The Full Portfolio

A pluralistic collation of strategies for the climate polycrisis

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How to read this document

This is a survey, not an argument for a single answer. Its organising claim is that the polycrisis is a **portfolio allocation problem**, not a search for the correct lever. Any framing that identifies one dominant intervention — whether that intervention is nuclear, degrowth, carbon pricing, geoengineering, or transforming human nature — is making a claim about dominance that the evidence rarely supports.

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Each entry below is assessed on the same axes:

Axis	Question
Maturity	Is this deployed, demonstrated, or speculative?
Time-to-effect	When does it move emissions or damages?
Scale ceiling	How much of the problem can it address at maximum?
Binding constraint	What actually stops it — physics, cost, supply chain, politics, or law?
Reversibility	Can a mistake be undone?
Fungibility	Is something cheaper doing the same job?

Figures are current as of mid-2026 and are cited to source. **Anything quantitative in this document should be re-checked before use** — the underlying numbers move fast, and several moved substantially in the last eighteen months.

A note on temperature figures. Single-year global temperatures swing by 0.1–0.15°C with ENSO state and should not be read as the underlying trend. The Paris thresholds refer to the long-term level. Quoting an El Niño-boosted annual or monthly figure as "where we are" overstates the position by roughly a decade of warming; quoting a La Niña year understates it. Use the long-term warming estimate, and state which you are using.

PART ONE — POSITION

1.1 Where the numbers actually stand

Warming. Copernicus/ERA5 records 2025 at 1.47°C above the 1850–1900 baseline, following 1.60°C in 2024 (the warmest year on record). Using several methods, the **current level of long-term global warming is estimated at around 1.4°C.** The 2023–2025 three-year average exceeded 1.5°C for the first time in the instrumental record. On current rates, the Paris long-term 1.5°C limit could be reached by the end of this decade — over a decade earlier than expected when the agreement was signed.

Projections. UNEP's *Emissions Gap Report 2025: Off Target* puts warming this century at 2.3–2.5°C under full NDC implementation and up to **2.8°C under current policies**, against 2.6–2.8°C and 3.1°C respectively the previous year. UNEP is explicit that this apparent improvement is largely artefactual: methodological updates account for 0.1°C, and the US withdrawal from Paris cancels another 0.1°C. **The new pledges themselves barely moved the needle.** Emissions grew 2.3% year-on-year to 57.7 $GtCO_2e$ in 2024.

But the long-run trend is real. Current-policy projections have fallen from just below 4°C at the time of the Paris Agreement to just below 3°C today. That is roughly a degree of avoided warming, achieved without any change in human nature, through treaties, subsidies, technology cost curves, litigation, and industrial policy.

The two errors to avoid

Both of these are common and both are demobilising in different directions:

Error	Claim	Why it's wrong
Complacency	"The trend is improving, we're fine"	2.3–2.8°C is a catastrophe. The gap between 1.5°C and 3°C is measured in hundreds of millions of lives and the habitability of large regions
Fatalism	"Extinction is locked in, only total solutions remain"	Not what the science projects. Severe, unevenly distributed harm ≠ end of the species. And the fatalist frame licences the most drastic and least tractable interventions by making incremental ones look pointless

The second error deserves particular attention because it is structurally load-bearing. If collapse is certain, then grid decarbonisation and planning reform are palliative gestures and only the total interventions make sense. Fatalism generates authoritarian conclusions. It is worth noticing that as a feature of the reasoning, independent of the premises.

1.2 Curve dynamics: why the forecasts failed, and where they will fail again

The single most useful analytical frame in this domain — and the one most often missing from public discussion — concerns **the shape of technology deployment and cost curves.**

1.2.1 Wright's law and learning rates

Manufactured technologies follow experience curves: unit cost falls by a roughly constant fraction with each doubling of cumulative production. Solar PV has sustained a learning rate in the region of 20% per doubling for decades. Lithium-ion has been comparably steep. Battery storage project costs fell about 40% in 2024 alone, to around $150/kWh (IEA), and utility-grade LFP cell prices had settled in the $55–75/kWh range by early 2026 — below where most analysts expected at that point on the curve.

The systematic forecasting failure. Integrated assessment models and agency forecasts repeatedly projected these curves as flattening. They did not. Peer-reviewed analysis of the projection record (Rezaee et al. and others) finds cost projections for solar PV, wind, and batteries have systematically over-estimated actual costs. This mattered enormously: policy built on flattening-curve assumptions under-invested in exactly the technologies

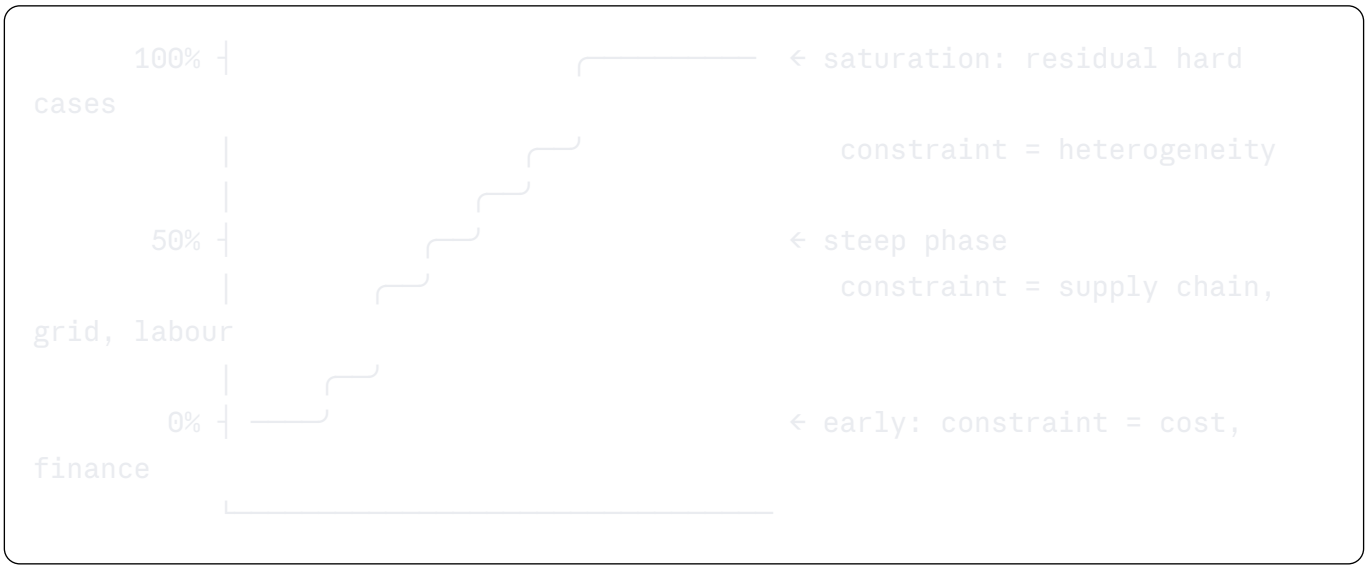
that then out-performed.

Why it happened. Learning curves are driven by cumulative *manufacturing* volume, and modellers consistently treated deployment as exogenous to cost while cost was in fact endogenous to deployment. The feedback loop was underspecified.

Where the same error is being made now. Any technology in a manufactured-goods learning regime and early on its curve is a candidate for repeat under-estimation: electrolysers, heat pumps, sodium-ion cells, thin-film and perovskite PV, grid-forming inverters, small modular reactors (contested), direct air capture (very early, very uncertain).

1.2.2 Logistic adoption and the asymptote

Deployment follows S-curves, not exponentials. Three phases, three different binding constraints:



The critical implication: the constraint changes as you move along the curve, and interventions calibrated to one phase fail in another. Purchase subsidies are appropriate in phase one and become deadweight in phase three. Grid and planning reform are irrelevant in phase one and binding in phase two. Mandates and standards do the work in phase three.

Getting this wrong is one of the most common failures in climate policy design. Much of the current argument about EV subsidies is really an unacknowledged argument about which phase the market is in — and the answer differs by country. Norway closed 2025 at roughly 96% BEV share of new cars; the US sits around 10%. Those two markets need opposite policies.

1.2.3 What actually saturates

Asymptotic behaviour is not uniform. Some things saturate hard, others do not:

Saturates hard	Doesn't (yet)
Solar capacity factor (physics-limited)	Manufacturing cost per unit
Battery energy density for a given chemistry	Cumulative deployment
Existing grid hosting capacity	Grid capacity itself, if built
Land available for utility-scale solar in dense countries	Rooftop, agrivoltaic, offshore
Behavioural change from information provision alone	Behaviour under changed defaults and prices
Political attention to any single issue	Institutional capacity, if funded

Practical rule: when someone claims a strategy has "hit its limit," ask which of these categories the limit belongs to. Physics-limited asymptotes are real. Most claimed limits are cost, permitting, or political-economy limits misdescribed as physical ones.

1.2.4 The residual problem

The last 10–20% of any transition is disproportionately hard, and its cost curve runs the *other* way — the residual cases are residual precisely because they are heterogeneous, dispersed, or structurally awkward. Deep retrofits of heritage housing stock. Off-grid and low-income households. High-temperature industrial heat. Long-haul aviation. Agricultural methane from smallholder ruminant systems.

Consequence for portfolio design: the technologies that address the residual should be funded *early*, during the steep phase of the mainstream curve, because they have long development timescales and cannot be started when they become urgent. This is the strongest argument for funding options that look uncompetitive today.

PART TWO — ENERGY AND TECHNOLOGY

2.1 Electricity supply

Solar PV

Maturity: Deployed at scale. **Time-to-effect:** Immediate. **Constraint:** Grid, land, and permitting — not cost.

Solar PV additions surpassed 600 GW for the first time in 2025, up around 12%, bringing cumulative capacity to roughly 2,800 GW — making it **the technology with the largest installed capacity globally**. Solar accounted for more than three-quarters of all new renewable capacity additions. Global renewable additions reached 800 GW in 2025, up 16%, the 23rd consecutive record year — despite supply chain strain, grid connection delays, financing pressure, and policy reversals.

The cost trajectory: roughly $5/W twenty-five years ago to around 10 cents/W today, with the IEA describing solar as the cheapest electricity in history.

Honest limitations. Capacity ≠ generation; capacity factors are typically 10–25% depending on latitude. Cheap solar creates its own integration problem — periods of overabundance where supply threatens to exceed demand, requiring curtailment, storage, demand shifting, or negative pricing. The binding constraint has fully shifted from cost to system integration.

Wind

Maturity: Deployed. **Constraint:** Permitting, grid, supply chain, offshore cost inflation.

Wind accounted for roughly 20% of 2025 renewable additions. Onshore wind is mature and among the cheapest generation in good resource areas. Offshore has had a hard three years: cost inflation, interest rate exposure, cancelled auctions, and supply chain distress. This is a genuine setback, not a narrative one, and offshore's contribution to 2030 targets in several countries should be revised down accordingly.

Battery storage and flexibility

Maturity: Deployed and scaling extremely fast. **This is arguably the most under-appreciated development of the last three years.**

108 GW of new battery storage was deployed in 2025, 40% more than 2024, with installed capacity now eleven times higher than 2021. Utility-scale battery power capacity increased more than twelve-fold between 2020 and 2024. LFP now accounts for around 90% of deployments, up from well below 50% five years ago. Around 80% of new capacity is utility-scale. Durations are lengthening — China's average new-installation duration rose from about 2.1 hours in 2021 to around 2.6 hours in 2025.

Why it matters strategically: storage directly attacks the oldest and most substantive criticism of variable renewables. One analysis suggests that by 2030 more than three-quarters of the world's population could access 80%-uptime solar-plus-storage below $80/MWh.

What storage does not solve: multi-day and seasonal storage. Four-hour lithium systems handle the diurnal cycle. They do not handle a week-long winter wind lull in northern Europe. That is a different problem requiring different technology (see below).

Complementary flexibility. The IEA notes that demand response and transmission expansion can reduce storage requirements by up to 30%. Demand flexibility is cheap, fast, and chronically under-deployed relative to its value.

Long-duration storage

Maturity: Pre-commercial. Iron-air (Form Energy), thermal (Antora, Rondo), and gravity-based (Energy Vault) systems have offtake contracts but none has reached lithium-scale deployment volumes as of early 2026.

Assessment: genuine residual-problem technology. Fund now, expect deployment in the 2030s, do not build 2030 plans around it.

Nuclear fission

Maturity: Mature technology, immature current delivery capability in the West.

Existing plants: keeping them open is among the highest-value, lowest-cost decarbonisation actions available anywhere. Premature closure of operable nuclear capacity has reliably increased emissions.

New build: the Western record on cost and schedule is poor — Hinkley Point C, Flamanville, Vogtle. Costs in China and South Korea are substantially lower, which suggests the problem is institutional (loss of serial construction capability, regulatory ratcheting, first-of-a-kind penalties) rather than intrinsic to the technology.

SMRs: contested. The theoretical case rests on factory serial production moving reactors onto a learning curve. No commercial SMR fleet exists to test this. Treat 2030s deployment claims sceptically and 2020s claims very sceptically.

Portfolio role: firm, dispatchable, land-efficient zero-carbon generation. Genuinely valuable in systems with poor renewable resource or high land constraint. Not a substitute for building solar and wind now, and arguments framing it that way are usually political rather than technical.

Fusion

Maturity: Pre-commercial. Physics substantially demonstrated; engineering and economics unproven.

The honest 2026 position: **no commercial fusion plant has produced electricity for the grid, and no company is within twelve months of doing so.** The 2022 NIF ignition result settled that net-energy fusion is physically possible. What remains open is whether the engineering and economics work on a climate-relevant timeline.

Current status: private fusion has raised roughly $9.8bn. The US NRC has separated fusion from fission in its regulatory framework. Commonwealth Fusion Systems' SPARC was around 75% complete in mid-2026 with first plasma targeted for 2027 (slipped from 2025); CFS has filed for grid connection for a subsequent 400 MW plant in Virginia, a process expected to take four to six years, with offtake agreements signed with Google and Eni. ITER is now expected to reach first plasma in the mid-2030s with full deuterium-tritium operation around 2039, and will not produce electricity.

Caution on sourcing. Some low-quality outlets in early 2026 reported commercial net energy gain as already achieved. More reliable reporting from the same period contradicts this. Verify fusion claims against primary sources — the field has a persistent gap between press release and peer-reviewed result.

Realistic timeline: grid-connected pilot plants early-to-mid 2030s at the earliest; meaningful global generation contribution not before the 2040s, with many expert assessments putting commercial operation in the 2040s–2050s.

Portfolio role — and this is the important part. Fusion is not a climate mitigation strategy for the decisive decade. It arrives after the carbon budget question is settled. Its actual value is as a **post-2050 energy abundance technology** and as a hedge against a world that needs enormous amounts of firm clean power for desalination, direct air capture, and industrial heat. Fund it as basic science and long-horizon infrastructure. Do not let it appear in a 2035 emissions pathway, and treat its invocation as a reason to delay near-term action as what it

is.

Geothermal

Maturity: Conventional is mature and geographically constrained. Enhanced/advanced geothermal (EGS) is early-commercial and interesting.

Why it deserves more attention: it directly leverages oil and gas drilling capability, supply chains, and workforce. It provides firm, dispatchable, zero-carbon baseload with a small land footprint. Fervo and others have demonstrated meaningful drilling cost reductions. This is one of the more plausible candidates for surprise upside — a technology with a real learning curve that has barely started climbing it.

Hydropower

Mature, large, and largely allocated. Remaining potential is concentrated in regions with significant ecological and displacement costs. Existing capacity is highly valuable for flexibility. Increasingly exposed to hydrological change — drought has repeatedly cut output in Brazil, China, and the western US, which is a coupling worth noting: **climate change degrades one of our largest clean generation assets.**

2.2 Grids, transmission, and permitting

This is the most under-weighted item in the entire portfolio relative to its leverage.

Generation is now cheap. Connecting it is the bottleneck. Interconnection queues in the US, UK, and across the EU run to hundreds of gigawatts with waits measured in years to over a decade. Transmission build times are dominated by consenting and legal challenge, not construction. Grid connection delays were explicitly among the constraints on 2025's record renewable additions.

Why it is under-weighted: it is unglamorous, jurisdictionally fragmented, has no product to sell, no constituency to advocate for it, and produces no announceable technology. It is pure institutional plumbing.

Interventions, roughly in order of leverage:

- Planning and permitting reform (consenting timescales, judicial review scope, statutory deadlines)
- Interconnection queue reform (first-ready-first-served rather than first-come-first-served; deposits to deter speculative applications)
- Anticipatory investment frameworks — allowing grid operators to build ahead of demonstrated demand
- Community benefit and compensation schemes for transmission corridors
- Grid-enhancing technologies: dynamic line rating, advanced conductors, topology optimisation. Cheap, fast, and dramatically under-deployed
- Regional and cross-border interconnection

Assessment: high leverage, low cost, fast-acting, reversible, politically difficult in a mundane rather than an ideological way. Should be near the top of any allocation.

2.3 Transport

Light vehicles

Maturity: Deployed, in the steep phase of the S-curve in most major markets.

Global electric car sales exceeded 20 million in 2025, up 20%, meaning **one in four new cars sold worldwide was electric**. Around 40 countries saw EVs reach 10% or more of new sales. Roughly 5% of the global car stock is now electrified, displacing about 1.2 million barrels of oil per day. The IEA projects 23 million sales in 2026, around 28% share.

Regional divergence is now the dominant feature. China: nearly 55% of car sales. Europe: up more than 30%, reaching 28% share, following tightened EU CO_2 standards. Norway: about 96% BEV share. Vietnam: over 40% penetration, driven by cheap domestic small models. The US: around 10%, with over 85% of available EV models being SUVs or large vehicles — the highest such share in the world, which prices the mass market out. Canada's share fell from about 17% to 11% after a rebate programme ended.

The lessons in that spread: (1) standards and mandates outperform subsidies for durable change — the EU CO_2 standards did more than any purchase incentive; (2) subsidy withdrawal at the wrong phase of the curve reverses progress; (3) vehicle size and affordability determine mass-market penetration more than range or charging.

Caution: global EV sales fell around 8% year-on-year in Q1 2026, on weaker Chinese and US demand. S-curves are not monotonic. One quarter is not a trend, but it is a reminder that the steep phase is not automatic.

Heavy freight, shipping, aviation

Electric heavy-freight truck sales tripled in 2025 to over 200,000 units, with European medium/heavy electric truck sales up around 40% to a 3% market share. Faster than most expected; still very early.

Shipping: ammonia and methanol are the leading candidates; IMO regulation is the main lever; the fuel production chain barely exists.

Aviation: the genuinely hard case. Sustainable aviation fuel is supply-constrained and expensive; battery-electric is confined to short-haul commuter routes on any realistic timeline; hydrogen requires airframe redesign. **Realistic near-term levers are demand-side** — frequent flyer levies, short-haul substitution by rail, business travel norms — which places aviation partly in the human-layer section below.

Modal shift and urban form

Chronically under-weighted in technology-focused strategies. Density, public transport, cycling infrastructure, and 15-minute-city planning reduce transport energy demand structurally rather than substituting one drivetrain for another. Slow-acting (decades, via the building stock) but permanent, and delivers large co-benefits in air quality, health, and cost of living.

2.4 Industry and materials

The hard-to-abate core. Roughly a quarter of emissions, and the part least amenable to

electrification.

Sector	Leading approaches	Status
Steel	Hydrogen direct reduction (H_2-DRI); electrolytic iron; scrap-based EAF	H_2-DRI demonstrated at pilot/first-commercial scale; cost gap remains large. Electrolytic routes early
Cement	Clinker substitution; alternative chemistries; carbon capture	~60% of emissions are process CO_2 from calcination, not fuel — **cannot be electrified away**. Capture is unavoidable for a large share
Chemicals	Electrified crackers; bio- and CO_2-derived feedstocks; recycling	Very early. Feedstock as well as energy problem
High-temp heat	Electric resistance/induction; thermal storage; hydrogen	Thermal storage (Antora, Rondo) genuinely promising for the 400–1500°C range

The demand-side lever nobody uses. Material efficiency — designing structures with less steel and concrete, extending building life, reuse of structural elements, lightweighting — offers reductions comparable to supply-side decarbonisation at negative cost, and is almost entirely ignored because it has no product to sell. Building codes and procurement standards are the levers.

Green public procurement deserves specific mention: governments buy a large fraction of the world's steel and concrete. Embodied-carbon requirements in public procurement create guaranteed demand for green materials without subsidy, and are among the cheapest available industrial policy.

2.5 Buildings and heat

Heat pumps are the core technology: mature, three-to-four times more efficient than resistance heating, and cost-competitive over lifetime in most climates. Uptake is constrained by capital cost, the electricity-to-gas price ratio (a policy choice, not a physical fact), installer workforce capacity, and — for older housing stock — retrofit complexity.

Retrofit is the residual problem in miniature: heterogeneous, labour-intensive, disruptive to occupants, with split incentives between landlords and tenants. It resists economies of scale by construction. The Dutch *Energiesprong* model — industrialised whole-house retrofit packages — is the most promising attempt to force it onto a learning curve.

Underrated levers: minimum energy efficiency standards for rented property; rebalancing levies between electricity and gas; heat networks in dense areas; passive cooling and shading standards, which will matter enormously and are almost absent from current building codes in temperate countries now facing regular heat extremes.

2.6 Food, agriculture, and land

Roughly a quarter to a third of emissions, and structurally different from energy: dispersed

across hundreds of millions of actors, culturally loaded, politically protected, and poorly measured.

Ruminant methane is the largest single agricultural source. Options: feed additives (3-NOP/Bovaer, seaweed-derived compounds), breeding for lower-emitting animals, herd management, and demand shift. Additives work in housed systems and are much harder to deliver in extensive grazing — which is most of the global herd.

Nitrous oxide from fertiliser is under-addressed relative to its warming contribution. Precision application, nitrification inhibitors, and improved nitrogen use efficiency all work and are cheap. Green ammonia addresses production emissions but not field emissions.

Alternative proteins — plant-based, fermentation-derived, cultivated. Plant-based has hit a commercial plateau in several Western markets after rapid early growth; fermentation-derived proteins look more promising on cost trajectory. Cultivated meat remains far from cost parity. **The honest assessment: public R&D funding here is tiny relative to the emissions at stake, and this is one of the clearer under-investments in the portfolio.**

Land use, deforestation, and soil. Deforestation is substantially a governance and enforcement problem, not a technology problem — Brazil's enforcement-driven reductions in the 2000s and again post-2023 demonstrate that political will translates directly into forest outcomes. Supply chain due diligence regulation (EUDR and equivalents) is a real lever. Soil carbon sequestration is genuine but with contested permanence and severe measurement difficulty.

Food loss and waste — roughly a third of food produced. High-leverage, low-tech, and neglected.

2.7 Short-lived climate pollutants — the near-term lever

Methane deserves separate billing because it is the fastest-acting lever available.

Methane accounts for roughly a third of net warming since the industrial revolution and has a short atmospheric lifetime, meaning cuts deliver temperature benefits within decades rather than centuries. Meeting the Global Methane Pledge — 30% below 2020 levels by 2030, now with 159 participating countries — has the potential to reduce warming by at least 0.2°C by 2050 while preventing an estimated 255,000 premature deaths, 26 million tonnes of crop losses, and 775,000 asthma-related hospitalisations annually.

Much oil and gas methane abatement is **cost-negative** — the captured gas is worth more than the equipment costs. This is close to a free lunch and is not being taken.

The measurement revolution is the real story here. MethaneSAT, GHGSat's fourteen-satellite constellation, Carbon Mapper, UNEP's IMEO and its Methane Alert and Response System have transformed methane from an estimated quantity to an observed one. MethaneSAT provided data covering roughly 23 basins across 16 countries — about a third of global oil and gas production — during its year of operation before the satellite failed; its data continues to yield results. Carbon Mapper became the first third-party notifier to the US EPA's Super Emitter Program.

But the gap between observation and action is stark. The IEA's assessment is blunt: few

countries or companies have formulated real implementation plans for their methane commitments, and even fewer have demonstrated verifiable emissions reductions. About half the industry has yet to set near-zero methane targets, and global efforts remain off course for the 2030 target.

This is the cleanest case in the entire document of a problem that is neither technical nor economic. The technology is deployed, the abatement is profitable, the emissions are now visible from orbit, and it is still not happening. Anyone arguing that the constraint on climate action is knowledge or capability should be asked to explain methane.

Also in this category: **HFCs** (Kigali Amendment — a functioning international agreement with real compliance), **black carbon**, and **tropospheric ozone precursors**.

2.8 Carbon dioxide removal

Framing first: CDR is not an alternative to emissions reduction. Every credible pathway uses it for genuinely residual emissions and for drawing down overshoot. UNEP notes that reversing each 0.1°C of overshoot would require permanently removing and storing about five years of current global annual CO_2 emissions. That number should calibrate expectations about how much CDR can rescue.

Approach	Maturity	Scale potential	Permanence	Cost trajectory
Afforestation/ reforestation	Deployed	Moderate	**Weak** (fire, disease, land pressure, political reversal)	Low cost, high monitoring difficulty
Soil carbon	Deployed	Moderate	Weak–moderate	Low, measurement-limited
BECCS	Early commercial	Moderate	Strong	Land and feedstock competition is the binding constraint
Direct air capture	Early	High in principle	Strong	Very expensive; early on learning curve; **energy-intensive**
Enhanced rock weathering	Early	High	Strong	Uncertain; MRV is the hard part
Ocean alkalinity enhancement	Research	High	Strong	Ecological risk poorly characterised
Biochar	Deployed	Low–moderate	Moderate–strong	Cheap, limited ceiling

The systemic risk is moral hazard. The availability of CDR in models has repeatedly been used to justify delayed mitigation, with the removals implicitly assigned to a future that

then inherits an unbuilt industry. Guard against this structurally: separate removal targets from reduction targets in law, so they cannot be traded off.

Measurement, reporting and verification (MRV) is the actual bottleneck — not capture technology. This connects to a theme running through this document: the constraint on many interventions is our ability to *measure* the thing, not our ability to *do* the thing.

2.9 Solar radiation management

Included for completeness, with heavy caveats.

What it is: stratospheric aerosol injection, marine cloud brightening, and related approaches to increase planetary albedo.

The case for research: it is cheap enough that a single mid-sized state or wealthy individual could attempt it unilaterally. That fact alone makes governance research urgent regardless of one's view on deployment. Better to understand the physics and have governance frameworks before someone acts than after.

The case against deployment:

- **Termination shock** — abrupt cessation produces very rapid warming, creating a multi-generational commitment
- Does not address ocean acidification
- Regionally uneven effects on precipitation; creates identifiable winners and losers, and therefore a permanent international grievance
- **Severe moral hazard** — the most plausible political effect is reduced mitigation pressure
- Governance is unsolved: no framework exists for who decides, at what temperature, with what compensation

Assessment: research and governance work, yes, with strong norms against unilateral deployment. This is a tail-risk hedge, not a strategy, and it shares a structural property with the moral-modification proposals discussed in Part Four: it is invoked most confidently by those who have concluded that ordinary levers cannot work.

2.10 Adaptation and resilience

The most under-weighted domain in the entire portfolio, and the one where the moral case is strongest.

Mitigation dominates attention because it addresses causes. But at 1.4°C now and 2.3–2.8°C projected, a large quantity of damage is already committed regardless of mitigation success. Adaptation is where the difference between a hot world and a catastrophic one is actually made for the people most exposed.

Domains:

- Heat: early warning systems, cooling centres, urban greening and albedo, building codes for passive cooling, occupational heat regulation. **Heat action plans are among the highest lives-saved-per-pound interventions available anywhere.**

- Water: storage, efficiency, reuse, desalination (energy-intensive, increasingly viable with cheap solar), transboundary basin agreements
- Agriculture: drought and heat-tolerant cultivars, irrigation efficiency, crop insurance, diversification
- Coastal: managed retreat (politically toxic, often correct), hard defences, nature-based buffers, revised flood mapping
- Health systems: surge capacity, vector-borne disease surveillance, mental health provision
- Infrastructure: revised design standards for heat and flood — most existing infrastructure is engineered for a climate that no longer exists

Finance is the binding constraint. UNEP notes global climate finance flows need to triple by 2030, with only about a third of required funding currently mobilised, and the shortfall concentrated in developing nations. Adaptation finance is a fraction of mitigation finance, and adaptation is precisely where the need is greatest for those least responsible.

Why it is neglected: adaptation has no emissions number attached, benefits are diffuse and counterfactual (deaths that don't happen), and it lacks the technological glamour that attracts capital and attention. It also carries an unhelpful stigma as "giving up on mitigation," which is analytically false — the two are complements, not substitutes.

PART THREE — POLITICAL ECONOMY

3.1 Corruption, capture, and rent-seeking

A pluralistic strategy that omits this is not serious. This section covers the mechanisms by which good policy is prevented, diluted, or looted.

3.1.1 Subsidy structures

The IMF's 2025 update puts **explicit fossil fuel subsidies at $725 billion in 2024** (0.6% of global GDP) and **implicit subsidies — chiefly the underpricing of environmental externalities — at $6.7 trillion** (5.8% of GDP). Around three-quarters of the implicit total comes from underpriced air pollution and climate damage. UNEP notes fossil subsidies currently run about five times higher than clean energy support.

Two findings deserve emphasis:

1. **Explicit subsidy removal alone** would cut CO_2 roughly 6% below baseline by 2035, avoid an estimated 70,000 premature air pollution deaths a year, raise 0.6% of GDP in revenue, and generate net economic benefits worth about 0.5% of GDP. This is a policy with negative cost and large health co-benefits that mostly isn't happening.
2. **Fuel subsidies are regressive.** Of the $289 billion in explicit subsidies covered by IMF distributional analysis, **the wealthiest 50% of households captured about three-quarters**. The standard political defence — that subsidies protect the poor — is empirically false, and this fact should be deployed much more aggressively than it is.

Caveat on the $7 trillion figure. It is frequently quoted without explanation and invites the objection that it isn't really a "subsidy" in the ordinary sense. Be precise: explicit subsidies are direct fiscal transfers; implicit subsidies are unpriced externalities. Both are real, they

are different things, and conflating them damages credibility.

3.1.2 Lobbying and political influence

Documented, quantified, and consequential. Oil and gas lobbying expenditure runs to hundreds of millions of dollars per election cycle in the US alone. The mechanisms are well characterised: direct lobbying, campaign finance, revolving-door appointments, funding of think tanks and front groups, trade association cover (allowing individual firms to maintain public climate commitments while their associations lobby against implementation), and strategic litigation.

Countermeasures with evidence behind them:

- Lobbying transparency registers with meaningful enforcement
- Mandatory disclosure of trade association memberships and alignment
- Conflict-of-interest rules on advisory bodies and delegations
- Restrictions on revolving-door movement
- Beneficial ownership registers

3.1.3 Procurement fraud and emergency-condition looting

This deserves specific treatment because it is the mechanism by which crisis spending is diverted, and because it is often invoked as evidence of irreducible human greed.

The UK pandemic response is the best-documented case: billions written off in unusable or overpriced PPE, a "VIP lane" ruled unlawful by the High Court, and billions more lost to Bounce Back Loan fraud where lending proceeded with minimal verification. A counter-fraud commissioner was subsequently appointed to attempt recovery.

The analytically important point is the mechanism. Normal procurement controls — competitive tender, due diligence, published contracts, audit trail — were suspended under emergency powers. Fraud losses then rose by orders of magnitude. Same population, same dispositions, different controls. The Bounce Back scheme is close to a natural experiment: verification was explicitly traded for speed, and produced exactly the predicted result.

This generalises directly to climate spending. Large, fast, emergency-framed disbursement is precisely the condition under which looting occurs. Any serious climate investment programme must design its integrity architecture *in advance*, because the emergency framing will otherwise be used to suspend it:

- Published contracts and beneficial ownership as a condition of award
- Standing audit capacity rather than post-hoc inquiries
- Whistleblower protection with teeth
- Real-time spending transparency
- Explicit refusal to accept "speed requires suspending verification" — the Bounce Back evidence shows what that trade actually costs

3.1.4 Carbon market integrity

Voluntary carbon markets have suffered serious and well-documented credibility failures: over-crediting from inflated baselines, non-additionality (paying for what would have

happened anyway), permanence failures in forestry credits, and double counting. Journalistic and academic investigations have repeatedly found large fractions of certain credit categories to be worthless.

This matters beyond the credits themselves: it has damaged trust in market mechanisms generally and provided ammunition to opponents of carbon pricing in general.

Remedies: Article 6 corresponding adjustments, stricter and independent MRV, moving from avoidance credits to removal credits, criminal liability for fraudulent issuance, and — most importantly — **not allowing offsets to substitute for direct reductions in compliance regimes**.

3.1.5 Greenwashing and disclosure

Mandatory climate-related financial disclosure (ISSB, CSRD, and successors), transition plan requirements, and advertising standards enforcement. The trend line is positive but implementation is uneven and there has been meaningful political rollback in some jurisdictions.

3.1.6 Litigation

An increasingly effective lever, and under-appreciated by those focused on legislation. *Urgenda* established a state duty of care in the Netherlands. *Milieudefensie v Shell* established (though subsequently modified on appeal) corporate obligations. The ICJ and ITLOS advisory opinions on climate obligations have shifted the legal landscape. Attribution science has advanced to the point where specific damages can increasingly be linked to specific emissions, opening liability routes.

Why litigation is strategically valuable: it operates on a different timescale and through different institutions than legislation, it is relatively resistant to electoral cycles, and it can force disclosure that lobbying has prevented.

3.2 Finance and economic instruments

Carbon pricing. Roughly a quarter of global emissions are now covered by some pricing mechanism, at widely varying and mostly inadequate prices. The EU ETS is the most consequential functioning example. Border adjustment (CBAM) addresses leakage and, more importantly, creates incentives for trading partners to adopt their own pricing — its diffusion effect may exceed its direct effect.

The political economy problem is well understood and repeatedly ignored: carbon prices are regressive without revenue recycling, and visible cost increases generate disproportionate backlash (*gilets jaunes*). Dividend or rebate mechanisms address this and are politically under-used.

Green industrial policy. The dominant paradigm of the last five years — IRA, EU Green Deal Industrial Plan, China's approach. Strengths: builds constituencies, drives learning curves, politically durable because it creates beneficiaries. Weaknesses: expensive per tonne, distorts trade, vulnerable to capture and to political reversal (US policy reversals are estimated to have raised projected 2030 US emissions by around 1 $GtCO_2e$ relative to the previous year's assessment).

Public R&D. Chronically under-funded relative to the scale of the problem — this is one of the clearest and least controversial recommendations available. It is also where the residual-problem technologies (§1.2.4) must come from.

Development finance and MDB reform. Capital cost is the binding constraint on clean energy deployment in emerging markets: the IEA–WEF Cost of Capital Observatory confirms persistently higher financing costs across EMDEs, which directly raises the levelised cost of renewables and storage relative to OECD markets. **Reducing the cost of capital in developing countries may be the single highest-leverage financial intervention available**, because it applies a multiplier to every physical technology in this document. Currency hedging facilities, MDB guarantees, and concessional first-loss capital are the mechanisms.

Loss and damage. The Fund exists and is under-capitalised. Beyond the moral case, it is functionally the price of continued participation by vulnerable states in the international framework.

Divestment and shareholder engagement. Contested effectiveness. Divestment's principal demonstrated effect is stigmatisation and shifting the political Overton window rather than raising capital costs directly. Engagement has a thin but non-zero record. Neither should be treated as a primary lever.

PART FOUR — THE HUMAN LAYER

This section exists because technology-and-policy framings routinely treat human behaviour as a downstream implementation detail — how to persuade people to accept the heat pump — rather than as a component with its own mechanisms, evidence base, and failure modes. That is a genuine gap in mainstream climate strategy.

But depth matters. The human layer contains interventions ranging from the immediately actionable to the entirely speculative, and they should not be assessed as one thing.

4.1 What the evidence actually supports

Defaults, choice architecture, and friction

The best-evidenced behavioural finding in the field: defaults dominate. Green electricity tariff defaults produce large and durable switching. Opt-out beats opt-in in nearly every domain tested. Reducing friction (installer availability, financing at point of sale, single-visit installation) outperforms information provision by a wide margin.

Limitation, stated honestly: nudge effects are typically modest in magnitude, some canonical results have failed replication, and the field has been over-sold. Real, useful, not transformative.

Social norms and observability

Descriptive norms ("most of your neighbours have done this") reliably outperform injunctive norms and factual appeals. Visibility drives adoption — solar panel installation clusters spatially in ways not explained by income or irradiance, and the same appears true for EVs and heat pumps.

Design implication: make adoption visible. This is a cheap and under-used lever.

The information environment

This is the highest-leverage part of the human layer and the least addressed.

The demonstrated fact that matters: mask-wearing was recoded from a public health measure into a political identity marker within roughly eighteen months, and hostility toward the masked became legible as a political stance rather than an assault. Deliberate coughing during the pandemic was common enough that prosecuting authorities issued specific charging guidance and people were imprisoned for it.

The analytically crucial point: this behaviour was not present in early 2020, surged, and receded. **A behaviour that switches on and off with the information environment over eighteen months is not a fixed property of human nature.** It is a property of what a coordinated information campaign made socially legible.

This cuts both ways, and both directions matter for strategy:

- It means disposition-focused pessimism about human nature is over-stated — the behaviour is environmentally contingent
- It means the information environment is an extraordinarily powerful lever, currently operated primarily by actors with interests opposed to climate action

Interventions:

- Platform transparency and algorithmic accountability regulation
- Attribution and disclosure requirements for coordinated campaigns and astroturfing
- Prebunking / inoculation approaches — better evidenced than debunking, which suffers from continued-influence effects
- Consistency of official messaging (governments breaking their own rules measurably shreds compliance — this is one of the clearest findings from the pandemic period, and it applies directly to climate policy legitimacy)
- Trusted-messenger strategies: the messenger's group identity affects reception more than the content does

Collective action and efficacy beliefs

Fatalism is demobilising in measurable ways. Belief that action is futile predicts disengagement more strongly than disbelief in climate change does in many populations. This makes accurate calibration a *strategic* concern and not merely an epistemic one: overstating catastrophe reduces action.

Perceived social efficacy — the belief that others are also acting — is a stronger predictor of sustained individual action than personal concern.

Implication: communicate progress accurately alongside risk. Not as reassurance, but because the fatalism→disengagement pathway is real and is currently being fed by well-intentioned catastrophist communication.

Participatory and deliberative institutions

Climate assemblies (Ireland, France, UK, Scotland) reliably produce more ambitious recommendations than the electorates they are drawn from, once participants engage with

the material. This is a robust and somewhat surprising finding.

Limitation: the implementation gap is severe. Assemblies without a binding link to legislation produce recommendations and little else, and can then serve as legitimation theatre. The design question — how to bind deliberative output to legislative process — is the open problem.

Just transition

Not a moral add-on but a functional requirement. Transitions that impose concentrated costs on identifiable communities while diffusing benefits generate durable political opposition capable of reversing the policy. Coalfield precedents are unambiguous. Retraining, regional investment, and pension protection are cheap relative to the cost of political reversal.

4.2 Individual behaviour change

Honest assessment: **real but limited, and strategically double-edged.**

The high-impact individual actions are well characterised (dietary shift, flying, vehicle choice, home heating). The evidence base for durable voluntary change at scale, absent price or infrastructure change, is weak.

The strategic risk is well documented: individual-responsibility framing has been actively promoted by fossil interests precisely because it displaces attention from structural change. The "carbon footprint" concept's popularisation by BP is the canonical example.

Where individual action does matter disproportionately: as a signal of social norms (visible adoption), as political constituency formation (people who install heat pumps vote for heat pump policy), and via professional and institutional roles, where an individual's leverage may exceed their consumption footprint by orders of magnitude.

4.3 Deep interventions on human disposition

Assessment: excluded from the portfolio, on entry criteria rather than on ethics alone.

Because this is a live proposal in some quarters — moral bioenhancement, engineered prosociality, pharmacological or genetic modification of cooperative disposition — it warrants explicit treatment rather than silent omission.

Portfolio entry criteria for a long-horizon component. A slow-acting intervention earns a place if it is:

- **(a) Specifiable** — well-defined enough that work on it converges, with milestones on which progress can be observed
- **(b) Non-fungible** — not duplicating something cheaper
- **(c) Non-extractive** — not drawing resources or legitimacy from faster-acting components
- **(d) Genuinely diversifying** — hedging a failure mode the rest of the portfolio doesn't cover

Deep disposition modification fails (a) and (d), and probably (c).

On (a): this is an unspecified bet, not merely a slow one — and those are different objects. A slow bet has a defined endpoint and a research path with milestones; fusion has a Q value, and you can tell whether a decade moved you closer. Disposition modification has no validated outcome measure for the target construct, which means there is no metric on which progress could be observed. You cannot allocate to it, because there is nothing to allocate *to*. What you *can* allocate to is the upstream science — measurement theory for latent psychological constructs, causal circuit-level neuroscience, properly-phenotyped genetics. That belongs in a research portfolio. It is a different line item, and it carries no delivery date.

On (d), which is where it fails hardest. The failure mode it hedges is presumably *we know what to do and cannot get ourselves to do it*. But consider what deployment would require: global regulatory coordination, decades of sustained multinational funding, agreement on the value specification across states with divergent interests, and institutional integrity sufficient that no actor captures the mechanism. **That is a strictly harder coordination problem than decarbonisation**, which requires no consensus on human nature and has an actual price signal behind it. The hedge is therefore maximally correlated with the risk it insures: any world competent enough to deploy it safely is a world that could simply have built the grid. It pays out only in states of the world where it cannot be executed.

On timing. Germline modification acts on people not yet conceived, who need two to three decades to reach positions of influence. Population-scale pharmacological or neurotechnological deployment requires development, multi-decade trials, manufacture, and distribution to billions. The intervention resolves in the 2080s a question decided in the 2030s. Under an accelerating threat timeline this argument *strengthens*: faster crises argue for faster instruments.

On (c). The cost is not only financial. The framing *the problem is human nature* carries an implicature that near-term levers are insufficient — which is demobilising by the same mechanism as fatalism (§4.1). One need not intend that effect for it to occur.

And there are structural objections that apply regardless of technical progress: the consent problem for germline intervention, value lock-in of one generation's contested moral specification, and a novel pharmacovigilance failure in which the intervention alters the faculty that would report harm — eliminating the constituency capable of identifying the error. Irreversibility is not one cost among others; it removes the mechanism by which later costs get weighed.

What survives from this line of thinking, and it is not nothing: the diagnosis that the human layer is under-weighted in climate strategy is correct. The response is §4.1 — norms, information environment, deliberative institutions, collective action psychology. These operate on decade timescales rather than generational ones, are reversible, require no consent problem to be solved, and have an existing evidence base. **That is a real and underfunded portfolio slot. It is simply at a different depth.**

PART FIVE — ALLOCATION

5.1 The lever matrix

Lever	Time-to-effect	Maturity	Reversible	Binding constraint	Weighting
Methane abatement (O&G)	**1–5 yr**	Deployed	Yes	**Political will only** — often cost-negative	**Under**
Grid/ transmission/ permitting	2–10 yr	Deployed	Yes	Planning law, institutional capacity	**Severely under**
Solar + storage deployment	Immediate	Deployed	Yes	Grid, land, capital cost in EMDEs	Appropriate
Fossil subsidy reform	1–5 yr	N/A	Yes	Political economy, distributional framing	**Under**
Adaptation & resilience	1–20 yr	Mixed	Partly	**Finance**	**Severely under**
EV standards & mandates	5–15 yr	Deployed	Yes	Phase-appropriate policy design	Appropriate
Cost-of-capital reduction (EMDE)	2–10 yr	Deployed	Yes	MDB reform, currency risk	**Severely under**
Buildings & heat	5–25 yr	Deployed	Yes	Workforce, capital, split incentives	Under
Deforestation enforcement	1–10 yr	Deployed	Partly	Governance, enforcement capacity	Under
Information environment	2–15 yr	Emerging	Yes	Regulatory will, speech trade-offs	**Severely under**
Deliberative institutions	5–20 yr	Emerging	Yes	Binding to legislative process	Under
Industry (steel/ cement/chem)	10–30 yr	Early	Yes	Cost gap, process emissions, procurement	Appropriate

Lever	Time-to-effect	Maturity	Reversible	Binding constraint	Weighting
Nuclear fission (existing)	Immediate	Mature	—	Political decisions on closure	Under
Nuclear fission (new)	10–20 yr	Mature tech, weak delivery	Yes	Institutional construction capability	Contested
Alternative proteins R&D	10–25 yr	Early	Yes	R&D funding, cost parity	**Under**
Long-duration storage	10–20 yr	Pre-commercial	Yes	Cost, demonstration	Appropriate
Enhanced geothermal	5–20 yr	Early-commercial	Yes	Drilling cost, subsurface risk	**Under**
CDR (durable)	15–40 yr	Early	Partly	Cost, energy, MRV	Appropriate, watch moral hazard
Fusion	**25–40 yr**	Pre-commercial	Yes	Engineering, economics	Fund as science, **not** as mitigation
SRM research & governance	Research only	Research	**No, if deployed**	Governance vacuum	Research yes, deployment no
Disposition modification	**50+ yr**	**Unspecifiable**	**No**	No outcome measure exists	**Exclude**

5.2 Allocation principles

1. Time-band the portfolio and don't let bands substitute for each other. Anything acting after 2050 cannot be counted toward the 2030s decision. The most common rhetorical failure in this space is invoking a long-horizon technology as grounds for near-term inaction. Fusion and CDR are the usual vehicles; they should be funded *and* firewalled from near-term accounting.

2. Weight by leverage-per-unit-attention, not by salience. The single largest mismatch in the entire portfolio is that methane abatement and grid permitting are near-free, fast-acting, and technically solved, while receiving a fraction of the attention given to technologies that arrive decades later.

3. Prefer reversible interventions, at real cost in efficacy if necessary. Reversibility is not one attribute among many; it preserves the capacity to correct errors, which is the

precondition for all later optimisation.

4. Design integrity architecture before disbursement, not after. The Bounce Back evidence is unambiguous about what happens when verification is traded for speed. Climate spending will face the same emergency framing and the same pressure.

5. Match policy instrument to S-curve phase. Subsidies early, infrastructure and supply chain in the steep phase, standards and mandates at saturation. Most policy failures in this domain are phase mismatches.

6. Expect learning-curve upside and don't plan as though the curves flatten. They have not, and the systematic error has run in one direction for twenty years.

7. Fund the residual problem early. The last 20% has long lead times and cannot be started when it becomes urgent.

8. Treat the human layer as a component with mechanisms, not as an implementation detail — at the depth the evidence supports.

9. Assume adversarial response. Every effective lever will be lobbied against, litigated, captured, or looted. Interventions should be assessed on their robustness under adversarial conditions, not their performance in the ideal case.

5.3 If forced to name the most under-weighted items

1. **Methane** — cost-negative, fast-acting, now satellite-observable, still not happening
2. **Grid, transmission, and planning reform** — the actual bottleneck on everything electrical
3. **Adaptation finance** — where the deaths are, and where the money isn't
4. **Cost of capital in developing economies** — a multiplier on every physical technology here
5. **The information environment** — the lever currently operated almost exclusively by the other side

None of these require new science. All of them are institutional.

PART SIX — UNCERTAINTY

6.1 What would change this analysis

Stated in advance, so the document can be falsified rather than merely revised:

If this happened	It would change
Sustained deviation of observed warming from projections in either direction	Baseline urgency and adaptation/mitigation balance
Evidence of a crossed tipping point (AMOC, ice sheet, permafrost)	Everything — would substantially raise the weighting on adaptation and SRM research
Fusion or SMR reaching commercial cost parity a decade early	Post-2040 energy planning, not the 2030s
DAC cost falling an order of magnitude	Overshoot strategy; would *not* justify delayed mitigation
Learning curves genuinely flattening	Deployment forecasts and the case for demand-side measures
Major reversal of climate policy in a large emitter	Near-term projections (this has already partly occurred)
A validated, gameable-resistant measure of prosocial disposition	§4.3, and much of psychiatry and policy evaluation besides
Unilateral SRM deployment by any actor	Governance priorities, immediately and completely

6.2 Known weaknesses in this document

- **Figures go stale fast.** Deployment, cost, and policy numbers change on annual or faster cycles. Re-verify before use.
- **The "under-weighted" judgements are the author's assessment**, not consensus findings. They are the most contestable claims here.
- **Coverage is uneven.** Energy is better covered than agriculture, which is better covered than water and biodiversity. Ocean, biodiversity collapse, and the interaction between climate and conflict are under-treated relative to their importance.
- **Geographic bias toward OECD framing.** The politics, finance, and technology mix look substantially different from India, Nigeria, or Indonesia, and the cost-of-capital point in §3.2 is a partial acknowledgement of a much larger gap.
- **The polycrisis framing implies couplings that are asserted more than demonstrated here.** Climate–pandemic–conflict–inequality interactions are real but the causal pathways are less well characterised than the individual domains, and this document does not do them justice.

6.3 Primary sources to track

- **Warming and observations:** Copernicus C3S monthly bulletins and annual Global Climate Highlights; NASA GISS; NOAA; Berkeley Earth; UK Met Office
- **Emissions and gap:** UNEP *Emissions Gap Report* (annual, autumn); Global Carbon Project

- **Energy:** IEA *Global Energy Review*, *Electricity*, *Global EV Outlook*, *Global Methane Tracker*; BloombergNEF; Ember
- **Physical science:** IPCC assessment and special reports; *Indicators of Global Climate Change* (Forster et al., annual)
- **Analysis:** Carbon Brief; The Climate Brink
- **Subsidies and finance:** IMF fossil fuel subsidy database (biennial); IEA–WEF Cost of Capital Observatory
- **Governance:** Climate Action Tracker; Global Methane Pledge annual reports

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Closing note

The portfolio framing carries an implication worth stating plainly: **there is no single intervention that resolves this, and any proposal claiming otherwise should be treated as a claim about dominance that requires evidence.**

That applies symmetrically. It applies to the technologist who thinks fusion or DAC dissolves the problem, to the economist who thinks a sufficient carbon price does, to the activist who thinks degrowth does, and to anyone who concludes that the real fix must be to human nature itself.

The recurring structural feature is that the levers with the highest measured leverage — methane, grid permitting, subsidy reform, adaptation finance, cost of capital — are unglamorous, institutional, and already technically solved. They are not blocked by knowledge, capability, or human nature. They are blocked by the ordinary difficulty of getting institutions to do things they have no strong incentive to do.

That is a less satisfying diagnosis than a broken species. It has the compensating advantage of being addressable by people who are alive now.

Document version 1.0, July 2026. Figures current to mid-2026 and should be re-verified. Assessments marked "under-weighted" are judgements, not findings.