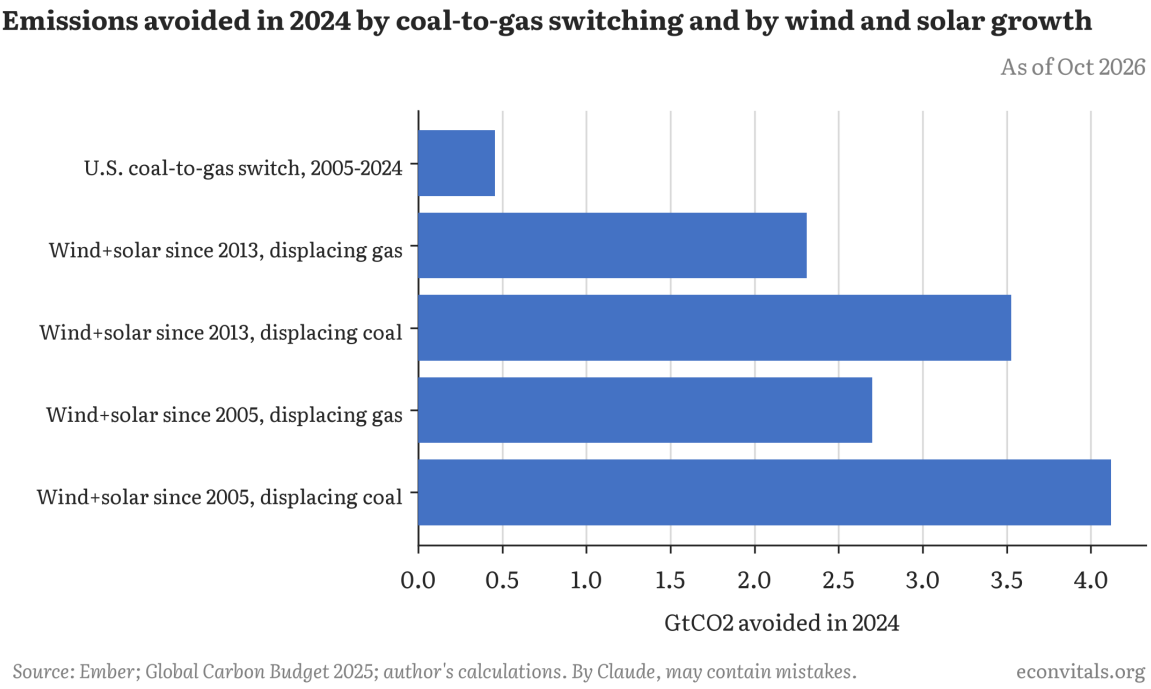


Figure 12. Bounds on the 2024 emissions avoided by two channels of carbon-intensity improvement. Wind and solar are bounded by whether the new generation displaced gas or coal; explicit carbon pricing could not be sized on the same basis.

Source: Ember; Global Carbon Budget 2025; author's calculations. By Claude, may contain mistakes.

So the carbon-intensity improvement since the turn is mostly wind and solar, and the U.S. coal-to-gas switch is a small piece of it globally. We could not size explicit carbon pricing on the same basis. No published estimate of emissions abated by the EU Emissions Trading System was among the sources, and we chose not to infer it as a residual. The hypothesis that explicit pricing is the smallest of the three channels is therefore a judgment from the literature here, not a measured result.

Climate legislation as a whole

The broadest estimate of policy comes from Eskander and Fankhauser (2020), who studied climate laws in a large panel of countries.[25] The analysis covers 1,092 mitigation laws in 133 countries over 1999-2016. Each new national climate mitigation law reduces annual CO2 emissions per unit of GDP by about 0.78 percent in the short term (first three years). Each new national climate mitigation law reduces annual CO2 emissions per unit of GDP by about 1.79 percent in the long term (beyond three years). By 2016, national climate laws were associated with annual global CO2 emissions 5.9 Gt of CO2 lower than a no-legislation counterfactual. The 2016 legislation effect equals a cut in annual CO2 emissions of about 15 percent from the no-legislation baseline. Globally, climate legislation offset only about a third of CO2 emissions growth between 1999 and 2016, while in OECD/EU countries it is credited with holding CO2 at roughly 1999 levels.

Two features matter for reconciling this with the accounting above. The outcome is CO2 per unit of GDP, so a law that improves efficiency counts. And the design removes the common global trend in technology. The global fall in clean technology costs is absorbed by the year fixed effect, so the law coefficients are estimated net of common technology trends. Cost declines common to all countries are absorbed by the year effect. The estimate measures policy's effect on top of technology, not policy's role in creating it.

Why *technology unrelated to climate policy* is mostly an empty category

The solar learning curve did not happen on its own. Grubb and coauthors reviewed the induced-innovation literature.[26] Decomposing solar PV cost declines, Kavlak et al. (2018), as reviewed, estimate that public R&D and spillovers accounted for almost 50 percent of cost reductions over 1980–2000. From 2001 to 2012, public R&D and spillovers accounted for roughly one quarter (25 percent) of solar PV cost reduction, with scale economies and learning-by-doing accounting for about half (Kavlak et al. 2018, as reviewed). Kavlak et al. (2018) suggest the remaining PV cost reduction, attributed to private R&D, was largely catalyzed by deployment-support policies such as feed-in tariffs. The review concludes that numerous lines of evidence point to dominant causality from at-scale deployment to cost reduction.

Those deployment policies were climate and energy policies, from European feed-in tariffs to Chinese support for manufacturing and deployment. The cost decline that the IEA projections missed was therefore induced in large part by policies that the IEA's convention excluded until they were law. The review also finds that targeted policy pulls harder than carbon pricing. The review judges that well-designed targeted policies may provide a far stronger pull on innovation than any plausible level of general carbon pricing.

The clean categories of *technology unrelated to climate policy* are narrow. Shale gas is one, though even it had policy support. General efficiency progress is another, and part of it responds to prices rather than policy. Knittel (2012) finds gasoline prices, not fuel-economy standards, were the principal driver of a 60 percent improvement in U.S. car and truck fuel efficiency over 1990–2006, once weight and power are controlled for. The IEA itself says both forces operate. The IEA states that innovation and technology progress occur both in response to policies and independently of them.

A rough apportionment

Before the turn there was no shortfall to explain. Emissions ran at the top of the range, and the scenarios that did best happened to project slower growth and faster efficiency gains.

Since the turn, three forces of similar size explain why emissions fell below the high scenarios. Slower growth, concentrated in China and only partly structural, accounts for a little over a quarter of the gap against trend. Faster improvement in energy intensity accounts for about a third; its causes mix structural change in China's economy, efficiency technology, prices and

efficiency policy. Falling carbon intensity accounts for narrowly the largest share on this measure, and most of it is wind and solar displacing coal and gas.

On the policy question, then, the answer depends on how one counts. Explicit carbon pricing is probably the smallest channel, though we could not size it. Climate legislation in total, net of common technology trends, is a material but minority contributor. Deployment policy induced part of the cost decline behind the carbon-intensity term; the evidence covers solar more than wind or batteries. Even counting all wind and solar displacement as policy puts policy's share (30% to 45%) about level with energy intensity's, not clearly above it. Counting only the induced part puts it lower. Policy and technology are entangled, and any single ratio hides that.

What this means for today's projections

The current benchmarks have moved down

Today's benchmarks embed the lessons of the last two decades, and they have moved down accordingly. The IEA's 2025 World Energy Outlook puts global energy-related CO2 emissions in 2050 under its Current Policies Scenario some 10 Gt lower than the same scenario projected when it was last modeled in 2019. The IEA now projects emissions flat to falling under existing policies. In the IEA's Current Policies Scenario, global energy-related CO2 emissions rise from 38 Gt in 2024 to 39 Gt in the early 2030s and stay around that level to 2050. In the IEA's Stated Policies Scenario, global energy-related CO2 emissions fall to around 35 Gt by 2035, a level last seen in 2015. The implied warming has come down with them. The IEA's projected 2100 warming is almost 3 °C under its Current Policies Scenario and 2.5 °C under its Stated Policies Scenario. In its 2025 report, UNEP projected that a continuation of current policies would hold warming this century below 2.8 °C with a 66 percent chance.[27] UNEP's newest edition, released in late October, was not among the sources read here.

The IPCC itself has downgraded the high scenarios. AR6 judges the likelihood of the high-emissions RCP8.5 and SSP5-8.5 scenarios to be low in light of recent energy-sector developments, and notes that IEA WEO 2020 stated policies implies roughly constant fossil CO2 emissions to 2070, in line with RCP4.5, RCP6.0 and SSP2-4.5. Pielke, Burgess and Ritchie (2022) found that the IEA's projection lined up with the plausible scenarios. The median 2050 emissions of the plausible scenarios are essentially identical to the IEA's independent WEO 2021 projection.

But the downward revisions have just reversed

The latest round of projections moved the other way for the first time. The STEPS warming outcome in the 2025 edition is about 0.1 °C higher than in the 2024 edition, the first year the IEA reports the gap between stated policies and climate targets widening rather than narrowing. The IEA's 2025 Stated Policies Scenario has the United States with 30% less renewables capacity in 2035 than the 2024 edition did. The 2025 Stated Policies Scenario projects coal demand in 2035 10% higher than the 2024 edition did, mainly for power in China and the United States, and natural gas 8 percent higher. UNEP records the same shift for U.S. emissions. In the same report, UNEP's 2030 projection for U.S. emissions under current policies rose by 1 Gt of CO2-equivalent from the prior edition, largely because of policy reversals. The Global Carbon Budget projects a U.S. emissions rise in the latest year. U.S. fossil CO2 emissions are projected to rise 2.5 percent in 2025, reversing long-term decreases.

Which projections to trust

The scorecard suggests a simple ranking.

The physics deserves the most trust, conditional on the inputs. Temperature projections scored per unit of realized forcing have held up, and concentration projections have held up given emissions. That trust belongs to the assessed ranges, not raw model output. AR6 finds the CMIP6 models' range of equilibrium climate sensitivity broader than the very likely range it assesses by combining multiple lines of evidence. The open question is sensitivity at the high end, which the acceleration debate keeps alive.

Aggregate energy demand and the fossil share of total energy deserve moderate trust at horizons of a decade or two. The IEA's current-policies case got these right while missing everything inside electricity.

The composition of electricity supply deserves the least trust. Projections of solar and wind have missed by multiples for two decades, and the error has always run in the same direction. The cost trend that Way and coauthors fit has done better than the models; a reader should weight it more heavily than any scenario's cost assumption.

Emissions projections deserve moderate trust at short horizons and little beyond a decade. Their error has run in both directions, and it has turned on growth in a single economy that no model forecast well.

For the SSPs specifically, the lesson is to treat SSP5-8.5 and SSP3-7.0 as stress tests, not baselines, for the next few decades. The plausible central paths now cluster around SSP2-4.5, which on our numbers sat close to the latest observed emissions.

What commentators are saying

Substacks & blogs. Noah Smith argues the global electric-vehicle and battery revolution is accelerating worldwide, with components largely made in China. Noah Smith relays reports that China is disinvesting in renewable generation while accelerating fossil-fuel plant and grid-storage investment amid its economic slowdown. **Think tanks.** Harvard Kennedy School / M-RCBG: Aldy and Tingley estimate that a first-wave industrial carbon-pricing coalition with border adjustments could cut global greenhouse gas emissions by about 1.5% relative to 2023 levels.

The commentary view worth weighing is the dissent on China. If new Chinese power investment tilts back toward fossil plants as growth slows, the cyclical reading gains ground.[28] The one new climate-policy proposal in recent commentary is small relative to global emissions.[29]

Methods and limits

What was pre-specified. The numbers analysis was planned before the data were examined. The growth-rate comparisons across periods, the cross-checks on CO2 growth and the re-basing of Hansen's call are exploratory; the rest was pre-specified. Global fossil CO2 grew 1.1% a year over 1990-2000.

Data. Temperature is the mean of GISTEMP v4, Berkeley Earth and HadCRUT5, each re-based to a common pre-industrial baseline. Emissions are the Global Carbon Budget territorial fossil series, net of cement carbonation. Concentrations are NOAA's global marine-surface means. Generation is Ember. Scenario paths come from the IPCC's SRES files and the RCMIP harmonized RCP and SSP data. Past temperature projections come from the Hausfather digitization. WEO projections were read from each edition's World annex tables.[1]

Identity checks. The Kaya terms sum to the total change by construction, and the emitter contributions sum to the world shortfall. Our concentration for the previous year matches the published figure, and our fossil emissions match the Budget's published total. The source put 2024 global mean CO2 at about 422.8 ppm; the frozen NOAA GML global annual mean is 422.79 ppm (exploratory check).

What the analysis cannot determine. Four limits matter most. First, the Kaya decomposition is an accounting split, not a causal one. Second, the trend-gap counterfactual assumes the early-century trends would have continued. For China that assumption is generous, so its share is better read in relative than absolute terms. Third, the wind-and-solar bounds assume the new generation displaced fossil generation one for one. If it partly met new demand, it displaced less. Fourth, the temperature scoring beyond the published windows is as issued only, because we did not assemble the forcing series a forcing-adjusted update would need.

What is missing. The central forcing-adjusted test is the Hausfather paper, which the analysis used through its published data and the AR6 chapter's summary. The Peters et al. (2013) scoring of the early miss and Creutzig et al. (2017) on solar are available only in summary. We could not score the IS92 scenarios or the AR5 and AR6 near-term envelopes from machine-readable files, so the AR4 envelope stands in for the latter. We did not score the IEA's stated-policies cases against outcomes, so the energy-mix scorecard is for reference and current-policies cases only. And we could not size explicit carbon pricing, so that part of the attribution rests on the literature.

What to monitor

- **China's emissions in the coming year.** A year of flat or falling emissions with GDP growth near its recent pace would support the structural reading. A rebound with a growth recovery would support the cyclical one.
- **The annual indicators update.** The next Forster update will show whether the warming rate tracks the upper end of AR6's range or exceeds it, and whether aerosol estimates move toward Hansen's. PIIE's Insider newsletter headlined that a super El Niño has arrived. A strong El Niño lifts temperatures and the CO2 growth rate for a year or two, whatever the trend.
- **The IEA's next World Energy Outlook.** Whether the upward revisions to coal and gas projections continue, and whether solar additions again exceed the current-policies case. It arrives during an energy-price shock. CFR's Benn Steil attributes the past year's rise in U.S. and euro-area inflation to higher energy prices tied to the stalemate in the Strait of Hormuz.
- **U.S. renewables deployment under the policy rollback.** A modest slowdown would favor the cost explanation of the post-turn decline; a sharp one would favor the policy explanation.
- **The land sink.** A return of the airborne fraction toward its long-run average after the El Niño would confirm that the latest jump was weather. A persistent rise would be an unwelcome carbon-cycle surprise.
- **Methane.** Whether growth slows as the methane pledges take effect, or stays near the high scenarios, with the wetland feedback a growing share.

Appendix

This appendix sets out every series and transform the numbers analysis computed.

Temperature projections scored against the record

Projection	As issued, ratio to observed trend	Per unit realized forcing, ratio
Hansen et al. (1988) Scenario B	1.52	1.20
IPCC FAR best estimate	1.37	0.88

Extended to the latest year, as issued	Ratio of projected to observed trend
IPCC FAR best estimate	1.16
IPCC TAR best estimate	0.69
IPCC AR4 multi-model mean	0.66

Quantity	Value
Projections scored	8
Within a quarter, as issued	2
Within a quarter, per unit forcing	4
Observed temperature, latest year	1.39 °C
Observed average, latest decade	1.24 °C
Observed trend, latest eleven years	0.29 °C
Observed trend, from Hansen's publication	0.22 °C
AR4 low end, recent trend	0.24 °C
AR4 high end, recent trend	0.26 °C
Position of observed trend in AR4 range	2.02

Fossil CO2 emissions against the scenarios

Global fossil CO2 emissions were 37.8 Gt of CO2 in 2024 (Global Carbon Budget 2025, net of cement carbonation). Each cell below is the scenario's projection for that year relative to the outcome; positive means the scenario was above.

Scenario	Deviation, latest year
SRES A1FI	22%
SRES A2	17%
SRES A1B	25%

Scenario	Deviation, latest year
SRES B1	2%
SRES B2	-8%
RCP8.5	21%
RCP6.0	-9%
RCP4.5	0%
RCP2.6	-18%
SSP5-8.5	17%
SSP2-4.5	2%

Early comparison and cumulative measures	Deviation
SRES A1FI, first comparison year	-3%
SRES A2, first comparison year	-5%
SRES B1, first comparison year	-5%
RCP8.5 cumulative fossil CO2	8.9%
RCP8.5 cumulative total CO2, including land use	2.7%

Growth of world fossil CO2	Annual rate
Before the century	1.1%
Early century to the turn	2.4%
Since the turn	0.8%

Emitters against their own trends

Item	GtCO2
World shortfall against trend, latest year	-4.9 Gt
China’s part of that shortfall	-3.0 Gt
India against its own trend	0.34 Gt
World rise, early period	9.8 Gt
China rise, early period	6.3 Gt

Item	GtCO2
China rise, since the turn	2.35 Gt
India rise, since the turn	1.20 Gt
U.S. change, since the turn	-0.57 Gt
EU27 change, since the turn	-0.75 Gt

Kaya decomposition

World gap against a path with early-century factor growth	GtCO2
Total	-7.81 Gt
GDP per person	-1.05 Gt
Energy per unit of GDP	-2.74 Gt
CO2 per unit of energy	-2.93 Gt
Population	-1.09 Gt

World change, by term and period (LMDI)	GtCO2
GDP per person, full period	13.47 Gt
Energy intensity, full period	-10.96 Gt
Carbon intensity, full period	-0.76 Gt
Carbon intensity, before the turn	0.87 Gt
Carbon intensity, since the turn	-1.82 Gt
Energy intensity, before the turn	-4.08 Gt
Energy intensity, since the turn	-7.28 Gt

China gap against its own factor trends	GtCO2
Total	-10.96 Gt
GDP per person	-6.68 Gt
Energy intensity	-2.36 Gt
Carbon intensity	-1.38 Gt

Other emitters, full period (LMDI)	GtCO2
United States, carbon intensity	-0.98 Gt
United States, energy intensity	-2.32 Gt
EU27, carbon intensity	-0.57 Gt
India, GDP per person	1.86 Gt

Concentrations and the airborne fraction

Measure	Value
Global mean CO2, previous year	422.8 ppm
Global mean CO2, latest year	425.6 ppm
RCP8.5 level deviation	1.3%
RCP4.5 level deviation	-0.6%
RCP2.6 level deviation	-0.5%
SSP5-8.5 level deviation	1.3%
SSP2-4.5 level deviation	0.8%
RCP8.5 rise-since-base deviation	12%
RCP4.5 rise-since-base deviation	-6%
RCP2.6 rise-since-base deviation	-5%
NOAA growth, exploratory check	3.44 ppm
Budget growth in ppm, exploratory check	3.73 ppm

Airborne fraction	Share
Earliest decade of the record	36%
Fourth decade of the record	39%
Last full decade	46%
Latest five years	51%
Lowest decade	36%
Highest period	51%

The energy mix against the IEA World Energy Outlook

Ratio of realized to projected generation	Ratio
Solar, WEO-2002 Reference	31.57
Solar, WEO-2004 Reference	19.82
Solar, WEO-2006 Reference	8.54
Solar, WEO-2008 Reference	13.96
Solar, WEO-2010 Current Policies	5.46
Solar, WEO-2012 Current Policies	2.66
Solar, WEO-2015 Current Policies	1.81
Wind, WEO-2002 Reference	5.18
Wind, WEO-2004 Reference	2.85
Wind, WEO-2008 Reference	2.19
Wind, WEO-2010 Current Policies	1.47
Wind, WEO-2012 Current Policies	1.39
Coal, WEO-2008 Reference	0.78
Coal, WEO-2010 Current Policies	0.81
Coal, WEO-2015 Current Policies	0.87
Nuclear, WEO-2008 Reference	0.83
Nuclear, WEO-2010 Current Policies	0.75
Gas, WEO-2008 Reference	1.18
Total, WEO-2008 Reference	1.05

Level	Generation
World solar, latest year	2,807 TWh
World wind, latest year	2,705 TWh
WEO-2008 solar projection for that year	201 TWh

Fossil share of primary energy	Share
Realized	79.4%
WEO-2002 Reference projection	82.6%
WEO-2008 Reference projection	80.8%
WEO-2010 Current Policies projection	79.8%
Largest miss across editions	3.3pp
Average miss across editions	1.5pp

Bounds on the carbon-intensity channels

Channel	Value
U.S. coal-to-gas switching, avoided	0.46 Gt
Share of world shortfall against trend	6%
Wind and solar since the turn, gas end	2.3 Gt
Wind and solar since the turn, coal end	3.5 Gt
Share of shortfall, gas end	30%
Share of shortfall, coal end	45%
Share of carbon-intensity term, gas end	79%
Wind and solar over the full period, gas end	2.7 Gt
Wind and solar over the full period, coal end	4.1 Gt

Horizon errors

The full mean-absolute-error table is the scorecard in the body; the electricity rows not shown there are gas generation at the three horizons: 10%, 7% and 14%.

Notes

1. Own analysis. Temperature: NASA GISTEMP v4, Berkeley Earth and HadCRUT5 (via Our World in Data). Emissions and the airborne fraction: Global Carbon Budget 2025. Concentration: NOAA Global Monitoring Laboratory. Generation: Ember. GDP and population: World Bank. Primary energy and fossil share: Our World in Data and IEA World Energy Outlook 2025, Annex A. Scenarios: IPCC SRES marker files (via pymagicc) and RCMIP v5.1.0. Past temperature projections: Hausfather et al. (2020) digitization, github.com/hausfath/OldModels. Past WEO projections: World Energy Outlook 2002, 2004, 2006, 2008, 2010, 2012 and 2015, World annex tables.

2. Hausfather, Z., Drake, H. F., Abbott, T. and Schmidt, G. A. (2020). "Evaluating the Performance of Past Climate Model Projections." *Geophysical Research Letters*. https://doi.org/10.1029/2019GL085378

3. Hansen, J., Fung, I., Lacis, A., Rind, D., Lebedeff, S., Ruedy, R., Russell, G. and Stone, P. (1988). "Global Climate Changes as Forecast by Goddard Institute for Space Studies Three-Dimensional Model." *Journal of Geophysical Research*. https://pubs.giss.nasa.gov/abs/ha02700w.html

4. Chen, D., Rojas, M., Samset, B. H., Cobb, K., et al. (2021). "Framing, Context, and Methods." Chapter 1 in *Climate Change 2021: The Physical Science Basis*, IPCC Sixth Assessment Report, Working Group I. https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-1/

5. Forster, P. M., Smith, C., Walsh, T., Lamb, W. F., Lamboll, R., et al. (2025). "Indicators of Global Climate Change 2024." *Earth System Science Data*. https://doi.org/10.5194/essd-17-2641-2025

6. Forster, P. M., Walsh, T., Smith, C., Lamb, W. F., Hausfather, Z., et al. (2026). "Indicators of Global Climate Change 2025." *Earth System Science Data* (preprint). https://essd.copernicus.org/preprints/essd-2026-287/

7. Hansen, J. E., Kharecha, P., Sato, M., Tselioudis, G., et al. (2025). "Global Warming Has Accelerated: Are the United Nations and the Public Well-Informed?" *Environment: Science and Policy for Sustainable Development*. https://doi.org/10.1080/00139157.2025.2434494

8. Hansen, J. E., Sato, M., Simons, L., Nazarenko, L. S., et al. (2023). "Global warming in the pipeline." *Oxford Open Climate Change*. https://academic.oup.com/oocc/article/3/1/kgad008/7335889

9. Raupach, M. R., Marland, G., Ciais, P., Le Quéré, C., Canadell, J. G., Klepper, G. and Field, C. B. (2007). "Global and regional drivers of accelerating CO2 emissions." *Proceedings of the National Academy of Sciences*. https://doi.org/10.1073/pnas.0700609104

10. Manning, M. R., Edmonds, J., Emori, S., Grubler, A., et al. (2010). "Misrepresentation of the IPCC CO2 emission scenarios." *Nature Geoscience*. https://www.nature.com/articles/ngeo880

11. Peters, G. P., Andrew, R. M., Boden, T., Canadell, J. G., Ciais, P., Le Quéré, C., Marland, G., Raupach, M. R. and Wilson, C. (2013). "The challenge to keep global warming below 2 °C." *Nature Climate Change*. https://doi.org/10.1038/nclimate1783

12. Friedlingstein, P., et al. (2026). "Global Carbon Budget 2025." *Earth System Science Data*. https://essd.copernicus.org/articles/18/3211/2026/

13. Hausfather, Z. and Peters, G. P. (2020). "Emissions: the 'business as usual' story is misleading." *Nature*. https://www.nature.com/articles/d41586-020-00177-3

14. Schwalm, C. R., Glendon, S. and Duffy, P. B. (2020). "RCP8.5 tracks cumulative CO2 emissions." *Proceedings of the National Academy of Sciences*. https://doi.org/10.1073/pnas.2007117117

15. Hausfather, Z. and Peters, G. P. (2020). "RCP8.5 is a problematic scenario for near-term emissions." *Proceedings of the National Academy of Sciences*. https://www.pnas.org/doi/10.1073/pnas.2017124117

16. Pielke, R., Jr., Burgess, M. G. and Ritchie, J. (2022). "Plausible 2005-2050 emissions scenarios project between 2 °C and 3 °C of warming by 2100." *Environmental Research Letters*. https://doi.org/10.1088/1748-9326/ac4ebf

17. Saunois, M., et al. (2025). "Global Methane Budget 2000-2020." *Earth System Science Data*. https://doi.org/10.5194/essd-17-1873-2025

18. Metayer, M., Breyer, C. and Fell, H.-J. (2015). "The projections for the future and quality in the past of the World Energy Outlook for solar PV and other renewable energy technologies." Energy Watch Group and Lappeenranta University of Technology. https://energywatchgroup.org/wp/en/studies/

19. International Energy Agency (2025). *World Energy Outlook 2025*. https://www.iea.org/reports/world-energy-outlook-2025

20. Way, R., Ives, M. C., Mealy, P. and Farmer, J. D. (2022). "Empirically grounded technology forecasts and the energy transition." *Joule*. https://doi.org/10.1016/j.joule.2022.08.009

21. Mohn, K. (2020). "The gravity of status quo: A review of IEA's World Energy Outlook." *Economics of Energy & Environmental Policy*. https://doi.org/10.5547/2160-5890.8.2.kmoh

22. Jaxa-Rozen, M. and Trutnevyte, E. (2021). "Sources of uncertainty in long-term global scenarios of solar photovoltaic technology." *Nature Climate Change*. https://doi.org/10.1038/s41558-021-00998-8

23. Le Quéré, C., Korsbakken, J. I., Wilson, C., Tosun, J., Andrew, R., et al. (2019). "Drivers of declining CO2 emissions in 18 developed economies." *Nature Climate Change*. https://doi.org/10.1038/s41558-019-0419-7

24. Burgess, M. G., Ritchie, J., Shapland, J. and Pielke, R., Jr. (2021). "IPCC baseline scenarios have over-projected CO2 emissions and economic growth." *Environmental Research Letters*. https://doi.org/10.1088/1748-9326/abcdd2

25. Eskander, S. M. S. U. and Fankhauser, S. (2020). "Reduction in greenhouse gas emissions from national climate legislation." *Nature Climate Change*. https://doi.org/10.1038/s41558-020-0831-z

26. Grubb, M., Drummond, P., Poncia, A., McDowall, W., Popp, D., et al. (2021). "Induced innovation in energy technologies and systems: a review of evidence and potential implications for CO2 mitigation." *Environmental Research Letters*. https://doi.org/10.1088/1748-9326/abde07

27. UN Environment Programme (2025). *Emissions Gap Report 2025*. https://www.unep.org/resources/emissions-gap-report

28. Noahpinion (Noah Smith), September 1, 2026.

29. Harvard Kennedy School, Mossavar-Rahmani Center for Business and Government (Aldy and Tingley), September 21, 2026.

Principal sources

Principal sources behind this briefing, drawn from the evidence it cites. Public sources carry their publication and link; commentary is named by source and date.

- Annual Energy Outlook, Energy Information Administration, 2026. https://www.eia.gov/outlooks/aeo/
- World Energy Outlook, International Energy Agency, 2025. https://www.iea.org/reports/world-energy-outlook-2025
- Emissions Gap Report, UN Environment Programme, 2025. https://www.unep.org/resources/emissions-gap-report
- Framing, Context, and Methods (Chapter 1, including Section 1.3 on past projections), in Climate Change 2021: The Physical Science Basis, Working Group I Contribution to the IPCC Sixth Assessment Report, Deliang Chen, Maisa Rojas, Bjørn H. Samset, Kim Cobb, et al., IPCC AR6 WG1, Cambridge University Press, pp. 147-286, 2021. https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-1/
- Indicators of Global Climate Change 2024: Annual Update of Key Indicators of the State of the Climate System and Human Influence, Piers M. Forster, Chris Smith, Tristram Walsh, William F. Lamb, Robin Lamboll, et al., Earth System Science Data 17, 2641-2680, 2025. https://doi.org/10.5194/essd-17-2641-2025
- Global and regional drivers of accelerating CO2 emissions, Michael R. Raupach, Gregg Marland, Philippe Ciais, Corinne Le Quéré, Josep G. Canadell, Gernot Klepper, Christopher B. Field, Proceedings of the National Academy of Sciences 104(24), 10288-10293, 2007. https://doi.org/10.1073/pnas.0700609104
- Plausible 2005-2050 emissions scenarios project between 2 °C and 3 °C of warming by 2100, Roger Pielke Jr., Matthew G. Burgess, Justin Ritchie, Environmental Research Letters 17(2), 024027, 2022. https://doi.org/10.1088/1748-9326/ac4ebf
- RCP8.5 tracks cumulative CO2 emissions, Christopher R. Schwalm, Spencer Glendon, Philip B. Duffy, Proceedings of the National Academy of Sciences 117(33), 19656-19657, 2020. https://doi.org/10.1073/pnas.2007117117
- Drivers of declining CO2 emissions in 18 developed economies, Corinne Le Quéré, Jan Ivar Korsbakken, Charlie Wilson, Jale Tosun, Robbie Andrew, Robert J. Andres, Josep G. Canadell, Andrew Jordan, Glen P. Peters, Detlef P. van Vuuren, Nature Climate Change 9, 213-217, 2019. https://doi.org/10.1038/s41558-019-0419-7
- IPCC baseline scenarios have over-projected CO2 emissions and economic growth, Matthew G. Burgess, Justin Ritchie, John Shapland, Roger Pielke Jr., Environmental Research Letters 16, 014016, 2021. https://doi.org/10.1088/1748-9326/abcdd2
- Induced innovation in energy technologies and systems: a review of evidence and potential implications for CO2 mitigation, Michael Grubb, Paul Drummond, Alexandra Poncia, Will McDowall, David Popp, Sascha Samadi, Cristina Penasco, Kenneth T. Gillingham, Sjak Smulders, Matthieu Glachant, Gavin Hassall, Emi Mizuno, Edward S. Rubin, Antoine Dechezleprêtre, Giulia Pavan, Environmental Research Letters 16(4), 043007, 2021. https://doi.org/10.1088/1748-9326/abde07
- Reduction in greenhouse gas emissions from national climate legislation, Shaikh M. S. U. Eskander, Sam Fankhauser, Nature Climate Change 10, 750-756, 2020. https://doi.org/10.1038/s41558-020-0831-z
- Empirically grounded technology forecasts and the energy transition, Rupert Way, Matthew C. Ives, Penny Mealy, J. Doyne Farmer, Joule 6(9), 2057-2082, 2022. https://doi.org/10.1016/j.joule.2022.08.009
- Sources of uncertainty in long-term global scenarios of solar photovoltaic technology, Marc Jaxa-Rozen, Evelina Trutnevyte, Nature Climate Change 11, 266-273, 2021. https://doi.org/10.1038/s41558-021-00998-8
- The gravity of status quo: A review of IEA's World Energy Outlook, Klaus Mohn, Economics of Energy & Environmental Policy 9(1), 63-82 (bound in: working-paper precursor 'Undressing the emperor: A critical review of IEA's WEO', University of Stavanger Working Papers in Economics and Finance 2016/6), 2020.

https://doi.org/10.5547/2160-5890.8.2.kmoh

- Global Carbon Budget 2025, Pierre Friedlingstein et al. (Global Carbon Project), Earth System Science Data 18, 3211-3288, 2026. https://essd.copernicus.org/articles/18/3211/2026/
- Global Methane Budget 2000-2020, Marielle Saunois et al., Earth System Science Data 17, 1873-1958, 2025. https://doi.org/10.5194/essd-17-1873-2025
- Global Warming Has Accelerated: Are the United Nations and the Public Well-Informed?, James E. Hansen, Pushker Kharecha, Makiko Sato, George Tselioudis, et al., Environment: Science and Policy for Sustainable Development 67(1), 6-44, 2025. https://doi.org/10.1080/00139157.2025.2434494
- Indicators of Global Climate Change 2025: annual update of key indicators of the state of the climate system and human influence, Piers M. Forster, Tristram Walsh, Chris Smith, William F. Lamb, Zeke Hausfather, et al., Earth System Science Data (preprint essd-2026-287), 2026. https://essd.copernicus.org/preprints/essd-2026-287/
- Emissions - the 'business as usual' story is misleading, Zeke Hausfather, Glen P. Peters, Nature 577, 618-620, 2020. https://www.nature.com/articles/d41586-020-00177-3
- RCP8.5 is a problematic scenario for near-term emissions, Zeke Hausfather, Glen P. Peters, Proceedings of the National Academy of Sciences 117(45): 27791-27792, 2020. https://www.pnas.org/doi/10.1073/pnas.2017124117
- Global warming in the pipeline, James E. Hansen, Makiko Sato, Leon Simons, Larissa S. Nazarenko, et al., Oxford Open Climate Change 3(1): kgad008, 2023. https://academic.oup.com/oocc/article/3/1/kgad008/7335889
- The projections for the future and quality in the past of the World Energy Outlook for solar PV and other renewable energy technologies, Matthieu Metayer, Christian Breyer, Hans-Josef Fell, Energy Watch Group / Lappeenranta University of Technology report (also presented at the 31st European PV Solar Energy Conference), 2015. https://energywatchgroup.org/wp/en/studies/
- Global land-ocean surface temperature anomaly, calendar-year mean, °C vs 1951-1980 (NASA GISTEMP v4), NASA Goddard Institute for Space Studies, gistemp, 2025-01
- Global land+ocean surface temperature anomaly, calendar-year mean, °C vs 1951-1980 (Berkeley Earth, preliminary high-resolution dataset), Berkeley Earth, berkeley, 2025-01
- owid:temperature-anomaly/World#near_surface_temperature_anomaly, owid, owid, 2026-01
- Atmospheric CO2, global marine-surface annual mean, ppm (NOAA GML), NOAA Global Monitoring Laboratory, gml, 2025-01
- gcp:FOSSIL_NET#2025, gcp, gcp, 2024-01
- gcp:LUC#2025, gcp, gcp, 2024-01
- gcp:ATM_GROWTH#2025, gcp, gcp, 2024-01
- gcp:TERRITORIAL/World, gcp, gcp, 2024-01
- gcp:TERRITORIAL/CHN, gcp, gcp, 2024-01
- U.S. territorial fossil CO2 emissions, MtC/yr (Global Carbon Budget), Global Carbon Project, gcp, 2024-01
- gcp:TERRITORIAL/EU27, gcp, gcp, 2024-01
- gcp:TERRITORIAL/IND, gcp, gcp, 2024-01
- World solar generation, monthly, TWh (Ember), Ember, ember, 2025-01
- ember:WIND, ember, ember, 2025-01
- World coal-fired electricity generation, monthly, TWh (Ember), Ember, ember, 2025-01
- ember:GAS, ember, ember, 2025-01

- ember:NUCLEAR, ember, ember, 2025-01
- ember:Total Generation#gen, ember, ember, 2025-01
- ember:COAL/USA, ember, ember, 2025-01
- ember:GAS/USA, ember, ember, 2025-01
- wb:NY.GDP.MKTP.PP.KD/WLD, wb, wb, 2025-01
- wb:SP.POP.TOTL/WLD, wb, wb, 2025-01
- owid:primary-energy-cons/World, owid, owid, 2025-01
- ember:Coal#emissions/USA, ember, ember, 2025-01
- ember:Gas#emissions/USA, ember, ember, 2025-01
- ember:Coal#emissions, ember, ember, 2025-01
- ember:Gas#emissions, ember, ember, 2025-01
- IPCC SRES marker and illustrative scenarios (A1B, A1FI, A1T, A2, B1, B2): world fossil and other CO2 emissions, 1990-2100, Nakicenovic et al. (IPCC Special Report on Emissions Scenarios, 2000); files as distributed with MAGICC6 via openscm/pymagicc, IPCC SRES (2000), MAGICC6 .SCEN scenario files (github.com/openscm/pymagicc), 2000. https://github.com/openscm/pymagicc/tree/master/pymagicc/MAGICC6/run
- RCMIP v5.1.0 world CO2 emissions (fossil and industrial; AFOLU) for RCP2.6/4.5/6.0/8.5 and SSP1-1.9/1-2.6/2-4.5/3-7.0/5-8.5, Nicholls et al. (Reduced Complexity Model Intercomparison Project), compiling the RCP (Meinshausen et al. 2011) and SSP (Riahi et al. 2017; Gidden et al. 2019) harmonized emissions, RCMIP protocol data v5.1.0 (rcmip-emissions-annual-means-v5-1-0.csv), 2020. https://rcmip-protocols-au.s3-ap-southeast-2.amazonaws.com/v5.1.0/rcmip-emissions-annual-means-v5-1-0.csv
- RCMIP v5.1.0 world atmospheric CO2 concentration paths for RCPs and SSPs, Nicholls et al. (RCMIP), compiling Meinshausen et al. 2011 (RCP) and Meinshausen et al. 2020 (SSP) concentrations, RCMIP protocol data v5.1.0 (rcmip-concentrations-annual-means-v5-1-0.csv), 2020. https://rcmip-protocols-au.s3-ap-southeast-2.amazonaws.com/v5.1.0/rcmip-concentrations-annual-means-v5-1-0.csv
- Past climate model projections (Hansen 1981/1988, IPCC FAR-AR4) digitized, with projected and observed warming and forcing trends, Hausfather, Drake, Abbott and Schmidt (2020, Geophysical Research Letters) replication data, github.com/hausfath/OldModels (data/raw/model_temp_data, data/interim), 2020. https://github.com/hausfath/OldModels
- IEA World Energy Outlook 2002-2015 World annex tables (Reference / Current Policies Scenario): electricity generation by source and primary energy demand by fuel, transcribed with page references, International Energy Agency, World Energy Outlook 2002, 2004, 2006, 2008, 2010, 2012, 2015 (full-text PDFs from iea.org/files); realized 2010/2024 values from WEO-2025 Annex A (E-lit-002), 2002-2015. https://www.iea.org/reports/world-energy-outlook-2010
- Noahpinion, 2026-09-01
- Bruegel, 2026-09-10
- Noahpinion / Noah Smith, 2026-09-12
- Harvard Kennedy School / M-RCBG, 2026-09-21
- Council on Foreign Relations / Benn Steil, 2026-10-01
- Bruegel, 2026-10-02
- Jared Bernstein, 2026-10-03
- PIIE / PIIE Insider, 2026-10-07
- Urban Institute / Tax Policy Center, 2026-10-13

- EconoFact, 2026-10-09