Lethame Capital Management
Technology : Research : Investing

What Is Global Warming: An Energy-Balance Note

Why the planet is warming, explained from first principles: a bathtub, two kinds of light, and a blocked drain

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Executive Summary

Global warming happens because Earth is receiving more energy from the Sun than it sends back to space. Carbon dioxide causes the gap by making it harder for heat to escape. This note tells that story in five steps, starting from a bathtub and ending at the bottom of the ocean, then asks whether mirrors could turn the heat back down.

Every planet settles at the temperature where the heat it radiates to space matches the sunlight it absorbs. Sunlight and outgoing heat are different kinds of light, and carbon dioxide absorbs only the second kind. Adding CO_2 lifts the height from which heat escapes into colder air, so less heat leaves. Earth is now absorbing about 1 W/m² more than it emits, a gap that has more than doubled since the late 1970s.[8] Reflective surfaces can offset some of this, but only by treating the symptom rather than the cause.

Warming at the surface has also sped up, from about 0.04 °C per decade before 1970 to about 0.36 °C per decade since 2010 (Figure 1). Fossil fuel use and energy-related CO_2 emissions both hit new records in 2025, even as renewables overtook coal in global electricity generation.[12]

1. The Planet's Energy Bill

Every planet has an energy bill to settle. Sunlight pays energy in; the planet must pay the same amount back out to space, or it warms up.

Measuring the flow: what W/m² means. Energy flow is measured in watts (W). One watt is one joule of energy every second; an old-fashioned light bulb used 60 W. Because the Earth is large, climate scientists quote energy flow per square metre of the planet's surface: watts per square metre W/m². It answers the question "how much energy passes through each square metre, each second?" To picture 1 W/m², imagine a 1-watt night-light on every square metre of the Earth, land and sea, left on day and night.

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Rule one: energy is never lost. The First Law of Thermodynamics says energy cannot be created or destroyed, only moved or changed in form. For a planet this is plain bookkeeping. Every joule that arrives from the Sun either leaves again as heat radiated into space, or stays behind and warms something.

Rule two: everything glows. Every object gives off radiation, and hotter objects give off far more. The Stefan–Boltzmann law puts a number on it:

$$\text{Power radiated per square metre} = \sigma T^4, \quad \text{where } \sigma = 5.67 \times 10^{-8}\ \text{W/m}^2\ \text{per K}^4$$

T is temperature in kelvin (degrees Celsius plus 273). Because of the fourth power, doubling the temperature makes an object glow 16 times as strongly.

The bathtub. Put the two rules together and you get a bath with the tap on and the plug out. Sunlight is the tap. Heat radiated to space is the drain. The water level is the planet's temperature. This drain has a special property: the higher the water, the faster it empties, because warmer planets glow more. So the level rises until outflow matches inflow, then holds steady. Global warming is anything that partly blocks the drain. The water then rises until the extra pressure pushes enough out to balance the tap again.

Settling the bill. Sunlight reaching Earth delivers 1361 W/m².[2] About 30% bounces straight back off clouds, ice and bright ground. And the Earth catches sunlight on its sunlit face only, but radiates from its whole surface, four times the area of the disc it presents to the Sun. Spread over the whole globe, the planet absorbs $1361 \times 0.70 \div 4 \approx 238$ W/m². Balance needs:

$$\sigma T^4 = 238\ \text{W/m}^2 \quad \Rightarrow \quad T \approx 255\ \text{K}\ (-18\ ^\circ\text{C})$$

The puzzle. The real average surface temperature is about 288 K, a mild +15 °C. The surface is 33 K warmer than the bill says it should be. That gap is the natural greenhouse effect, supplied mostly by water vapour and carbon dioxide (CO_2). Without it the oceans would freeze. Global warming is what happens when we add to it.

2. Two Kinds of Light

The energy coming in and the energy going out are equal in amount but different in kind. That difference is what allows a gas to block the drain without touching the tap.

Hot things glow blue, cool things glow red, and cooler still is invisible. A stove ring glows dull red; a welding torch glows blue-white. Wien's law makes this precise: the wavelength at which an object glows brightest is 2898 ÷ T micrometres. The Sun's surface is 5772 K,[1] so it glows brightest near 0.5 µm, which is visible light. The Earth, at 255 K, glows brightest near

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11 µm, deep in the infrared, which we feel as heat but cannot see. The two kinds of light barely overlap.

That is the key to the whole story. Air is almost transparent to visible light, so sunlight passes straight through to the ground. But a few gases, carbon dioxide and water vapour above all, strongly absorb infrared light. They leave the tap alone and act only on the drain.

Same money, different notes. Light travels in packets called photons, and each photon's energy depends only on its frequency. A hot body sends out high-frequency, high-energy photons; a cool body sends out low-energy ones. Comparing typical photons, one from the Sun carries about 5772 ÷ 255 ≈ 22 times the energy of one from the Earth. Because energy in must equal energy out, the Earth has to send out about 22 heat photons for every sunlight photon it absorbs. It is like being paid in $100 notes and paying your bills in $5 notes: the totals match, but far more notes leave than arrive.

Rule three: energy spreads out. The Second Law of Thermodynamics says energy naturally spreads out, and never un-spreads on its own. Heat flows from hot to cold, not the reverse. Concentrated energy can do useful work; spread-out energy cannot. Twenty-two weak photons are a far more spread-out form of the same energy than one strong one. So the Earth takes in concentrated energy and throws out spread-out energy. That downhill flow is what drives the winds, grows the plants and, in the end, powers every economy.[3]

3. How Carbon Dioxide Blocks the Drain

Carbon dioxide warms the planet by pushing the height from which heat escapes to space higher up, into colder air. Colder air glows less, so less heat leaves.[4,5] The easiest way to see this is to follow some heat from the ground upwards.

The catch. A CO_2 molecule can bend, like a person flexing at the waist. That bending absorbs infrared light at 15 µm, right next to the 11 µm peak of the Earth's glow. This is why a gas making up only 0.04% of the air matters so much: it happens to be tuned to the Earth's own frequency.

The hand-off. Near the ground, air molecules collide billions of times a second. A CO_2 molecule that has just absorbed some heat is almost always bumped by a neighbour before it can send that energy back out as light. The energy simply becomes warmth in the surrounding air. The reverse happens too: collisions set CO_2 molecules bending, and they glow at whatever temperature the local air happens to be.[4] The upshot is that low down, CO_2 is so thick at 15 µm that heat cannot fly out directly. It is passed upwards, layer to layer, like buckets along a line of people.

The escape height. Climb high enough and the air thins out. Eventually there is too little CO_2 above to catch anything, and heat glowing from that layer flies straight off into space. Call this the escape height. The planet's heat loss in this band is set by how warm the air is there.

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Higher means colder. Air cools as you go up, by about 6.5 °C per kilometre in the lower atmosphere, because rising air expands and expanding air cools.

Adding CO_2. Put more CO_2 in the air and you have to climb higher before it thins out enough, so the escape height rises. It is now in colder air, which glows less. The drain is partly blocked. The planet keeps absorbing the same sunlight but loses less heat, so it warms until the whole column of air, escape height included, is warm enough to balance the bill again.[5]

How much warming? Doubling CO_2 cuts the heat escaping by about 3.7 W/m².[6] How much warmer must the planet get to make that up? Using the glow law from Section 1, each extra degree of temperature lets out about 3.8 W/m² more:

$$d(\sigma T^4)/dT = 4\sigma T^3 \approx 3.8 \text{ W/m}^2 \text{ per K at } T = 255 \text{ K}$$

So about 1 °C of warming restores balance, the same as lifting the escape height by roughly 150 m. That is the direct effect. Warmer air then holds more water vapour, itself a heat-trapping gas, and this and other knock-on effects roughly triple the total to about 3 °C per doubling.[7]

Diminishing returns, but only slowly. The middle of CO_2's absorption band is already completely blocked, so extra CO_2 works mainly at the edges of the band. The result is that each doubling of CO_2 adds about the same 3.7 W/m², whatever the starting level.[6] Going from 280 to 560 ppm does about as much as going from 560 to 1120 ppm.

A common misconception. A popular picture has CO_2 acting like a mirror, catching outgoing heat and throwing about half of it back down to the ground. It is a handy first image, but it is not how the warming works. Near the ground CO_2 rarely re-emits at all, because collisions get there first. What sets the planet's temperature is how cold the air is at the escape height, not a count of photons heading downwards.

4. What We Have Done

Since the industrial revolution, burning coal, oil and gas and clearing forests has released about 2,400 billion tonnes of CO_2 between 1850 and 2019,[7] and about 250 billion tonnes more

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between 2020 and 2025.[8] CO_2 in the air has risen by half, and the Earth's energy bill is now running a deficit of about 1 W/m².[8] The key measurements are:

Indicator	Value
CO_2 in the air, 1750	~278 ppm
CO_2 in the air, 2025	425.6 ppm
Heat trapped by the added CO_2, 1750–2025	2.37 W/m²
Energy imbalance, 1976–1995 average	0.40 W/m²
Energy imbalance, 2006–2025 average	1.04 W/m²
Human-caused warming, 2025	1.37 °C above 1850–1900

Source: Forster et al. (2026).[8] ppm means parts per million: 425.6 ppm is about 426 CO_2 molecules in every million molecules of air.

Still rising. CO_2 passed 428 ppm in May 2026, about 50% above pre-industrial levels, according to the 2026 State of the Climate report.[12] May is the seasonal peak, which is why this sits above the 2025 annual average in the table.

The warming itself. Figure 1 shows what the imbalance has done to surface temperature. Warming has not been steady; it has accelerated. The 2026 State of the Climate report measures about 0.05 °C per decade over 1880–1970, 0.19 °C over 1970–2010 and 0.36 °C over 2010–2024, and warns that at current rates 2 °C above pre-industrial levels could be reached before 2050.[12] Refitting the same periods to Berkeley Earth data through 2025 gives 0.04, 0.19 and 0.36 °C per decade; if the recent rate simply continued, the world would pass 2 °C above the 1850–1900 average around 2042.[13]

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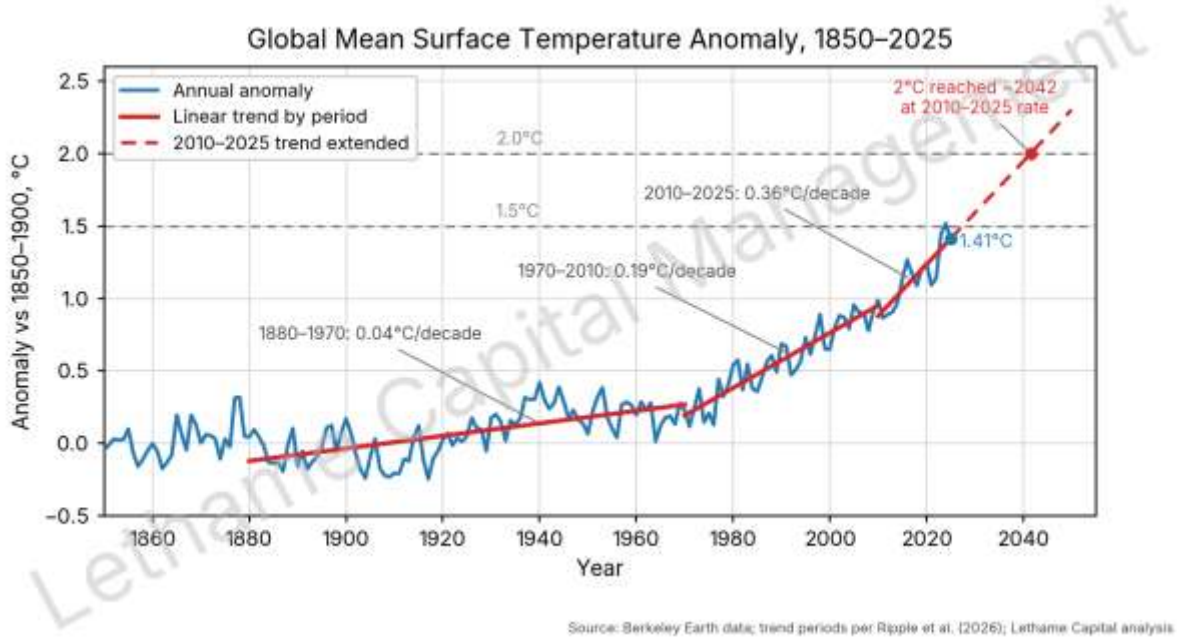


Figure 1: Global Mean Surface Temperature Anomaly Relative to 1850–1900 (°C)
Source: Berkeley Earth data;[13] trend periods per Ripple et al. (2026);[12] Lethame Capital analysis.

Is it really speeding up? The report itself is careful here. It cites one analysis finding the acceleration statistically significant since about 2015, and suggests part of it may come from cleaner air: cutting aerosol pollution removes haze that had been masking some greenhouse warming. It also cites work finding that recent warming, including the 2023–2024 spike, is consistent with climate model projections.[12] Either way, the direction is not in doubt; the debate is about how fast.

Picturing the imbalance. An imbalance of 1.04 W/m² is the night-light from Section 1, left burning on every square metre of the planet. Added up over the whole Earth, that is about 530 million million watts of continuous heating, nearly 40 times the heat given off by all human energy use, about 14 million million watts in 2005.[9]

Where the heat goes. If the surface has warmed, why has the glow law not closed the gap? Because the oceans are a vast heat sink. They absorb about 90% of the extra energy[8] and take decades to warm through, so the surface lags behind. Meanwhile CO_2 keeps rising, blocking the drain a little more each year. The imbalance has more than doubled since the late 1970s,[8] and reached a record of about 1.8 W/m² in 2023 before easing in 2024:[14] the tub is filling faster, not slower.

5. Where Machines Come In

Our machines affect the climate through the fuel they make us burn, not through the heat they give off.

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Machines waste most of their fuel. The Second Law of thermodynamics applies to every engine, boiler and power station: energy spreads out, so some of the fuel's energy always ends up as waste warmth rather than useful work. In practice the waste is large. Tracing the world's energy from fuel through every conversion device to the final service, Cullen and Allwood estimate that only about 11% ends up as useful work.[10] Roughly nine units of fuel are burned for every one unit of work delivered.

Why that matters for CO_2. Burning fossil fuels accounts for about 73% of global greenhouse emissions.[8] Every tonne of fuel releases its carbon as CO_2 whether its energy was used well or wasted. So each unit of useful work carries the CO_2 of about nine units of fuel. Better efficiency means less fuel, and less CO_2, for the same output; the same study finds that devices working at their theoretical limits could cut energy demand by almost 90%.[10]

More fuel, not less. The latest data show how far there is to go. Fossil fuel use rose 0.9% in 2025, with oil, coal and gas each at record highs, and energy-related CO_2 emissions passed 41 billion tonnes in a year for the first time. Renewables overtook coal in global electricity generation for the first time in more than a century, but demand grew so quickly that clean power was added alongside fossil fuels rather than replacing them.[12]

Why the waste heat itself does not matter. It is tempting to think the warmth pouring out of engines heats the planet directly. It does, but only a little: averaged over the globe, all the heat released by human energy use was about 0.03 W/m² in 2005.[9] The added CO_2 traps 2.37 W/m²,[8] roughly 80 times more. The machines warm the planet through their exhaust, not their warmth.

6. Could Mirrors Cool the Earth?

Mirrors work on the other side of the energy bill: instead of unblocking the drain, they turn down the tap by sending more sunlight straight back to space. MEER (Mirrors for Earth's Energy Rebalancing) is a non-profit deploying exactly this, using reflective roofs, canopies and special cooling materials.[11]

Two ways a surface can cool. A reflective surface, such as a white roof or a mirror, bounces sunlight back before it becomes heat. Because sunlight is visible light, it travels back out through the same clear air it came in through (Section 2). A second kind of material, called a passive radiative cooler, goes further: it is built to glow at 8–13 µm, a gap in the infrared where neither CO_2 nor water vapour absorbs much. Heat from such a surface skips the bucket line of Section 3 and escapes almost directly to space.

How much reflection would it take? Averaged over the globe, sunlight arrives at the top of the atmosphere at 1361 ÷ 4 ≈ 340 W/m². To cancel today's imbalance of about 1 W/m², the planet must reflect an extra 1 ÷ 340, about 0.3%, of the sunlight it receives. To cancel a full

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doubling of CO_2 (3.7 W/m²) takes about 1.1%. That is, the planet's reflectivity would need to rise from about 30% to about 31%.

That sounds small, but surface mirrors only work on sunlight that reaches the ground, and clouds and haze intercept much of it on the way down and again on the way back up. A rough estimate using our own round-number assumptions (about half of sunlight reaches the ground, and a bright surface reflects about 80% more than the ground it covers, about 70% of which escapes back out) suggests offsetting today's 1 W/m² would need bright surfaces over roughly 1% of the Earth's entire surface: around 5 million km², about two-thirds of the area of Australia. Cancelling a CO_2 doubling would need nearly four times that.

Local relief works now. Reflective roofs lower indoor and street temperatures immediately; MEER reports peak indoor cooling of 6.4 °C at its field sites.[11] For people facing heatwaves, that is a real benefit.

Mirrors treat the symptom, not the cause. They turn down the tap but leave the drain blocked. CO_2 keeps accumulating, so the mirrored area would have to grow as long as emissions continue, and be kept clean and maintained indefinitely.

The effect is uneven. The cooling happens where the mirrors are, mostly on land in sunny places, while the CO_2 trapping acts everywhere.

MEER itself describes surface cooling as a complement to cutting emissions, never a substitute.[11]

The 2026 State of the Climate report takes the same view. It lists reflective roofs among fast-track defences against extreme heat, alongside urban trees, cooling centres and the restoration of wetlands and mangroves, but warns that such measures lose effectiveness as warming intensifies and must be paired with rapid emission cuts.[12] The physics in this note supports that position.

Conclusion

Global warming is not mysterious once it is framed as an energy bill. The Sun pays in; the planet pays out; temperature adjusts until the two match. Carbon dioxide does not add energy. It raises the height from which heat escapes into colder air, so the planet must warm to pay out the same amount. Every tonne of CO_2 emitted since 1850 has pushed that escape height a little higher, and the oceans are absorbing most of the resulting surplus, which is why the surface lags and the imbalance keeps growing.

Two practical conclusions follow. First, the lever that matters is the carbon in the exhaust, not the waste heat from machines, which is why efficiency helps only insofar as it cuts fuel burned. Second, reflecting sunlight can buy local relief and some global headroom, but it leaves the underlying cause in place and must grow for as long as emissions continue.

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