Positive Tipping Points: Accelerating system change to repair our planet

Contents

Acknowledgements

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Executive Summary

This report synthesises five companion analyses prepared by the University of Exeter's Green Futures Solutions for the Earthshot Prize, applying the science of positive tipping points to the five Earthshots: Protect and Restore Nature, Clean Our Air, Revive Our Oceans, Build a Waste-free World, and Fix Our Climate. It is intended to identify the positive tipping points across the five Earthshots that collectively represent the best chance of repairing the planet. As part of The Earthshot Prize's overarching impact framework, these tipping points have application across three levels:

1. The Prize, informing the search, nomination and selection process so that Finalists are those with the greatest catalytic effect on the Earthshots.
2. The Finalist Portfolio, informing how the Prize supports Finalists and where to focus effort once they are selected.
3. Communications, shaping the brand and content that inspire new audiences.

Fifty-one high-priority solution areas are analysed across the five Earthshot chapters. The report refers throughout to "solution areas" as the domain of action, whereas a tipping point is the dynamic self-propelling change that can be triggered for a system within that solution area when a threshold is crossed. A final synthesis chapter draws together some cross-cutting patterns that emerge when the five chapters are considered together.

1. The central idea

Most environmental policy assumes that change is gradual and proportional: bigger problems need bigger budgets, and progress will be slow but linear. The science of positive tipping points tells a different story. Many of the systems we depend on – ecosystems, markets, technologies, social norms – can shift abruptly once a threshold is crossed, with reinforcing feedbacks then driving change without continued external push. Solar power, electric vehicles in leading markets, and the recovery of marine fish stocks after the establishment of well-managed protected areas are all current examples.

For a prestigious global award like The Earthshot Prize, this changes the question. Rather than asking only, "does this solution work?", the more powerful question is: "can this solution trigger exponential, self-propelling change at scale?" Solutions with the greatest potential for 'tipping' are those positioned to unlock reinforcing feedbacks – where early adopters inspire others, costs fall with scale, ecosystems recover enough to sustain their own recovery, or new norms and policies spread from one community or country to the next.

Three enabling conditions, repeated across all five Earthshots

The same three conditions recur across all five Earthshots as the prerequisites for positive tipping:

- **Affordable** – the desired solution must be cost-competitive with the damaging incumbent.
- **Accessible** – it must be practically and geographically available to those who need to adopt it.
- **Attractive** – it must perform well enough, with enough social proof, to make adoption the obvious choice.

These three conditions provide a simple lens that runs across the Prize's work. In selecting Finalists, they frame the question asked of any nomination: which conditions does a solution most directly advance, and is there a credible pathway to achieving the others? Across the Finalist Portfolio, they show where support should be focused to close the remaining gaps. And in communications, they offer a memorable way to explain why a solution is ready to scale.

2. Highest-leverage clusters across the five Earthshots

When the report is considered as a whole, five clusters of priority emerge:

- **Clean electricity as the master cascade.** Solar and wind have crossed positive tipping points in many markets; further scaling is now self-propelling. Because clean power unlocks electric mobility, heat pumps, clean industry and clean air simultaneously, this is the highest-leverage transition across all five Earthshots. The binding constraints are now grid expansion, permitting reform and the clean energy investment gap in the Global South.
- **Commodity supply chain transformation.** Concentrated global supply chains for beef, soy, palm oil, timber, cocoa and coffee make a small number of buyers and financiers the gatekeepers for tropical deforestation. The EU Deforestation Regulation has put this on a legal footing in one major market; alignment across other major importers (China, the UK, the US) could trigger a market-wide norm shift. The same 'Brussels Effect' mechanism operates across the Earthshots: industrial decarbonisation through the EU Carbon Border Adjustment Mechanism, refrigerant transition through the Kigali Amendment, and packaging circularity through EU Extended Producer Responsibility schemes.
- **High-quality marine protected areas, locally managed marine areas and fisheries co-management.** Well-designed and well-enforced ocean conservation produces visible recovery of fish stocks and biodiversity within years, generating social and political support for further expansion – the classic feedback loop of a positive tipping point.

- **Clean cooking and clean household energy.** Around 2.1 billion people still rely on solid fuels for cooking, the single largest source of indoor air pollution and a major source of black carbon. Pay-as-you-go business models combined with rural electrification expansion are bringing clean cooking close to tipping in several markets, with disproportionate health benefits for women and children.
- **Adaptation enablers.** Three solution areas in the report – anticipatory action, adaptation finance and climate-resilient infrastructure in Chapter 4; air quality governance, monitoring and social tipping in Chapter 5; and climate-resilient health systems in Chapter 5 – are explicitly identified as enablers of self-propelling adaptation. Adaptation is often assumed to be incremental, a defensive cost rather than an accelerating shift, but it can theoretically tip through the same dynamics as mitigation: once early measures are shown to visibly reduce losses, they lower insurance and financing costs, build investor and political confidence, and make further adoption the rational choice. Resilience could therefore spread through the same affordability-accessibility-attractiveness feedback rather than requiring continuous external funding. Each amplifies the health, environmental and economic returns from interventions across multiple Earthshots simultaneously. The track-record investor confidence loop documented in ocean finance, blue bonds, adaptation bonds and health adaptation finance is the dominant mechanism by which these systems tip.

3. Cross-Earthshot dynamics

Treating the five Earthshots as separate challenges misses the most powerful sources of leverage. The synthesis chapter at the end of this report identifies eight cross-cutting patterns. Five are particularly important for Prize assessment:

- Clean electricity drives clean transport, clean industry, clean buildings and clean air – a single cascade across four Earthshots, with cross-sector coordinated policy mixes able to bring forward tipping points by two to eight years.
- Monitoring democratisation – satellite methane detection, low-cost air quality sensors, satellite deforestation tracking, satellite fisheries monitoring – is creating an information cascade that is bringing accountability capacity to communities and contexts that previously had none.
- Methane reduction is the fastest available climate lever and one of the highest-impact air quality interventions, with co-benefits flowing through agriculture, waste and energy.
- Land tenure and community rights are the enabling foundation for most nature, ocean, fire and food-system solutions.
- A just transition is a prerequisite for durable tipping points: transitions that create losers without supporting them generate the backlash that stalls or reverses change.

Transitions that build their political base through equitable distribution of costs and benefits are structurally more durable than technically identical alternatives.

4. The Global South investment imperative

The investment gap between lead markets and the Global South is the single most binding constraint on global tipping in most solution areas. Africa receives less than 2% of global clean energy investment despite hosting 60% of the world's best solar resources. Adaptation finance globally is around $50 billion per year against an estimated need of $300–500 billion. Equivalent gaps exist for ocean conservation, clean cooking, health adaptation, circular infrastructure and nature-based solutions. Earthshot nominations that specifically address this gap – through innovative financing mechanisms, technology adaptation for lower-income markets, or governance innovations that reduce perceived investment risk – have particularly high leverage on global outcomes across every Earthshot. This is also relevant to how the Earthshot Prize supports nominations once selected as finalists and how they communicate a positive story.

The chapters that follow develop these themes in detail. Each Earthshot chapter explains the solution areas, analyses each one through a consistent six-part template, and identifies the specific tipping mechanisms, enabling conditions, risks and progress indicators most relevant for assessment. The synthesis chapter pulls together the cross-Earthshot dynamics that are easiest to miss when the challenges are considered separately and ends with a closing reflection on the Prize's leverage.

5. The Earthshot Prize and the scale of the challenge

The Earthshot Prize was created on the conviction that the 2020s are the decisive decade for Earth, and that the response demands rapid, transformative change. This report applies the science of positive tipping points to the work of The Earthshot Prize. The framework was developed in significant part by the University of Exeter's Global Systems Institute and has been articulated most fully in the Global Tipping Points Report 2023 and 2025 (https://global-tipping-points.org/) and a growing body of peer-reviewed literature.

A tipping point is a threshold in a system beyond which change becomes self-propelling. Up to that point, balancing (stabilising) feedbacks maintain the system's existing state and change is roughly proportional to the effort applied; past it, reinforcing (self-amplifying) feedbacks take over and the system reorganises rapidly into a qualitatively different state, often faster than expected, and often difficult to reverse. The concept sits within a wider tradition of systems thinking, for example Donella Meadows' work on leverage points, and the critical-transitions and resilience science of Scheffer and Holling. And it connects naturally to strategic foresight and scenario planning where the most important question is what the biggest potential outcome or impact is (what tipping threshold could we cross) rather than what is most likely outcome or impact.

Tipping points in complex systems are inherently difficult to locate in advance. Early-warning signals such as critical slowing down indicate that a system is losing resilience and give a sense of direction, but they rarely pinpoint the threshold before it is crossed. The practical implication for The Earthshot Prize is to act on the strength of the feedbacks and the direction of travel rather than wait for proof that a tipping point has been passed. The remainder of this section looks first at negative tipping points, which create the urgency, and then at positive tipping points, which are the response.

Negative tipping points are thresholds crossing in a damaging direction. Coral reefs can shift abruptly from coral-dominated to algae-dominated states once warming and pollution pass certain thresholds. The algal state then resists a return to coral. Tropical forests can shift to a savanna once moisture recycling falls beneath a threshold level; ice sheets, permafrost and the Atlantic Meridional Overturning Circulation (AMOC) carry comparable risks. It is the proximity of these damaging thresholds that gives the science of positive tipping points its urgency: incremental responses are no longer sufficient. This report links each relevant solution area to the dangerous negative tipping point it helps avert – forest and landscape restoration reducing the risk of Amazon dieback, coral-resilience work reducing the risk of reef collapse, and peatland rewetting forestalling carbon-release feedbacks.

Positive tipping points are the deliberate, desirable application of this logic. A positive tipping point occurs when a system reaches a threshold at which reinforcing (self-amplifying) feedbacks become strong enough to overwhelm the balancing (stabilising) feedbacks that previously held an unsustainable system in place. Beyond that threshold, change becomes self-propelling: it no longer requires the same level of external push. The system moves towards a qualitatively different, more desirable state, often faster than predicted.

Solar photovoltaic power offers a clear example. For decades it was a niche, expensive technology, kept alive by public subsidy. As deployment grew, manufacturing costs fell along a learning curve. Falling costs unlocked further deployment, which drove costs lower still, which attracted more investment, which improved the technology, and so on. Solar is now the cheapest source of new electricity in most of the world, and continued growth no longer needs continued subsidy. The tipping point was not the moment cost parity was reached – it was the moment self-reinforcing dynamics took over.

6. Three coupled domains

Recent work distinguishes three coupled domains in which tipping points operate:

- **Ecological tipping points** driven by human intervention – for example, the reintroduction of a keystone species triggering a trophic cascade that restores a wider food web; or the rewetting of a peatland triggering recovery of vegetation, hydrology and carbon storage.

- **Social-ecological tipping points** that arise from the coupling of human behaviour and ecosystem response – for example, the spread of community-led marine management areas, where each community's visible success encourages adoption by its neighbours.
- **Social and market tipping points** that reduce the drivers of environmental damage – for example, a market norm shift to deforestation-free commodity sourcing, or the diffusion of electric vehicles once they reach price and performance parity with combustion vehicles.

The most powerful and durable solutions tend to combine all three. A community-led mangrove restoration project may begin as a social-ecological tipping point (community organising plus mangrove recovery), connect upwards into a market tipping point (blue carbon finance), and depend on an ecological tipping point (mangroves sufficiently re-established to sustain themselves).

7. Why this matters for The Earthshot Prize

This report represents a foundational piece of work for The Earthshot Prize: the first time the science of positive tipping points has been applied to the five Earthshots. It gives the Earthshot Prize a shared analytical framework for identifying where transformative change is most achievable and what it will take to get there. It intends to embed this framework across several areas of its work over the coming years.

It shapes the Earthshot Prize's impact framework, moving beyond direct outputs to capture the catalytic, self-propelling change that tipping point thinking demands. It informs the Earthshot Prize's annual search, nomination and selection process, so that the solutions identified are those with the greatest potential to trigger system-level change. It guides how the Prize mobilises its global network to help the Finalist Portfolio scale. And it strengthens communications, offering a way to inspire action by telling the story of how Finalists and Winners are collectively working on the planet's most urgent problems.

The tipping-point lens reframes the central question asked of any candidate solution. Instead of asking only whether a solution works, it asks whether the solution can contribute to exponential, self-propelling change at scale. This is a much harder test to pass, but it is also the test that matters most given the time available.

Three implications follow for the Earthshot Prize assessment process.

First, identify the tipping mechanism. Each strong nomination should have a clear answer to the question: what is the reinforcing feedback that this solution unlocks? If the answer is "none – it just needs continued funding to keep working", the solution is doing useful work but is unlikely to be rapidly transformative. If the answer is, for example, "it reduces unit costs as it scales, so each year of deployment makes the next year cheaper", then it has a candidate tipping mechanism worth investigating.

Second, recognise hysteresis. Reversing a degraded state usually requires a larger push than the one that caused the original degradation – once a wetland is drained, restoring it is harder than draining it was. This argues for concentrating effort and finance at carefully chosen leverage points rather than spreading them thinly across many incremental projects. The same logic applies in reverse: once a positive tipping point is crossed, recovery can be faster and more self-sustaining than expected.

Third, use the three enabling conditions – affordable, accessible and attractive – as a simple assessment framework. A solution that is technically excellent but unaffordable to its intended adopters will not tip. Nor will one that is affordable but inaccessible, or one that is both affordable and accessible but unattractive (attractiveness is a broad term that could include what is fashionable or socially acceptable) compared with familiar alternatives. The most promising nominations are those that advance one of these conditions strongly while having credible plans to address the others.

Three clarifications: first, the tipping point lens is applied here at the level of principle: precisely how it is embedded in the Prize's selection process is best determined through a dedicated workshop. Second, the Earthshot Prize is looking both for solutions that are already close to their tipping point (typically at the early acceleration phase) and those that contribute to bringing forward the tipping point for solution areas that may still be in in their emergence phase – the phases of transition are explained below. Third, the higher-level concepts of environmental and social tipping points are now reasonably well developed, but how specific actors actually trigger these shifts remains an active area of research and experimentation.

8. Three phases of transition

Not all solutions are at the same point in their tipping trajectory, and the support they need is correspondingly different. The Global Tipping Points Report 2025 framework identifies three phases:

- **Emergence:** the innovation exists but is rare, expensive and socially unfamiliar. The bottleneck is demonstration and de-risking.
- **Acceleration:** reinforcing feedbacks have activated and adoption is spreading rapidly. The bottleneck is scaling capital, supportive policy and demand pull.
- **Stabilisation:** the new norm is dominant. The bottleneck is locking it in against reversal, through regulation, infrastructure and shared expectations.

Different Earthshots feature different mixes of phases. Climate solutions are heavily concentrated in acceleration (solar, wind, EVs in leading markets) with a tail of emergence-stage solutions (green hydrogen, durable carbon removal). Ocean solutions are mostly in emergence and early acceleration. Air quality solutions span the full range, from highly mature regulatory frameworks in some regions to entirely absent ones in others. Matching the form of support to the phase is essential. Emergence-stage solutions need demonstration, patient capital and de-risking; acceleration-stage solutions need scaling finance, supportive policy and demand pull; stabilisation-stage solutions need regulation, infrastructure and standard-setting to lock the new norm in against reversal. Each chapter tags every solution area with its current phase, so the kind of support an area most needs can be read directly from where it sits on the curve (see Figure 1).

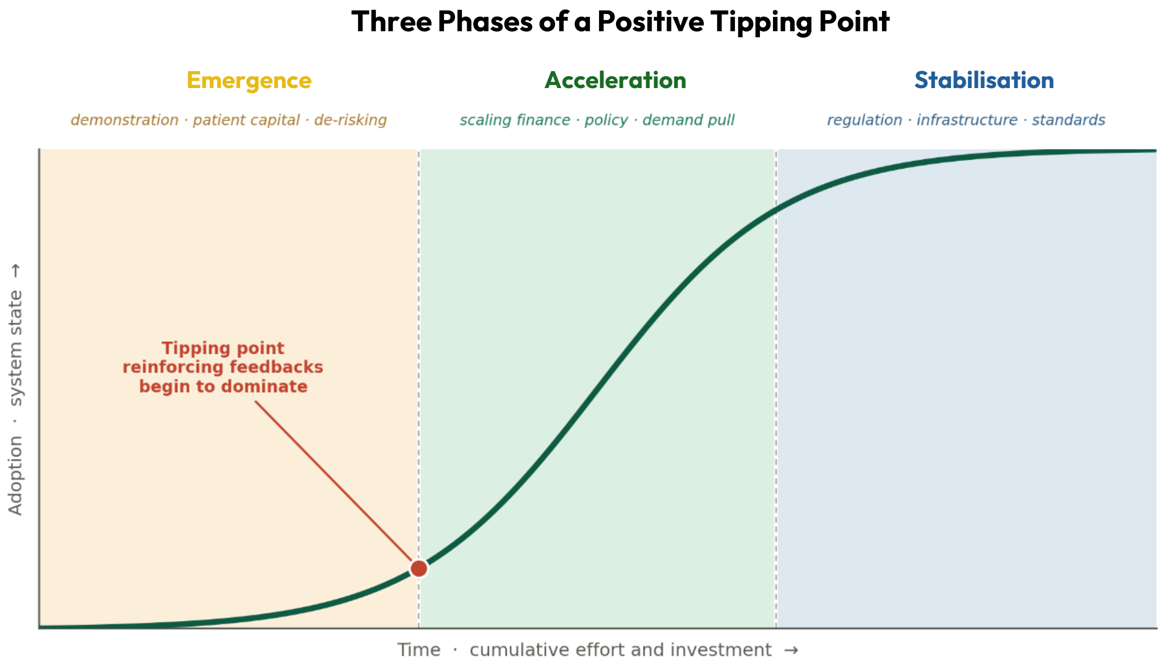

Figure 1. The three phases of a positive tipping point, and the form of support each phase requires. Each chapter's table locates its solution areas along this curve (adapted from Lenton et al., 2025)

9. How this report is structured

The report is structured as follows. An executive summary highlights the highest-leverage findings and recommendations. This introduction sets out the tipping-point lens. Five Earthshot chapters then apply the lens systematically to the solution areas identified in the underlying research. A cross-cutting synthesis chapter identifies the patterns that emerge when the five Earthshots are read together. References, a glossary of key terms, and an appendix follow at the end of the report.

Each of the five Earthshot chapters opens with a short challenge-specific introduction and a list of all solution areas in that Earthshot. Each solution area is then analysed through a consistent six-part template: What it is; Why it matters and how it could tip; Current state and desired future; Drivers and barriers (reinforcing feedbacks and balancing feedbacks);

Where to act and what to watch (priority geographies, key actors, key risks); and Top progress indicators. The progress indicators are presented as a quantified metrics table with explicit 2030 targets and data sources, designed for direct use in assessing Earthshot nominations against the priorities identified in the chapter. Throughout, the “desired future state (2030)” described for each solution area is a trajectory waypoint rather than the tipping point itself: it marks where a system should be by 2030.

Fifty-one solution areas are analysed across the five chapters:

- **Chapter 1 – Protect and Restore Nature** (10 solution areas): sustainable commodity supply transformation; protection of intact and high-integrity ecosystems; freshwater ecosystem-based adaptation; peatland and wetland restoration; forest and landscape restoration; keystone species reintroduction; sustainable and climate-resilient agriculture and agroforestry; community-based resource governance; fire-managed savannah and grassland ecosystems; and urban green infrastructure.
- **Chapter 2 – Clean Our Air** (9 solution areas): clean household energy and buildings; air quality governance, monitoring and social tipping; climate-resilient health systems and the air-heat-health nexus; clean electricity and combustion phase-out; clean mobility systems; agricultural reactive nitrogen and methane abatement; waste system tipping; industrial clean production and continuous monitoring; and wildfire smoke and Indigenous fire stewardship.
- **Chapter 3 – Revive Our Oceans** (11 solution areas): high-quality marine protected area networks and OECMs for 30x30; fisheries rebuilding, co-management and illegal fishing suppression; community-led locally managed marine areas; blue-carbon and coastal ecosystem restoration; climate-resilient reef systems and thermal refugia; kelp forest and seaweed systems restoration; sustainable aquaculture transformation; Integrated Sustainable Ocean Plans; pollution, nutrients and plastics source-to-sea strategies; ocean finance mechanisms; and clean shipping and ports.
- **Chapter 4 – Build a Waste-Free World** (11 solution areas): policy, procurement and finance mechanisms; Extended Producer Responsibility and eco-modulated fees; circular construction materials and the climate-adapted built environment; municipal waste infrastructure transformation; circular packaging and reuse / refill systems; deposit-return schemes; organic waste prevention, composting and anaerobic digestion; e-waste collection, circular electronics and repairability; industrial symbiosis and eco-industrial parks; toxins (microplastics, microfibres, PFAS and pellet loss prevention); and textile and fashion circularity.
- **Chapter 5 – Fix Our Climate** (10 solution areas): clean electricity and flexible power systems; electrified mobility and Avoid-Shift-Improve transport; sustainable cooling and the heat-mitigation nexus; methane abatement; land-based mitigation; heat pumps and deep retrofits; industrial transformation; demand-side tipping;

anticipatory action, adaptation finance and climate-resilient infrastructure; and durable carbon removal.

References are listed at the end in alphabetical order by lead author; the number on the left of each entry corresponds to the superscript citation number used in the body of the report.

Chapter 1: Protect and Restore Nature

The first Earthshot sets a clear ambition: by 2030 the natural world should be growing, not shrinking. Tipping points for nature operate in three coupled domains: ecological (e.g. a keystone species triggering a trophic cascade), social-ecological (e.g. a community taking control of its resource base and inspiring others) and social or market (e.g. a buyer norm shift that removes the financial incentive to clear forests). The most powerful solutions activate all three.[66]

Hysteresis matters: recovering a degraded system usually takes more effort than the degradation that created it, which argues for concentrating finance and political capital at carefully chosen leverage points. Once a positive tipping point is crossed, however, recovery is often faster and more self-sustaining than expected.[96]

Ten solution areas are analysed in this chapter. Each follows the same six-part template: what it is, why the area matters and how it could tip, the current and desired states, the feedbacks driving and resisting change, where to act and what to watch, and quantifiable progress indicators with 2030 targets. Finance, from biodiversity credits to nature-positive investment and government funding, runs through each solution area as an enabler.

Finance has good and bad sides, and the good side of nature conservation is the smaller one. Global spending on biodiversity conservation is $124-143 billion/year, a fraction of the estimate need of $722-967 billion by 2030[137]. Against that, governments spent an estimated $274-542 billion in 2019 on agricultural forestry and fisheries subsidies that damage biodiversity. UNEP's broader accounting is even starker: around $7.3 trillion/year flows to activities that degrade nature, of which $2.4 trillion is public subsidy and the rest private finance[138]. Redirecting money that is already being spent is a powerful lever. The barrier is political rather than financial. Although policy reform is not in the gift of The Earthshot Prize, what The Prize can do is back solutions that show how redirected finance can work and makes it more politically feasible.

Solution areas

Solution area	Phase	How it could Tip
Sustainable commodity supply transformation. Shift global trade in beef, soy, palm oil, timber, cocoa and	Emergence → Acceleration (EUDR live in one major market, but global buyer alignment not yet reached).	When the EU, China, UK and US align on deforestation-free sourcing, it becomes the default market standard and forest clearing rapidly loses its buyers.

Solution area	Phase	How it could Tip
coffee to deforestation-free.		
Protect intact, high-integrity ecosystems. Keep intact forests, wetlands, and grasslands.	Emergence (30×30 Kunming-Montreal GBF agreed but far from met; frontier clearing continues).	Once intact ecosystems are worth more standing than cleared — via carbon, biodiversity and resilience value — protection becomes the rational default and the loss curve reverses.
Freshwater ecosystem-based adaptation Use healthy rivers, wetlands and catchments to cut flood and drought risk	Emergence (coupled loops present but not yet self-sustaining).	When utilities and insurers routinely price catchment protection below built flood infrastructure, natural flood management becomes standard procurement.
Peatland and wetland restoration Wildlife recovers and carbon remains locked in.	Emergence (strong feedback once rewetted, but restoration still niche).	Rewetting reaches the point where restored peat is self-sustaining and carbon/biodiversity finance covers the cost, so it scales without subsidy.
Forest and landscape restoration	Emergence → Acceleration (the Bonn Challenge / UN DER and corporate demand pull active).	As commitments, carbon markets and supply-chain demand reinforce each other, restoration becomes financially self-propelling across whole regions.
Keystone species reintroduction (trophic rewilding). Return species that re-engineer whole ecosystems, such as wolves, bison and beaver.	Emergence (trophic cascades documented but reintroductions still rare).	Trophic cascade tipping documented in Yellowstone wolves, European bison and beaver returns; charismatic appeal accelerates social diffusion.
Sustainable and regenerative agriculture and agroforestry	Emergence (farmer-to-farmer diffusion early; subsidy reform pending)	When subsidies flip toward regenerative practice and peers prove yields hold, farmer-to-farmer diffusion carries adoption past the threshold.

Solution area	Phase	How it could Tip
Farming that rebuilds soil, biodiversity and water security		
Community-based resource governance. Recognises the rights of local / indigenous communities to manage the ecosystems they depend on.	Emergence → Acceleration (tenure recognition beginning to cascade politically).	As tenure recognition delivers better outcomes at lower cost, political precedent cascades and community rights become the norm.
Fire-managed savannah and grassland ecosystems	Emergence (Indigenous fire + carbon-credit models are nascent)	When carbon finance reliably rewards cool-burn stewardship, Indigenous fire management rapidly scales as the standard tool against catastrophic wildfire.
Urban green infrastructure Trees, parks, green roofs and corridors that cool cities, clean the air, and bring nature to people	Acceleration (widely adopted across cities as a multi-benefit standard)	As heat, air-quality and stormwater benefits are priced into planning codes, green infrastructure becomes a default requirement in development

Sustainable commodity supply transformation

What it is: transforming global trade in beef, soy, palm oil, timber, cocoa and coffee so that producing them no longer drives deforestation.

Why it matters and how it could tip

Agricultural expansion for beef, soy, palm oil, timber, cocoa and coffee is the single largest driver of tropical deforestation worldwide, accounting for around 70% of tropical forest loss.[81,83] Global supply chains are extraordinarily concentrated, so coordinated action by a critical mass of buyers, financiers and regulators can restructure incentives facing millions of producers without changing each one individually.[34,82]

The Amazon Soy Moratorium reduced soy-driven deforestation in the Brazilian Amazon to 1% of new clearing between 2006 and 2014; the EU Deforestation Regulation (EUDR) extends this logic to binding law.[12,62] The tipping potential is a market-wide norm shift in which deforestation-free sourcing becomes the default standard across all major consumer markets simultaneously. Removing the economic drivers of deforestation prevents deforestation faster than any restoration can repair it and lowers the risk of a dieback tipping point.

Because these commodities drive the clearance of the world's most biodiverse tropical forests, breaking the link between production and deforestation is also the single largest opportunity to halt terrestrial biodiversity loss and keep intact-forest species and ecosystems standing.

Current state and desired future

Current state: zero-deforestation commitments cover a significant share of major traders, but enforcement and traceability remain weak; deforestation-linked supply chains still drive around 4 million hectares of tropical forest loss per year globally.[62]

Desired future state (2030): deforestation-free sourcing is the legal and commercial baseline in all major consumer markets (EU, UK, US, China); supply chain transparency is routine through satellite monitoring; producers of all scales are financially rewarded for sustainable stewardship.[82,107] The tipping cascade runs through major trading hubs (London, Amsterdam, Singapore, São Paulo); when financing of deforestation-linked supply chains becomes simultaneously reputationally and legally untenable, holdouts find themselves commercially isolated.[34]

Drivers and barriers

Reinforcing feedbacks:

- **Regulatory cascade.** The EUDR creates a new legal baseline; UK, US and Chinese alignment would convert it into an international ratchet.[12]
- **Market access feedback.** As the deforestation-free segment grows, certification economies of scale make compliance progressively cheaper for producers.
- **Financial exclusion loop.** As major banks adopt deforestation risk policies, financing for non-compliant supply chains dries up.[3]
- **Technology learning curve.** Satellite monitoring and digital traceability costs are falling rapidly; supply chain transparency is becoming routine.[82]

Working against:

- **Leakage.** Restricting deforestation in EU-aligned markets may displace it to China and other less discriminating markets – the dominant near-term risk.
- **Smallholder exclusion.** Compliance costs can be prohibitive for smallholders, risking exclusion rather than transition.

- **Greenwashing.** Voluntary commitments without independent verification create false progress signals.[62]
- **Political resistance.** Producer-country governments may resist supply chain regulations citing sovereignty.
- Nature-negative capital. About two-thirds of the estimated $7.3 trillion a year flowing to nature-degrading activity is private capital. Nine tenths of the far smaller restoring flow is public money[138]. Bank deforestation policies only cover a fraction of the lending, trade finance and equity that funds agricultural frontier expansion.

Where to act and what to watch

Priority geographies: Brazil and the Amazon biome (largest concentration of commodity-driven deforestation globally); Indonesia and Malaysia (dominant palm oil suppliers); Congo Basin (rapid expansion, underserved by global standards); West Africa cocoa belt in Ghana and Côte d'Ivoire (directly affected by EUDR with smallholder-dominated supply chains).

Key actors: agribusiness corporations and commodity traders (Cargill, Bunge, Wilmar, JBS); financial institutions setting deforestation risk policies; consumer market regulators (EU, UK, US, China); producer country governments; Indigenous communities and local farmers; technology providers (Global Forest Watch, TRASE).

Key risks: leakage at scale if EUDR is not matched by parallel measures in China; smallholder marginalisation through poorly designed compliance regimes; EUDR rollback or dilution under economic pressure (implementation has already faced delays); greenwashing through inadequate monitoring.

Top progress indicators

Indicator	Quantification and target	Data source
Annual rate of tropical deforestation linked to commodity supply chains	Target: below 1 million ha/yr by 2030 (from around 4 million ha/yr today)	Global Forest Watch; PRODES (Brazil); TRASE supply chain transparency
Share of major commodity trade volumes covered by credible, verified zero-deforestation commitments	Target: above 75% of volume traded by 2028	Supply Change tracker (Forest500); CDP Forest disclosure; TRASE
Number of producer countries with enforceable domestic legislation aligned to importing market deforestation standards	Target: at least 10 producer countries by 2028, all major suppliers by 2030	FERN/Forest Peoples Programme; country NDC and REDD+ reporting

Protection of intact and high-integrity ecosystems

What it is: keeping the world's still-intact, high-integrity ecosystems – primary forests, undrained peatlands, intact wetlands, natural grasslands and the most pristine freshwater systems – standing, rather than letting them degrade and then trying to rebuild them.

Why it matters and how it could tip

Avoiding the loss of an intact ecosystem is cheaper, faster and more reliable than restoring a degraded one. Intact systems hold carbon stocks and species that have accumulated over millennia and that cannot be reconstructed on any timescale useful to this decade (Watson et al. 2018). The Kunming–Montreal Global Biodiversity Framework reflects this by setting protection and restoration as distinct goals; this report follows the same logic, treating protection as a solution area in its own right alongside the restoration areas that follow.

The tipping dynamic is a protection ratchet. Once an area gains durable legal protection, secure Indigenous or community tenure and a finance stream keep it standing, the political and economic cost of reversing that status rises, and each new designation makes the next more normal. Intact systems also sit close to their own negative tipping points – the Amazon's moisture-recycling threshold, peat-dome collapse, the unravelling of old-growth food webs – so protection is the most direct way to keep those damaging thresholds from being crossed (Armstrong McKay et al. 2022).

Current state and desired future

Current state: roughly 17% of land and inland waters and around 8% of the ocean carry some form of protection, but much of it is paper protection – designated yet under-resourced, weakly enforced, or not controlled by the communities best placed to defend it. Intact-forest landscapes continue to shrink each year, and high-integrity systems are still being lost faster than new ones are durably secured.

Desired future state (2030): the 30x30 target is met in area and, more importantly, in quality – protection concentrated on the most intact, highest-integrity and most irreplaceable systems; the majority delivered through recognised Indigenous and community tenure; and backed by finance that pays for protection to be maintained rather than merely declared.

Drivers and barriers

Reinforcing feedbacks:

- **Protection ratchet.** Legal designation and tenure security raise the cost of reversal and make further designation more normal.

- **Avoided-loss economics.** As carbon and biodiversity-credit markets mature, keeping high-integrity systems standing attracts payment, moving protection towards self-financing.
- **Indigenous stewardship feedback.** Recognised tenure improves ecological outcomes and builds political constituencies that defend protected status.

Working against:

- **Paper parks.** Designation without finance or enforcement creates the appearance of protection without the substance.
- **Frontier economics.** Commodity, mining and infrastructure rents can outbid protection at the frontier in the short term – which links this area directly to commodity supply transformation (solution area 1). These rents are often underwritten by public money: subsidies for commodity expansion, forestry and frontier infrastructure tip the scales against protection before any conservation finance arrives[137].
- **Leakage.** Protecting one area can displace pressure onto another unless underlying demand is addressed.

Where to act and what to watch

Priority geographies: the great intact biomes under active threat – Amazon, Congo Basin and New Guinea primary forests; the boreal forests and peatlands of Russia and Canada; intact tropical peatlands in the Congo, Indonesia and Peru. Prioritisation follows the methodology used throughout: severity of threat, proximity to a tipping threshold, density of co-benefits and leverage.

Key actors: Indigenous peoples and local communities (the most effective long-term stewards); national protected-area agencies and finance ministries; parties to the Kunming–Montreal framework; conservation-finance vehicles and philanthropies; and the commodity and extractive sectors whose frontier expansion is the principal pressure.

Key risks: paper protection that records area without securing integrity; displacement of Indigenous and local communities in the name of conservation (fortress conservation), which is both unjust and counter-productive; and underfinancing that leaves designated areas undefended.

Top progress indicators

Indicator	Quantification and target	Data source
Area of intact / high-integrity ecosystems under	Target: 30% of land and sea by 2030 (30x30), weighted towards the highest-integrity systems	Protected Planet (WDPA); Intact Forest Landscapes;

Indicator	Quantification and target	Data source
durable, well-resourced protection		Kunming–Montreal Target 3 reporting
Share of protected area under recognised Indigenous and community tenure or co-governance	Target: the majority of newly protected area by 2030	ICCA Registry; LandMark; national tenure records
Annual loss of intact-forest landscapes and other high-integrity systems	Target: approaching zero net loss by 2030 (from continuing losses today)	Intact Forest Landscapes; Global Forest Watch

Freshwater ecosystem-based adaptation and climate-resilient water management

What it is: using healthy rivers, wetlands and catchments as working infrastructure to manage water and cut flood and drought risk.

Why it matters and how it could tip

The nature gain is direct: freshwater species are among the most threatened. Protecting riparian woodland, floodplains and wetlands restores the habitat on which they depend. Approximately 4 billion people experience severe water scarcity at least one month per year, projected to rise to 5–6 billion by 2050.[57,102] Global flood damage is around $130 billion per year and rising; global drought damage is $6–20 billion per year in agricultural losses alone.[72] Natural water infrastructure (riparian forests, floodplains, wetlands, source-water protection catchments) is typically 2–5 times more cost-effective than equivalent grey infrastructure.

Three coupled tipping loops can break the current undervaluation: water utility procurement of catchment protection; insurance industry repricing of natural flood infrastructure; and integrated water resources management (IWRM) governance frameworks. The three reinforce each other: utility procurement creates market demand, insurance repricing creates commercial demand, IWRM frameworks embed practice in governance.

Current state and desired future

Current state: around 4 billion people in severe water scarcity at least one month/year; global flood damage around $130 billion/year; water infrastructure investment gap for adaptation estimated at $7–40 billion/year; natural water infrastructure undervalued in most jurisdictions despite the 2–5× cost-effectiveness advantage.

Operational precedents: New York City's Catskill watershed protection (around $1.5 billion in catchment investment versus an estimated $8–10 billion filtration plant avoided cost); the Netherlands Room for the River programme; China's Sponge Cities programme covering 30+ cities; the European Water Framework Directive across 27 member states.

Desired future state (2030): source-water protection operational for the 100 largest cities globally; floodplain restoration mainstreamed in OECD jurisdictions with measurable flood damage and insurance premium reductions; IWRM frameworks with ecosystem-based approaches operational in 50+ countries.

Drivers and barriers

Reinforcing feedbacks:

- **Water utility procurement track-record loop.** Each successful catchment programme builds evidence and capacity for the next; tips on 5–10-year procurement timescales.
- **Insurance industry repricing loop.** Actuarial models progressively incorporate natural infrastructure as a quantified risk-reduction asset.[72,98]
- **IWRM governance ratchet.** Lead jurisdictions (EU Water Framework Directive, China Water Ten Plan, India Atal Bhujal Yojana) propagate through international cooperation.
- **Cost-effectiveness compounding.** As natural infrastructure outperforms grey in standard cost-benefit appraisals, capital flows reflect this.[115]

Working against:

- **Grey infrastructure lock-in.** Existing capital stock and engineering cultures resist substitution.
- **Boundary mismatch.** Water utility service areas rarely match watershed boundaries, creating coordination challenges.
- **Long benefit horizons.** Catchment investments often deliver returns over 10–20 years, beyond typical political and financial cycles.
- **Land tenure complexity.** Catchment protection requires sustained access agreements with thousands of upstream landowners.

Where to act and what to watch

Priority geographies: tropical Global South regions where water adaptation is most urgent; dry-region cities at acute drought risk (Cape Town, São Paulo, Lima, Bangalore); flood-exposed river basins (Indus, Brahmaputra, Mekong, Mississippi, Rhine); water-scarce agricultural regions (Sahel, Mediterranean, US Southwest, North China Plain).

Key actors: water utilities (Thames, NYC DEP, Cape Town, São Paulo SABESP); national water ministries; reinsurance industry (Munich Re, Swiss Re, Zurich, Lloyd's); multilateral development banks; civil society (WWF, TNC, IUCN); Indigenous and upstream communities.

Key risks: greenwashing where catchment protection is announced without sustained finance; equity capture by wealthy urban utilities at the expense of rural upstream communities; maladaptation through ecosystem-based approaches deployed without local context understanding; over-confidence in natural infrastructure resilience as climate shocks intensify.

Top progress indicators

Indicator	Quantification and target	Data source
Number of major cities with operational source-water protection catchments	Target: 50 cities by 2028, 100 by 2030	TNC Water Funds; UNEP-DHI; national water utilities
Volume of insurance products incorporating natural flood infrastructure as quantified risk-reduction asset	Target: $50 billion cover by 2030	Geneva Association; reinsurer reports
Number of countries with operational IWRM frameworks integrating ecosystem-based approaches	Target: 50 countries by 2030	UN-Water; SDG 6.5.1 tracking; national water ministry reporting

Peatland and wetland restoration

What it is: rewetting and restoring peatlands and wetlands so their specialist wildlife recovers and their stored carbon stays locked away.

Why it matters and how it could tip

Peatlands store approximately twice as much carbon as the world's forests despite covering only around 3% of land area.[101] Degraded peatlands emit an estimated 1.9 $GtCO_2e$/year globally – around 4% of total anthropogenic emissions – and are massive ongoing sources of CO_2, methane and $PM_{2.5}$.

The tipping mechanism is biophysical self-reinforcement: as water tables rise through rewetting, peat-forming vegetation returns, decomposition slows, carbon accumulation resumes, and the system stabilises in its restored state.[66] Restoration scales through landscape-level rewetting combined with palm oil and pulp supply chain governance.

Beyond carbon, peatlands and wetlands are also important for biodiversity, being home to specialist plants, invertebrates and wading birds found nowhere else. They are also critical to bird migration, as the staging, breeding and overwintering grounds that entire flyways of migratory waterbirds and waders depend on, so draining one site has a knock-on impact on migratory routes far beyond it. Intact wetlands also filter water, recharge aquifers and buffer floods. Draining them destroys this biodiversity and these ecosystem services. Restoration recovers a unique habitat as well as locking carbon back in.

Current state and desired future

Current state: around 12–15% of global peatlands are degraded; degraded peatlands emit around 4% of total anthropogenic emissions against 3% of land area; Indonesia's Peatland Restoration Agency demonstrates landscape-scale rewetting is institutionally feasible (over 2 million ha commitments); the EU Nature Restoration Law sets binding restoration targets.

Desired future state (2030): all degraded peatlands globally on credible restoration trajectories; 5 million ha rewetted by 2030 with documented emissions reduction; peatland conservation embedded in palm oil and pulp supply chain standards; peatland-specific carbon finance scaling.

Drivers and barriers

Reinforcing feedbacks:

- **Biophysical recovery cascade.** Once water table rises above the critical threshold, vegetation, hydrology and carbon accumulation reinforce one another.[66]
- **Carbon finance pull.** High per-hectare carbon density makes peatland restoration economically competitive in voluntary and compliance markets.[101]
- **Supply chain integration.** Palm oil and pulp buyers increasingly require peatland conservation in supply chain standards.

Working against:

- **Fire-feedback risk.** Drained peat that ignites can burn for months; one large fire event can negate years of restoration.
- **Land tenure conflicts.** Peatlands are often customary Indigenous land; restoration without FPIC produces ethical and operational failures.
- **Hydrological complexity.** Restoration requires sustained management of canal blocking and water levels over decades.

Where to act and what to watch

Priority geographies: Indonesia (around 21 million ha of tropical peat); Malaysia (around 2.5 million ha); Congo Basin (Cuvette Centrale, around 145 thousand km², the largest tropical peatland complex globally); Peru (Pastaza-Marañón); UK, Ireland, Finland and Russia (boreal and temperate peatlands).

Priority biomes: within these geographies, tropical lowland peat-swamp forests are the first priority — they hold the deepest carbon and emit fastest once drained, so preventing new drainage there averts the largest losses; boreal and temperate peatlands (northern Europe and Russia) hold the single largest global peat-carbon store and are the priority for protecting intact systems and rewetting drained agricultural and forestry peat; and coastal peat with associated mangrove and tidal wetlands is the priority where carbon storage stacks with blue-carbon and flood-buffering value.

Key actors: tropical peatland nations and restoration agencies (Indonesia BRGM/M, UK Peatland Programme); palm oil and pulp companies (Wilmar, GAR, APP); carbon market actors (Verra, Gold Standard); Indigenous and local communities; scientific networks (Global Peatlands Initiative, IUCN).

Key risks: restoration failure through inadequate hydrological management; fire risk during transitional dry years; tenure conflicts where restoration excludes traditional users; carbon credit integrity challenges; greenwashing through small restoration footprints offsetting continued peat conversion.

Top progress indicators

Indicator	Quantification and target	Data source
Area of degraded peatland under active restoration	Target: 5 million ha cumulative by 2030	Global Peatlands Initiative; UNEP GPA; national peatland agency reporting
Emissions reductions from peatland restoration	Target: 200 $MtCO_2e$/yr by 2030	IPCC peatland inventory methods; UN REDD+ reporting; national GHG inventories
Area of intact peatland under enforced protection	Target: above 90% of remaining intact tropical peat under protection by 2030	Global Peatlands Initiative; Global Forest Watch

Forest and landscape restoration

What it is: bringing degraded forests and wider landscapes back to biodiverse, productive health, alongside the communities that steward them.

Why it matters and how it could tip

Around 2 billion hectares of degraded land globally have restoration potential; the Bonn Challenge has mobilised commitments to restore 350 million hectares by 2030; AFR100 commits African nations to restoring 100 million hectares.

Degraded land means ecosystems whose structure, species or function have been substantially diminished by human pressure, but which retain the capacity to recover. The term can refer to forests, grasslands, drylands, wetlands and mangroves. One important caveat is that foresting natural grasslands and savannas is a form of damage, not restoration, because these are ancient open ecosystems with their own endemic biodiversity.

The most powerful restoration tipping mechanism is moisture recycling: once enough forest is recovered in a region, transpiration sustains the rainfall that supports further forest growth.[75,120,133] The Atlantic Forest and Costa Rica cases show landscape-scale restoration is achievable within a generation when Payment for Ecosystem Services (PES) schemes, secure tenure and corporate net-zero supply chain demand align.[132]

Restoration is not only a carbon and land-productivity measure. Reconnecting fragmented forests rebuilds habitat and species corridors, and biodiversity co-benefits cascade as native plants, pollinators and other wildlife return.

Current state and desired future

Current state: Bonn Challenge commitments total around 230 million ha of which around 40 million ha are documented as on track or restored; Costa Rica has roughly doubled forest cover from 25% in 1985 to around 54% today.[132]

Desired future state (2030): 350 million ha under active restoration globally (full Bonn Challenge); 100 million ha in Africa (full AFR100); moisture-recycling tipping crossed in at least two further major tropical forest landscapes; corporate net-zero supply chains generating sustained restoration finance at scale.

Drivers and barriers

Reinforcing feedbacks:

- **Moisture recycling.** Restored forests transpire water that returns as rainfall downwind, sustaining further forest recovery.[120,133]
- **Biodiversity recovery cascade.** Returning fauna disperse seeds and create habitat structure that accelerates further recovery.[132]
- **Corporate net-zero demand pull.** Net-zero supply chain commitments generate sustained restoration finance.[62]
- **Carbon and biodiversity finance compounding.** Demonstrated outcomes lower investor risk perception; finance accelerates.[3]

Working against:

- **Wrong-tree risk.** Monoculture plantations counted as restoration deliver limited biodiversity benefit.
- **Tenure insecurity.** Restoration on contested land without recognised rights collapses when funding ends.
- **Climate-driven mortality.** Newly restored forests are particularly vulnerable to drought and fire under climate stress.
- **Funding cliff.** PES schemes often face funding gaps when project cycles end before forest is self-sustaining.

Where to act and what to watch

Priority geographies: Brazil's Atlantic Forest and the Amazon arc of deforestation (proven restoration model, and the biome closest to a moisture-recycling tipping threshold); Costa Rica and Central America (demonstrated forest-cover recovery through PES and tenure reform); the African Forest Landscape Restoration Initiative (AFR100) nations of Sub-Saharan Africa (Ethiopia, Rwanda, Kenya, Malawi, Cameroon); Indonesia's degraded forest and peatland landscapes; and India's Bonn Challenge landscapes.”

Key actors: national forest agencies (Brazil ICMBio, Costa Rica FONAFIFO, Ethiopia EFD, Indonesia KLHK); restoration finance institutions (Land Degradation Neutrality Fund, AFR100 partners, World Bank); restoration NGOs (WRI, IUCN, TNC, Rare); local communities and Indigenous peoples; agroforestry research centres (ICRAF, CIFOR-ICRAF).

Key risks: plantation-restoration confusion where monocultures are counted as restoration; restoration backslide when funding ends; equity capture by large landowners through PES; climate-driven mortality of newly restored forests; greenwashing of corporate offsets through low-integrity restoration credits.

Top progress indicators

Indicator	Quantification and target	Data source
Area under active restoration in priority landscapes	Target: 350 Mha cumulative by 2030 (full Bonn Challenge)	FERM (FAO); Bonn Challenge Barometer; Trillion Trees Platform
Share of restoration counted as native-species and ecologically appropriate	Target: at least 70% native-species restoration by 2030	IUCN restoration standards; SER restoration database

Indicator	Quantification and target	Data source
Documented rainfall recovery in restoration landscapes where moisture recycling is the tipping mechanism	Target: measurable rainfall trend reversal in at least two major restoration regions by 2030	Peer-reviewed hydrology; national meteorological services

Keystone species reintroduction (trophic rewilding)

What it is: returning species that re-engineer whole ecosystems – such as wolves, bison and beaver – to set wider recovery in motion.

Why it matters and how it could tip

The tipping mechanism is ecological: predators regulate herbivores; vegetation recovers; hydrology improves; biodiversity rebounds. The social tipping mechanism is the strong public appeal of charismatic species, which accelerates political and philanthropic support. Protecting a big enough area, such as for tigers in India, can also help protect the forest, water and biodiversity of its territory. Single species can therefore bring entire landscapes back to recovery.

Current state and desired future

Current state: wolf populations recovered across much of Europe and parts of North America; European bison population grown from around 50 in 1927 to over 11,000 today; beaver populations recovered to around 1.5 million in Europe from near extinction at the turn of the 20th century.

Desired state: for trophic rewilding to become a mainstream, publicly supported land-management tool, with keystone species (wolves, lynx, bison, beaver, and their aquatic equivalents) re-established across a connected network of large, well-managed landscapes. Ecological functions such as grazing regulation, hydrological engineering and seed dispersal are recognised and restored at landscape scale, and social-ecological co-existence is actively managed so that populations persist without continual intervention.

Drivers and barriers

Reinforcing feedbacks:

- **Trophic cascade.** Predator presence regulates herbivores, vegetation recovers, hydrology improves.[86]
- **Population expansion.** Once established above critical density, populations expand through reproduction.[66]

- **Charismatic-species visibility loop.** Public appeal drives philanthropy, tourism revenue and political protection.
- **Knowledge transfer.** Each successful reintroduction lowers the learning cost for the next.[87]

Working against:

- **Human-wildlife conflict.** Predator return creates real livestock and safety costs for rural communities.
- **Habitat fragmentation.** Insufficient connected habitat constrains population viability.
- **Genetic bottlenecks.** Reintroduced populations may have insufficient genetic diversity for long-term success.

Where to act and what to watch

Priority geographies: Western North America (wolves, bison, beavers, otters); European rewilding sites (60+ large initiatives); Patagonia (puma and condor); Eastern and Southern African savannahs; Australian dingo and quoll reintroductions.

Priority species and ecoregions: a recent ecoregion-scale analysis offers a ready-made prioritisation. Vynne et al. (2022) find that reintroducing just 20 large-mammal species — seven predators and 13 herbivores, including jaguar, puma, wolverine, hippopotamus, Pampas deer and gazelles — would expand the share of land holding complete large-mammal assemblages from 15% to 23% (around 11 million km²). They identify 30 high-priority ecoregions where this is most feasible, 16 of which need only a single reintroduction to restore an intact assemblage. This aligns well with the positive tipping point lens as it focuses on the few species and places where a well-chosen intervention could restore whole-ecosystem function. It also reinforces the point that protected-area designation alone is not enough — without the animals, we are "just setting aside scenery".

Key actors: national wildlife and parks agencies; specialised reintroduction NGOs (Rewilding Europe, Wildlife Conservation Society, Defenders of Wildlife); Indigenous communities; private landowners; insurance and compensation funds for livestock losses; tourism operators.

Key risks: human-wildlife conflict generating political backlash; insufficient genetic diversity for long-term population viability; charismatic species emphasis displacing attention from less visible but equally important ecological actors; tourism overuse degrading the landscapes reintroduction is meant to protect.

Top progress indicators

Indicator	Quantification and target	Data source
Number of large-mammal keystone species reintroductions established globally with documented trophic cascade outcomes	Target: 30 documented landscape-scale cases by 2030	Rewilding Europe; IUCN Reintroduction Specialist Group
Total area under active rewilding management globally	Target: 5 Mha by 2030	Rewilding Europe; IUCN Protected Areas Programme
Share of established reintroductions showing measurable ecosystem-scale outcomes	Target: at least 70% showing measurable outcomes by 2030	Peer-reviewed ecological research; SER databases

Sustainable and regenerative agriculture and agroforestry

What it is: farming that rebuilds soil health, biodiversity and water security while staying productive.

Why it matters and how it could tip

Soil is a key variable in regenerative agriculture, with soil biodiversity accounting for approximately a quarter of all species worldwide. Regenerative practices deliver biodiversity gains above as well as below ground (in terms of pollinators, soil microbes and invertebrates), as well as human health benefits, through the provision of more nutritious food and more drought-tolerant land. However, the current picture is stark. Approximately 3.5 billion people depend on agricultural systems that are already under climate stress.[57] Agriculture is responsible for around 23% of global GHG emissions and around 70% of freshwater withdrawals; soil degradation affects around 12 million hectares of arable land per year.

The diffusion-of-innovations dynamic is well documented in agroforestry adoption: the TIST programme in East Africa, Farmer-Managed Natural Regeneration in the Sahel and similar initiatives demonstrate that practices spread through farmer networks once cost and yield co-benefits become visible.[23,69,70,99]

Current state and desired future

Current state: global agricultural subsidies around $700 billion/year, mostly supporting production-volume incentives rather than soil, biodiversity or water outcomes; agroforestry covers an estimated 1 billion hectares globally but with wide variation in practice quality. Up to $450 billion a year of these subsidies are estimated to be harmful to biodiversity[137].

Desired future state (2030): subsidy reform redirecting at least $200 billion/year from production-volume incentives to soil carbon, biodiversity and water outcomes, in line with Kunming-Montreal Target 18's $500 billion/year by 2030; agroforestry expanded by 200 million hectares with documented yield and biodiversity benefits; nature-positive farming the default in major commodity production landscapes.

Drivers and barriers

Reinforcing feedbacks:

- **Farmer-to-farmer diffusion.** Practices spread through farmer networks once cost and yield co-benefits are demonstrated.[23,70]
- **Yield-stability feedback.** Climate-smart practices reduce yield variability under climate stress, lowering farmer risk.
- **Soil-carbon and biodiversity finance pull.** Outcome-based payments create direct economic incentives for sustainable practices.[66]
- Subsidy redirection. Every tranche of subsidy repurposed from production volume to payments based on positive outcomes supports the extension services, monitoring and data that make the next tranche more politically feasible. This is the rationale behind the Kunming-Montreal Target 18 commitment[107].
- **Buyer demand pull.** Retailer net-zero and biodiversity commitments create supply chain demand for nature-positive sourcing.

Working against:

- **Subsidy lock-in.** Existing production-volume subsidies create deep political constituencies resistant to reform. They are also the largest flow of nature negative public money. An estimated $274-542 billion a year of agricultural, forestry and fisheries subsidies harm biodiversity, two to four times total conservation spending. Reforming them would do more to close the biodiversity financing gap than any new mechanism for valuing nature. Regenerative practices currently compete against an incumbent that is paid to persist[137].
- **Land tenure insecurity.** Without secure tenure, farmers cannot invest in practices with multi-year payback.
- **Extension service gaps.** Many low-income country contexts lack the agricultural extension capacity needed to support transition.
- **Yield-perception risk.** Initial transition years can show yield dips, generating reversal pressure before benefits emerge.

Where to act and what to watch

Priority geographies: African farmer-managed natural regeneration belt (Niger, Mali, Burkina Faso); East African agroforestry landscapes (Kenya, Tanzania, Ethiopia); South Asian smallholder systems; Latin American Cerrado and Amazon agricultural frontiers; major agricultural subsidy programmes — the EU's is among the largest, at around €387 billion over 2021–2027 — represent the largest reform opportunity

Key actors: national ministries of agriculture and finance; food retailers and buyers (Walmart, Tesco, Carrefour); farmer cooperatives and organisations (La Via Campesina, World Farmers' Organisation); agricultural research centres (CGIAR, ICRAF, ICRISAT); extension and advisory services; carbon and biodiversity credit standards bodies.

Key risks: subsidy reform political backlash; equity capture by large farmers; greenwashing of agricultural carbon credits through low-integrity claims; yield-reduction during transition years; over-emphasis on technical practices versus structural inequality in food systems.

Top progress indicators

Indicator	Quantification and target	Data source
Share of agricultural subsidies aligned with sustainability outcomes	Target: 30% globally by 2030	FAO MAFAP; OECD agricultural support estimates
Area under climate-smart agriculture or agroforestry with documented outcomes	Target: 500 Mha by 2030	ICRAF; FAO; national agricultural census data
Number of smallholder farmers reached by sustainable agriculture extension programmes	Target: 200 million smallholders by 2030	GCF; IFAD; CGIAR programme reporting

Community-based resource governance

What it is: recognising the rights of local and Indigenous communities to govern and manage the ecosystems they depend on.

Why it matters and how it could tip

Indigenous and local community management of forests, fisheries and rangelands consistently delivers superior biodiversity outcomes at lower cost than equivalent state-managed alternatives where tenure is secure and rights are respected.[5,79] Indigenous peoples manage or have tenure rights over around a quarter of the world's land area, including some of the highest biodiversity regions.

The social tipping mechanism operates through demonstration and norm diffusion: as one community demonstrates successful collective management, neighbouring communities adopt similar institutions, and tenure recognition spreads through political networks.

Current state and desired future

Current state: Indigenous peoples and local communities have customary tenure over around 25% of global land area but only around 10% is legally recognised; deforestation rates on Indigenous-managed land are 2–3 times lower than on adjacent non-Indigenous land.[66]

Desired future state (2030): legal recognition of Indigenous and community tenure expanded to cover at least 30% of global land area (aligned with Kunming–Montreal 30x30); community-led conservation institutions operational in 50+ countries; Indigenous-led carbon and biodiversity finance scaling.

Drivers and barriers

Reinforcing feedbacks:

- **Tenure recognition cascade.** Each successful recognition lowers the political cost of subsequent recognitions.
- **Demonstration and norm diffusion.** Visible community-led success encourages adoption by neighbouring communities.[69]
- **Indigenous-led finance scaling.** Direct finance to community institutions lowers transaction costs and increases effectiveness.

Working against:

- **Exclusionary conservation.** Fortress conservation models override community rights, producing both ethical and conservation failures.[1]
- **Tenure rollback.** Recognised rights can be reversed under economic or political pressure (mining, agribusiness, infrastructure).
- **Finance bottlenecks.** Most conservation finance flows through intermediaries rather than directly to community institutions.

Where to act and what to watch

Priority geographies: Amazon basin (largest concentration of Indigenous-managed tropical forest); Central African Indigenous and community lands (Cameroon, Gabon, Republic of Congo); Southeast Asian customary forest territories (Indonesia, Philippines, Malaysia); Indigenous Australia; Native American tribal lands; Sub-Saharan African community conservancies (Kenya, Tanzania, Namibia).

Key actors: Indigenous federations (COICA in Amazon, AMAN in Indonesia, FIMI globally for Indigenous women); national land tenure agencies; bilateral and multilateral finance institutions (GCF, GEF, IFAD); civil society networks (Forest Peoples Programme, Rights and Resources Initiative); legal advocacy networks.

Key risks: tokenistic tenure recognition without enforceable rights or sufficient finance; equity capture by community elites; tenure rollback under extractive industry pressure; greenwashing through Indigenous-branded conservation initiatives without genuine Indigenous control.

Top progress indicators

Indicator	Quantification and target	Data source
Area of land under legally recognised Indigenous and community tenure	Target: doubling of recognised area by 2030	RRI; LandMark; national land registries
Volume of conservation finance flowing directly to Indigenous and community institutions	Target: $5 billion/year direct finance by 2030 (around 10% of total nature finance)	Forest Tenure Funders Group; CPI; GCF reporting
Deforestation rate differential between Indigenous-managed and adjacent non-Indigenous land in priority regions	Target: maintain or increase the 2–3× deforestation reduction differential	Global Forest Watch; PRODES; RAISG

Fire-managed savannah and grassland ecosystems

What it is: restoring skilful, often Indigenous, fire management to keep grasslands and savannas healthy and prevent destructive megafire.

Why it matters and how it could tip

Fire suppression as the universal management strategy across fire-adapted ecosystems has produced unsustainable fuel loads in many regions, increasing catastrophic megafire risk.[95,106] These destructive wildfires cause devastating habitat loss and impact millions of species; during Australia's 'Black Summer' megafires in 2019-20, for example, over 3 billion animals were killed, injured, or permanently displaced. Wildfires also bring a significant carbon cost: wildfire emissions globally estimated are at around 8 $GtCO_2e$/year on average, with extreme years exceeding 10 $GtCO_2e$.

Current state and desired future

Current state: Australia's Savanna Burning programme operational at scale; equivalent programmes emerging in Sub-Saharan Africa and the Americas but at smaller scale; fire-adapted ecosystems globally remain under suppression-only or no-management regimes in most contexts.

Desired future state (2030): Indigenous-led fire stewardship operational across all major fire-adapted savannah and grassland biomes; carbon credit revenue supporting community fire institutions in at least 20 countries; integration with biodiversity finance and air quality co-benefit accounting.

Drivers and barriers

Reinforcing feedbacks:

- **Fire stewardship recognition cascade.** Recognition in one jurisdiction propagates through professional and policy networks.[95]
- **Carbon credit revenue loop.** Savanna burning credits fund community fire institutions, which improve outcomes, which attract further credits.
- **Air quality co-benefit attribution.** As wildfire smoke health impacts are quantified, fire stewardship credit value rises.
- **Biodiversity recovery cascade.** Well-managed fire regimes restore biodiversity, attracting further finance.[106]

Working against:

- **Liability frameworks.** Prescribed burning programmes face significant liability exposure when burns escape control.
- **Climate-fire feedback.** Climate change is narrowing the safe windows for prescribed burning.
- **Public smoke aversion.** Communities understandably oppose any additional smoke production from prescribed burns.
- **Workforce constraints.** Trained Indigenous fire practitioners are limited in number.

Where to act and what to watch

Priority geographies: Australian savannah belt (operational model); Sub-Saharan African savannahs (Kenya, Tanzania, Mozambique, Zambia, Namibia, South Africa); Brazilian Cerrado and Pantanal; US Western fire-adapted forests; Mediterranean and Southern European fire-adapted ecosystems; Himalayas and Central Asia.

Key actors: Indigenous land management institutions (Indigenous Protected Area managers in Australia, Tribal forestry agencies in North America); national forest and land management agencies; carbon market actors; insurance industry (wildfire risk pricing); air quality and public health agencies.

Key risks: tokenistic Indigenous engagement without legal recognition; prescribed burn escapes producing political backlash; carbon credit integrity challenges if methodology rigour is inadequate; equity capture if external credit aggregators absorb most of the revenue.

Top progress indicators

Indicator	Quantification and target	Data source
Area under active Indigenous-led fire stewardship management	Target: 100 Mha by 2030	Indigenous fire management networks; national land management agencies
Wildfire emissions in priority fire-adapted biomes	Target: 30% reduction by 2030 in priority landscapes	GFED; NASA FIRMS; Global Fire Atlas
Carbon and air quality credit revenue flowing to community fire institutions	Target: $200 million/year by 2030	Australia ERF; voluntary market registries; community fire institution reporting

Urban green infrastructure

What it is: trees, parks, green roofs and corridors that cool cities, clean the air and bring nature and resilience to where people live.

Why it matters and how it could tip

Trees, green roofs, urban wetlands and habitat corridors in cities deliver simultaneous benefits across biodiversity, urban heat reduction (2–8°C cooler than equivalent built environments), air quality ($PM_{2.5}$ deposition), stormwater attenuation and human mental health.[123,125]. Urban green spaces bring nature into the daily lives of the urban majority and support pollinators and other urban wildlife. The urban share of global population will keep rising through the century. This is therefore a future-proofing solution with cross-Earthshot value related to nature, air, heat and health.

The integration tipping mechanism is the cross-benefit cost-effectiveness case: a single urban tree-canopy programme can be justified on health, climate adaptation, biodiversity and property-value grounds simultaneously, attracting finance from multiple sources that would not fund any single benefit stream alone.

Current state and desired future

Current state: urban tree canopy varies widely (from above 30% in lead cities like Singapore and Vancouver to below 5% in many rapidly growing Global South cities); urban biodiversity is declining globally; heat-related mortality in cities is rising rapidly.

Desired future state (2030): all major cities globally with minimum urban tree canopy targets (typically 30%); urban green infrastructure standard in new urban development; integration with heat action plans and air quality management.

Drivers and barriers

Reinforcing feedbacks:

- **Heat-island reduction visibility.** Measurable temperature reductions build political support for canopy expansion.[123]
- **Multi-source finance integration.** Health, climate adaptation, biodiversity, stormwater and property-value finance combine in single programmes.
- **Community stewardship loop.** Resident-led tree care reduces mortality and builds long-term political constituency.[87]

Working against:

- **Tree mortality.** Newly planted urban trees have high mortality without sustained care.
- **Maintenance cost.** Long-term canopy requires sustained municipal investment.[125]
- **Equity displacement.** Green amenity can drive gentrification and displacement of lower-income residents.

Where to act and what to watch

Priority geographies: rapidly urbanising Global South cities (Lagos, Kinshasa, Dhaka, Jakarta, Mumbai); heat-exposed Mediterranean and Middle East cities (Athens, Cairo, Riyadh); US Southern and Western cities under heat stress (Phoenix, Houston, Miami); European cities under EU green city framework; East Asian cities with established programmes (Singapore, Seoul, Tokyo).

Key actors: city governments and urban planning agencies; building regulators setting green roof and stormwater standards; community organisations and tree-planting volunteers; landscape architecture and urban forestry professional networks; insurance industry (urban heat risk pricing); city networks (C40, ICLEI, WHO Healthy Cities, Cool Coalition).

Key risks: tree mortality from inadequate maintenance; equity displacement through green amenity gentrification; species selection mismatch; over-claim of biodiversity benefit through low-quality urban green; conflict with utility infrastructure.

Top progress indicators

Indicator	Quantification and target	Data source
Urban tree canopy coverage in major cities globally	Target: at least 30% canopy in 100 major cities by 2030	Global Forest Watch urban tree data; city forestry departments; MIT Senseable City Lab Treepedia
Documented urban heat reduction attributable to green infrastructure	Target: at least 1.5°C documented reduction in heat-stressed neighbourhoods of lead cities by 2030	City heat monitoring networks; Lancet Countdown indicators
Co-benefit-integrated urban green infrastructure investment	Target: $50 billion/year globally by 2030	C40 Cities Finance Facility; municipal budget tracking; UNEP urban finance reports

Across these ten areas, three patterns recur: commodity supply chain governance is the highest-leverage market mechanism; community governance combined with secure tenure is the foundational social condition; ecosystem-based adaptation creates direct bridges to the climate and oceans Earthshots.

Chapter 2: Clean Our Air

The second Earthshot challenge carries the most direct human health mandate: everyone breathing clean air at WHO standard or better by 2030. WHO attributes approximately 7 million premature deaths annually to air pollution, the world's largest environmental health risk.[126,127] Air pollution is uniquely positioned across the five Earthshots: many air pollutants are co-emitted with greenhouse gases and methane drives ozone formation, so transitions motivated by climate, nature, waste and oceans deliver substantial air quality co-benefits.[58] Nine solution areas are analysed below.

Solution areas

Solution area	**Phase**	**How it Could Tip**
Clean household energy and buildings	Emergence → Acceleration (PAYG models tipping in several markets; 2.1bn still on solid fuels).	Pay-as-you-go clean cooking plus rural electrification crosses the affordability threshold, making clean cooking the cheaper default.
Air quality governance, monitoring and social tipping	Emergence → Acceleration (low-cost sensor networks spreading).	As cheap sensors make pollution visible everywhere, public accountability forces standards that lock in continuous improvement.
Climate-resilient health systems and the air-heat-health nexus	Emergence (COP28 Declaration on Climate and Health momentum, but little integration).	When health systems routinely attribute and act on air-and-heat mortality, the health case makes clean-air investment politically unavoidable.
Clean electricity and combustion phase-out	Acceleration (already tipping via solar/wind learning curves)	Renewables undercut fossil generation, so retiring combustion becomes the economic default and SO_2/NO_x fall as a by-product
Clean mobility systems	Acceleration (EV revolution well documented; LEZs delivering fast local gains)	EV cost parity plus low-emission zones make clean mobility the default, and urban NO_2 drops within a few years of each city's switch.
Agricultural reactive nitrogen and methane abatement	Emergence (the next biggest challenge after power and transport).	Once nitrogen-use efficiency and methane capture pay for themselves, cleaner agriculture becomes standard and the last major $PM_{2.5}$ source declines.

Solution area	Phase	How it Could Tip
Waste system tipping: end open dumping and burning	Emergence (~40% of waste still openly dumped).	When basic collection and controlled disposal reach coverage, open burning stops being necessary and toxic PM/dioxin exposure collapses.
Industrial clean production, BAT standards and continuous monitoring	Acceleration → Stabilisation in leading regions (mature regulation; ~30:1 benefit-cost).	As best-available-technology (BAT) standards and continuous monitoring spread to emerging economies, clean production becomes the global baseline.
Wildfire smoke and Indigenous fire stewardship	Emergence (fastest-growing PM source; stewardship models nascent).	Cool-burn stewardship and fuel management, backed by carbon and health finance, cut catastrophic fire and its smoke at source.

Clean household energy and buildings

What it is: replacing the polluting cooking and heating fuels that are the world's largest single source of fine-particle exposure with clean household energy.

Why it matters and how it could tip

Household air pollution from cooking and heating over open fires and inefficient stoves is the world's largest single source of total human $PM_{2.5}$ exposure; around 2.1 billion people still cook on polluting fuels, with indoor $PM_{2.5}$ concentrations sometimes 10–100 times outdoor WHO guideline levels.[128]

Pay-as-you-go business models are bringing clean cooking close to tipping in several markets; integration with rural electrification expansion creates a synergistic adoption pathway.[44,65] The diffusion-of-innovations dynamic operates through community health workers and women's organisations as trusted messengers.[69,87]

Current state and desired future

Current state: around 2.1 billion people without access to clean cooking; around 3.7 million premature deaths/year from household air pollution; pay-as-you-go solar and clean cooking businesses scaling in East and Southern Africa; LPG transition substantially complete in Latin America and parts of Asia.

Desired future state (2030): universal clean cooking access (SDG 7.1.2); household $PM_{2.5}$ emissions reduced by at least 80% in priority countries; clean cooking integrated with rural electrification; building heating electrification standard in lead markets (links to Chapter 4 SA 6).

Drivers and barriers

Reinforcing feedbacks:

- **PAYG business model scaling.** Pay-as-you-go financing makes clean cooking equipment affordable for low-income households.
- **Rural electrification synergy.** Combined clean cooking and electrification reduce per-household acquisition cost.[44]
- **Community health worker diffusion.** Trusted local messengers convert health data into adoption motivation.[69,87]
- **Carbon finance integration.** Clean cooking carbon credits create finance stream supporting affordability.[65]

Working against:

- **Affordability gap.** Upfront costs of clean cooking equipment remain prohibitive for poorest households.
- **Fuel supply chain gaps.** LPG and biogas supply chains incomplete in rural areas.
- **Cultural and culinary preferences.** Some clean cooking technologies have not yet adapted to local cooking practices and food traditions, limiting adoption even where affordability and supply are addressed.
- **Carbon credit integrity challenges.** Variable credit quality undermines clean cooking finance stream.

Where to act and what to watch

Priority geographies: Sub-Saharan Africa (largest unmet clean cooking access globally); South Asia (India, Pakistan, Bangladesh); Southeast Asia (Indonesia, Myanmar); rural China; informal settlements globally.

Key actors: national energy and health ministries; clean cooking enterprises (Burn, Envirofit, BioLite); LPG distributors; multilateral finance institutions (World Bank ESMAP, GCF clean cooking facilities); community health worker networks; women's organisations; carbon market actors.

Key risks: equity exclusion of poorest households unable to access PAYG financing; greenwashing through low-quality stoves counted as clean cooking; carbon credit integrity failures undermining finance stream; supply chain gaps limiting deployment; cultural mismatch reducing adoption.

Top progress indicators

Indicator	Quantification and target	Data source
Number of people without access to clean cooking (SDG 7.1.2)	Target: universal clean cooking access by 2030 (SDG 7.1.2) – reduction from 2.1 billion to under 100 million	WHO Household Energy Database; IEA SDG7 tracking
Household $PM_{2.5}$ emissions in priority countries	Target: at least 80% reduction in household $PM_{2.5}$ emissions in priority countries by 2030	WHO Indoor Air Quality monitoring; national household energy surveys
Clean cooking carbon credit issuance from high-integrity programmes	Target: 30 $MtCO_2e$/year of ICVCM-compliant clean cooking credits by 2030	Verra; Gold Standard; Clean Cooking Alliance; ICVCM Core Carbon Principles

Air quality governance, monitoring and social tipping

What it is: the laws, monitoring networks and public demand that make every other clean-air solution stick.

Why it matters and how it could tip

Governance and monitoring is simultaneously a solution area and enabling platforms without which other solutions cannot deliver durable results.[65,104,126]

The information cascade mechanism is well documented: monitoring data makes pollution visible and attributable; visibility creates accountability pressure; pressure produces stronger standards; standards improve air quality; visible improvement builds support for further ambition. China's 2013–2020 $PM_{2.5}$ reduction of approximately 42% is the paradigm case.[37,80] Low-cost sensor democratisation is bringing accountability capacity to communities previously without it.

Current state and desired future

Current state: WHO 2021 AQG operational; around 90% of world population exposed to $PM_{2.5}$ above WHO guideline; reference-grade monitoring networks concentrated in high-income economies; low-cost sensor networks expanding rapidly (PurpleAir, Atmotube, AQICN); China and EU with mature regulatory frameworks.

Desired future state (2030): national air quality standards aligned with WHO 2021 AQG in lead jurisdictions; reference-grade monitoring operational in all major cities globally; low-cost sensor networks providing community-level accountability; air quality data integrated into health surveillance.

Drivers and barriers

Reinforcing feedbacks:

- **Information cascade.** Monitoring data drives accountability, accountability drives standards, standards drive air quality improvement.[37,80]
- **Low-cost sensor democratisation.** Community-level monitoring makes pollution visible and attributable where it was previously invisible.
- **WHO AQG ratchet.** Each national standard alignment with WHO 2021 AQG raises peer pressure for others.[126]
- **Health-economic case strengthening.** Each new mortality estimate strengthens regulatory mandate.[65]

Working against:

- **Industry political resistance.** Polluting industries resist tighter standards through political and legal channels.
- **Monitoring capacity gaps.** Reference-grade monitoring infrastructure limited in low-income economies.
- **Standards-enforcement gap.** Standards on paper often lack enforcement and verification capacity.
- **Data integration gaps.** Air quality data not always integrated with health, climate and transport policy.

Where to act and what to watch

Priority geographies: South Asian megacities (Delhi, Lahore, Dhaka, Karachi, Kolkata, Mumbai); Sub-Saharan African cities (Lagos, Kinshasa, Cairo, Accra); Southeast Asian cities (Hanoi, Jakarta, Manila, Bangkok); Latin American cities; Eastern European and Central Asian cities transitioning from coal.

Key actors: WHO; national environment and health ministries; city air quality authorities; low-cost sensor networks and community science platforms; satellite air quality monitoring (NASA, ESA Sentinel-5P); UNEP-led Climate and Clean Air Coalition; air quality research institutions.

Key risks: tokenistic standards adoption without enforcement; equity exclusion of low-income communities from low-cost sensor networks; greenwashing through PM monitoring without addressing source emissions; data integration gaps preventing health-policy linkage; industry political reversal of standards.

Top progress indicators

Indicator	Quantification and target	Data source
Number of countries with national air quality standards aligned with WHO 2021 AQG	Target: at least 50 countries by 2030	WHO national air quality standards database; national environment ministries
Number of major cities with operational reference-grade and community-level air quality monitoring	Target: 500 cities by 2030	WHO Urban Air Quality Database; OpenAQ; PurpleAir global coverage
Population-weighted average $PM_{2.5}$ exposure trend in lead jurisdictions	Target: at least 30% reduction in lead jurisdictions by 2030 from 2020 baseline	WHO Air Quality Database; State of Global Air; HEI

Climate-resilient health systems and the air-heat-health nexus

What it is: preparing health systems for the linked threats of heat, ozone, particulates and wildfire smoke that increasingly peak together.

Why it matters and how it could tip

The air-heat-health nexus describes three physically linked problems: a warming climate increases low-level ozone, particulate pollution, and wildfire smoke. Extreme heat is a health threat in itself. Heat and polluted air tend to peak together and affect the same vulnerable people – the elderly, the very young, outdoor workers and those with lung or heart conditions. The 2003 European heatwave killed approximately 70,000 people; the 2022 European heatwave killed approximately 62,000; combined heat-ozone-PM exposure substantially exceeds the impact of any pollutant alone.[35,64,94]

The COP28 Declaration on Climate and Health, endorsed by 140+ countries, signals political mobilisation.[16,129] Three coupled loops: health surveillance integration, health-sector adaptation finance scaling, and integrated air-health policy ratchet through cities like Ahmedabad showing 30–50% mortality reduction.[10,61,88,130]

Current state and desired future

Current state: COP28 Declaration on Climate and Health endorsed by 140+ countries; health adaptation finance around $1 billion/year against target of $11 billion/year; heat action plans operational in around 30 cities globally; air-heat-health surveillance integration limited.

Desired future state (2030): heat action plans operational in 200 cities globally; health adaptation finance scaled toward $11 billion/year target; air-heat-health surveillance integrated in all major urban health systems; health system climate resilience standard across all G20.

Drivers and barriers

Reinforcing feedbacks:

- **Health surveillance integration.** Each surveillance integration improves attribution and outcome tracking, strengthening case for further investment.[10,130]
- **Health adaptation finance scaling.** Track-record investor confidence applies as for other adaptation finance.[51]
- **COP28 Declaration ratchet.** Political mobilisation creates international peer pressure for national action.[16]
- **Heat action plan demonstration.** Cities like Ahmedabad show 30–50% mortality reduction; demonstration drives adoption.[61]

Working against:

- **Health finance political competition.** Health adaptation competes with other climate finance categories.
- **Health sector capacity.** Health systems already under strain; integration with air-heat surveillance is additional burden.
- **Attribution gaps.** Air-heat-health outcome attribution requires sophisticated data integration.
- **Equity dimensions.** Most heat- and pollution-vulnerable populations have least access to health protection.

Where to act and what to watch

Priority geographies: heat-vulnerable cities (Ahmedabad as demonstration; Phoenix, Athens, Cairo, Karachi, Delhi as priority); air-pollution-vulnerable cities (South Asian and African megacities); LDCs and SIDS with climate-vulnerable health systems; major adaptation finance recipient countries.

Key actors: WHO; national health ministries; city public health authorities; health adaptation finance institutions; climate and health professional networks (Global Climate and Health Alliance, Lancet Countdown); city networks (C40, Cool Coalition, WHO Healthy Cities); air quality research institutions; insurance industry pricing climate-health risk.

Key risks: health adaptation finance under-scaling against accelerating climate-health impacts; equity exclusion of most vulnerable populations; tokenistic heat action plans without operational substance; attribution gaps undermining policy case; political reversal of COP28 commitments.

Top progress indicators

Indicator	Quantification and target	Data source
Number of cities with operational heat action plans integrated with air quality surveillance	Target: 200 cities by 2030	WHO heat action plan database; C40; Cool Coalition; Lancet Countdown indicators
Annual health adaptation finance flow ($bn/yr)	Target: $11 billion/year by 2030 (current around $1 billion/year)	WHO climate finance for health tracking; OECD DAC; GCF health portfolio
Documented heat- and pollution-attributable mortality reduction in lead cities	Target: 30–50% mortality reduction in lead cities by 2030	Peer-reviewed epidemiology; Lancet Countdown; national mortality statistics

Clean electricity and combustion phase-out

What it is: phasing out coal and other combustion — a major source of sulphur dioxide and acid pollution — by switching to clean electricity.

Why it matters and how it could tip

Coal power generation is responsible for approximately 30% of global SO_2 emissions and the dominant source of acid deposition and heavy metal pollution.[41] The clean electricity tipping mechanism is described in Chapter 4 SA 1.

The air-specific addition is the health narrative as political enabler: the direct attribution of premature deaths to coal plant emissions in local communities is often more politically tractable than climate arguments. China's 2013–2020 actions – driven by visible health crises – produced $PM_{2.5}$ reductions of around 42%.[37] Air quality benefits of plant closure are measurable within weeks by satellite, strengthening political feedback loops.

Current state and desired future

Current state: coal power around 35% of global electricity generation; SO_2 and NO_x emissions controls operational in OECD power sectors and China; remaining coal-heavy economies (India, Indonesia, Vietnam, South Africa, Poland, Australia) at various phases of transition.

Desired future state (2030): coal generation reduced 50%+ from 2020 baseline in OECD; coal additions ceased globally; SO_2 and NO_x emissions from power sector reduced 70%+ from 2020 baseline; integrated power-air planning standard.

Drivers and barriers

Reinforcing feedbacks:

- **Health narrative political enabler.** Direct mortality attribution makes coal phase-out politically tractable.[37]
- **Clean electricity learning curves.** Chapter 4 SA 1 drivers apply directly.
- **Satellite air quality verification.** Plant closure benefits measurable within weeks, strengthening political feedback.
- **Insurance and finance withdrawal.** Coal insurance and finance availability falling.[3]

Working against:

- **Just transition for coal-dependent communities.** Coal closures create real economic dislocation requiring sustained transition finance.
- **State-owned coal political constituencies.** State-owned coal generators are politically protected in many economies.
- **Capital stranding accounting.** Coal plant stranded asset accounting creates fiscal pressure resistant to early retirement.
- **New coal in emerging markets.** New coal additions continue in some emerging market economies.

Where to act and what to watch

Priority geographies: India, China, Indonesia, Vietnam, South Africa, Poland, Australia (largest coal generation economies); Sub-Saharan Africa (preventing coal lock-in); SIDS (small but disproportionately polluting diesel power); just transition lead jurisdictions (Germany, Spain, UK as templates).

Key actors: national energy and finance ministries; coal power generators (state-owned and private); just transition coalitions (Powering Past Coal Alliance, Just Energy Transition Partnerships); MDBs and DFIs financing just transition; insurance industry withdrawing coal coverage; community organisations in coal regions.

Key risks: just transition failures generating political backlash that slows broader energy transition; equity displacement of coal-dependent communities; new coal lock-in in emerging markets; stranded asset accounting blocking early retirement; greenwashing through coal-to-gas substitution presented as clean.

Top progress indicators

Indicator	Quantification and target	Data source
Global coal generation capacity (GW) and electricity share	Target: coal generation reduced 50%+ from 2020 in OECD by 2030; no new coal additions globally	IEA Coal; Global Energy Monitor; Ember
Power sector SO_2 and NO_x emissions reduction from 2020 baseline	Target: 70%+ reduction in power sector SO_2 and NO_x emissions in lead jurisdictions by 2030	UNECE EMEP; EDGAR; national emissions inventories
Just Energy Transition Partnership (JETP) finance flow and implementation	Target: full operational JETP implementation in priority countries (Indonesia, South Africa, Vietnam, Senegal) by 2030	JETP secretariats; CPI; OECD

Clean mobility systems: EVs, public transport and low emission zones

What it is: cutting the traffic emissions that dominate urban air pollution through electric vehicles, public transport and low-emission zones.

Why it matters and how it could tip

Transport is the dominant source of urban NO_2 and near-road $PM_{2.5}$ in most cities globally; roadside NO_2 concentrations are routinely 2–5 times the WHO annual guideline level.

The EV tipping cascade is described in Chapter 4 SA 2.[48,71] The air-specific addition is the health-visibility-political feedback through Low Emission Zones: London's ULEZ expansion produced measurable roadside NO_2 reductions within months.[38]

Current state and desired future

Current state: roadside NO_2 routinely 2–5× WHO annual guideline; LEZ operational in around 320 European cities (mostly EU); EV adoption from Chapter 4 SA 2; public transport modal share varies widely (60%+ in lead cities to below 10% in car-dependent cities).

Desired future state (2030): roadside NO_2 within WHO interim target 4 in all major cities; LEZ or zero-emission zone operational in 500+ cities globally; integration with EV scaling (Chapter 4 SA 2) and modal shift to public transport, cycling and walking.

Drivers and barriers

Reinforcing feedbacks:

- **LEZ health-visibility loop.** Visible roadside NO_2 reduction within months builds political support for zone expansion.[38]
- **EV cascade.** Chapter 4 SA 2 drivers apply directly to air quality.
- **Modal shift co-benefits.** Cycling and public transport deliver air quality plus climate plus health benefits.
- **Lead city standardisation.** London, Paris, Madrid LEZ templates spreading through city networks.

Working against:

- **Non-exhaust emissions.** Tyre and brake wear PM persist even in electric fleets, requiring separate policy attention.
- **Equity dimensions of LEZ.** LEZ can disproportionately burden lower-income vehicle owners without targeted support.
- **Public transport investment gap.** Public transport investment lags in many car-dependent cities.
- **Car-dependent urban form.** Suburban infrastructure path dependencies limit modal shift potential.

Where to act and what to watch

Priority geographies: roadside-pollution-vulnerable cities (Delhi, Beijing, Mexico City, Cairo, Jakarta, Lagos); LEZ-leading cities (London, Paris, Madrid, Brussels, Milan as templates); EV cascade lead markets (Chapter 4 SA 2); cycling and public transport leading cities (Copenhagen, Amsterdam, Bogotá, Tokyo, Singapore).

Key actors: city governments and transport authorities; national transport and environment ministries; auto manufacturers (Chapter 4 SA 2); public transport operators; cycling and active transport advocates; LEZ implementation networks (C40, Cities for Clean Transport); insurance industry pricing transport-related air pollution risk.

Key risks: equity displacement through LEZ design; non-exhaust emissions persisting under EV fleet; public transport investment gaps limiting modal shift; LEZ political reversal; rebound effects from cleaner vehicles increasing total travel; tokenistic clean mobility without infrastructure backing.

Top progress indicators

Indicator	Quantification and target	Data source
Roadside NO_2 concentrations in major cities globally	Target: roadside NO_2 within WHO interim target 4 (40 μg/m³) in all major cities by 2030	Local air quality monitoring networks; WHO Urban Air Quality Database; ICCT roadside surveys

Indicator	Quantification and target	Data source
Number of cities with operational Low Emission Zones or Zero-Emission Zones	Target: 500 cities globally by 2030	Urban Access Regulations database; C40; ICCT; CLOCS
Modal share of public transport, cycling and walking in major cities	Target: 60%+ in at least 100 major cities by 2030	UITP; ITF; C40 transport metrics

Agricultural reactive nitrogen and methane abatement

What it is: reducing farm ammonia and methane — leading drivers of fine-particle pollution and warming — through better nutrient and livestock management.

Why it matters and how it could tip

Agricultural ammonia (NH_3) is the dominant unresolved $PM_{2.5}$ precursor in Europe, North America and East Asia, reacting with NO_x and SO_2 to form ammonium nitrate and sulphate aerosols.[29,67] Unpacking that phrase: $PM_{2.5}$ is fine particulate matter (under 2.5 micrometres in diameter) , the air pollutant most strongly linked to premature death. A 'precursor' is a gas that isn't harmful in itself but becomes harmful due to a chemical reaction; ammonia from fertiliser and livestock combines with other gases to create particulate pollution. It is the dominant unresolved precursor because it remains largely unregulated with no established control regime. As power and transport emissions are controlled, agriculture becomes the marginal source determining whether WHO $PM_{2.5}$ guideline levels are achievable.

The tipping mechanism could be the diffusion of better practices through farmer networks.[23,87] Once a better practice – for example covered manure storage or precise fertiliser timing – is demonstrated to work, it spreads; the new standard becomes the norm. Methane reduction from agriculture provides a dual benefit: tropospheric ozone reduction with respiratory health gains alongside climate mitigation.

Current state and desired future

Current state: agricultural NH_3 emissions around 60 Mt/year globally; secondary inorganic $PM_{2.5}$ dominant in many European, North American and East Asian regions; agricultural methane emissions around 150 Mt CH_4/yr; precision nutrient management and feed additive interventions at early commercial scale.

Desired future state (2030): agricultural NH_3 emissions reduced 30%+ from 2020 baseline in lead jurisdictions; secondary $PM_{2.5}$ reduced through coordinated NO_x-SO_2-NH_3 management; methane interventions scaled (Chapter 4 SA 4 cross-reference).

Drivers and barriers

Reinforcing feedbacks:

- **Standards-extension diffusion.** Each farmer adopting improved nutrient management practices accelerates peer adoption.[23,87]
- **EU nitrate and ammonia regulations.** EU Nitrates Directive and National Emission Ceilings Directive create regulatory ratchet.
- **Precision agriculture cost decline.** Precision nutrient application costs falling as technology scales.
- **Air-climate co-benefit accounting.** NH_3 and CH_4 reductions deliver both air quality and climate benefits.

Working against:

- **Agricultural political constituencies.** Agricultural reform can stall where transition support and livelihood protection for farmers are not built into policy design from the outset
- **Diffuse source monitoring difficulty.** Agricultural emissions are difficult to monitor and attribute at facility level.
- **Yield-perception risk.** Some nutrient management changes can produce yield variability during transition.
- **Cross-pollutant complexity.** $PM_{2.5}$ secondary chemistry requires coordinated NO_x, SO_2 and NH_3 management.

Where to act and what to watch

Priority geographies: EU under Nitrates and NEC Directives (lead jurisdiction); US Midwest and California Central Valley (high NH_3 emissions); North China Plain (largest agricultural NH_3 source globally); India and South Asia (rapidly growing agricultural NH_3); Brazilian Cerrado (rapidly intensifying agricultural region).

Key actors: national agriculture and environment ministries; agricultural research and extension networks (CGIAR, ICRISAT, USDA, EU JRC); fertiliser industry; precision agriculture technology providers; livestock industry (for enteric methane); agricultural carbon and air-quality credit standards bodies.

Key risks: agricultural political resistance blocking standards adoption; equity exclusion of smallholders unable to access precision agriculture; greenwashing through tokenistic nutrient management labelling; cross-pollutant policy uncoordinated; methane offset integrity failures.

Top progress indicators

Indicator	Quantification and target	Data source
Agricultural NH_3 emissions reduction from 2020 baseline in lead jurisdictions	Target: 30%+ reduction by 2030 in lead jurisdictions	EMEP; EDGAR; national emissions inventories
Adoption of precision nutrient management across major agricultural areas	Target: 50%+ of major agricultural areas using precision nutrient management by 2030	FAO; USDA; EU Common Agricultural Policy reporting
Agricultural methane emissions reduction (cross-reference Chapter 4 SA 4)	Target: 25%+ reduction in lead jurisdictions by 2030	UNFCCC national GHG inventories; GMI

Waste system tipping: end open dumping and burning

What it is: ending the open dumping and burning of waste, one of the most acutely toxic sources of air pollution.

Why it matters and how it could tip

Open waste burning is one of the most acutely toxic sources of air pollution globally, releasing $PM_{2.5}$, black carbon, dioxins, furans, heavy metals and polycyclic aromatic hydrocarbons.[104,131] Around 40% of global waste ends in open dumps; agricultural crop residue burning produces acute $PM_{2.5}$ emergencies affecting hundreds of millions seasonally.

The tipping mechanism (Chapter 3 trust–revenue feedback plus regulatory ratchet on burning) is complemented by the acute health event creating political windows for rapid regulatory response, as seen in Delhi's recurring pollution emergencies.[11,65,111]

Current state and desired future

Current state: around 40% of global waste in open dumps with widespread burning; agricultural crop residue burning operational in major producing regions (Indo-Gangetic Plain, Southeast Asia, Sub-Saharan Africa); urban waste burning bans operational in lead jurisdictions but enforcement variable.

Desired future state (2030): open waste burning prohibited and effectively enforced in all major economies; agricultural crop residue burning eliminated through residue management alternatives (composting, biogas, mulching, baling); waste collection coverage universal in cities above 1 million (Chapter 3 SA 4 cross-reference).

Drivers and barriers

Reinforcing feedbacks:

- **Acute health-event political window.** Visible pollution emergencies create political windows for rapid regulatory response.[11,65,111]
- **Waste collection trust-revenue loop.** Chapter 3 SA 4 drivers apply directly.
- **Agricultural alternative scaling.** Crop residue management alternatives (composting, biogas, baling) becoming commercially viable.
- **Satellite-based burn detection.** Fire detection through MODIS and VIIRS makes burn events visible and attributable.

Working against:

- **Enforcement capacity gaps.** Open burning bans on paper often lack enforcement capacity.
- **Agricultural economics.** Crop residue burning is the cheapest disposal method; alternatives need subsidy support.
- **Cultural and seasonal patterns.** Burning is deeply embedded in some agricultural and household cultural patterns.
- **Equity exclusion.** Most-affected populations have least access to political channels for change.

Where to act and what to watch

Priority geographies: Indo-Gangetic Plain (Delhi recurring pollution emergencies); Southeast Asia (seasonal haze from peatland and agricultural fires); Sub-Saharan African urban centres; Latin American agricultural burning regions; Eastern European household waste burning; Russian and Central Asian household burning during winter heating season.

Key actors: national environment and agriculture ministries; municipal waste authorities (Chapter 3 SA 4 actors); agricultural extension services; ASEAN under transboundary haze framework; FIRMS and satellite fire detection providers; air quality and public health agencies; civil society advocacy organisations. Satellites are already driving action, e.g. in India's Punjab and Haryana to detect post-harvest stubble burning, and across SE Asia with the ASEAN transboundary haze framework.

Key risks: equity exclusion of agricultural workers from residue management alternatives; tokenistic burning bans without enforcement; greenwashing through subsidies to alternatives that don't scale; transboundary haze diplomatic failures; cultural pattern persistence undermining policy effect.

Top progress indicators

Indicator	Quantification and target	Data source
Number of countries with operational and enforced open waste burning bans	Target: full G20 + ASEAN coverage by 2030	WHO open burning database; UNEP GWMO; national environment ministry reporting
Annual area of agricultural crop residue burning detected by satellite	Target: 70%+ reduction from 2020 baseline by 2030 in priority regions	NASA FIRMS; ESA Sentinel-3; Global Fire Atlas
Share of urban population with formal waste collection (Chapter 3 SA 4 cross-reference)	Target: 100% in cities above 1 million by 2030	UN-Habitat City Prosperity Index; What a Waste 2.0 updates

Industrial clean production, BAT standards and continuous monitoring

What it is: cutting industrial air pollution by requiring best-available techniques and continuous emissions monitoring at major facilities.

Why it matters and how it could tip

Industrial facilities are dominant point sources of SO_2, NO_x, PM and toxic air pollutants. Best Available Techniques (BAT) standards have a proven regulatory ratchet effect: the US Clean Air Act's benefit-to-cost ratio is approximately 30:1.[24] Best Available Techniques means that regulators set the legal emission limit in line with what the cleanest proven technology or practice can already achieve. As better technique are developed the required emissions limit tightens.

Continuous emissions monitoring systems (CEMS) are the governance tipping mechanism: when real-time emissions are continuously visible, non-compliance is automatically exposed rather than hidden between periodic inspections. China's CEMS deployment on most major industrial point sources demonstrates national-scale feasibility.[37,65]

Current state and desired future

Current state: BAT standards mature in EU under Industrial Emissions Directive; equivalent frameworks operational in US, China and Japan; CEMS operational on most major point sources in EU, US and China; less coverage in other major industrial economies.

Desired future state (2030): BAT standards adopted in all G20 industrial economies; CEMS operational on all major industrial point sources globally; integration with public emissions registries (PRTR) standard; air toxics standards parallel to climate-aligned industrial transformation (Chapter 4 SA 7).

Drivers and barriers

Reinforcing feedbacks:

- **BAT regulatory ratchet.** Each BAT update raises the floor across all covered facilities.
- **CEMS continuous visibility.** Real-time emissions make non-compliance automatically exposed.[37]
- **Public emissions registry transparency.** Public PRTR data creates accountability and competitive pressure.
- **Integration with industrial transformation.** Chapter 4 SA 7 industrial decarbonisation aligns with air toxics control.

Working against:

- **BAT adoption lag in emerging economies.** Many emerging economies have less rigorous industrial emissions standards.
- **CEMS reliability and tampering.** CEMS systems require maintenance and are vulnerable to tampering without enforcement.
- **Toxics-climate misalignment.** Some climate-aligned industrial technologies (e.g., biomass co-firing) can have toxics implications.
- **Enforcement capacity.** BAT and CEMS require regulatory enforcement capacity often limited in emerging economies.

Where to act and what to watch

Priority geographies: EU under Industrial Emissions Directive (lead jurisdiction); US under Clean Air Act amendments; China under Air Pollution Prevention Action Plan; India, Indonesia, Vietnam, South Africa, Brazil, Turkey (large industrial economies needing BAT adoption); informal industrial clusters globally.

Key actors: national environment ministries; industrial facility operators; CEMS technology providers; BAT reference document working groups (EU JRC IPTS); public emissions registry administrators (E-PRTR, TRI); industrial trade associations; environmental enforcement agencies; public interest advocacy organisations.

Key risks: BAT tokenistic adoption without enforcement; CEMS tampering and reliability failures; equity exclusion of community organisations from emissions data access; toxics-climate misalignment in some industrial transformation pathways; enforcement capacity gaps undermining standards.

Top progress indicators

Indicator	Quantification and target	Data source
Number of countries with operational BAT standards equivalent to EU IED	Target: full G20 coverage by 2030	EU JRC IPTS BAT reference documents; UNECE Convention on LRTAP; OECD
Share of major industrial point sources with operational CEMS	Target: 90%+ in lead jurisdictions; 70%+ globally by 2030	National air quality regulators; PRTR reporting; satellite emissions verification
Public emissions registry (PRTR) coverage globally	Target: 50+ countries with operational PRTR by 2030	OECD PRTR; UNECE PRTR Protocol; national environment ministries

Wildfire smoke and Indigenous fire stewardship

What it is: reducing the fastest-growing source of particle pollution, wildfire smoke, through Indigenous-led fire stewardship and landscape management.

Why it matters and how it could tip

Wildfire smoke is the fastest-growing $PM_{2.5}$ source globally, intensifying with climate change across boreal, temperate and tropical forest systems simultaneously.[9,106] The 2023 Canadian wildfire season produced $PM_{2.5}$ concentrations exceeding 200 μg/m³ (40 times WHO guideline) across major US East Coast cities for sustained periods.

Three coupled tipping mechanisms: Indigenous fire stewardship recognition cascade (Chapter 1 SA 8 cross-reference), prescribed burning learning curve, smoke-protective infrastructure tipping (residential and institutional filtration, clean air centres).[95,126] Underlying climate action remains the necessary precondition for sustained fire management capacity.

Current state and desired future

Current state: wildfire $PM_{2.5}$ emissions rising rapidly globally; Indigenous fire stewardship operational at scale in Australia (Chapter 1 SA 8); equivalent programmes emerging in North America and Brazil; smoke-protective infrastructure (filtration, clean air centres) limited.

Desired future state (2030): Indigenous fire stewardship operational across all major fire-adapted biomes (Chapter 1 SA 8 cross-reference); prescribed burning programmes scaled in priority temperate and boreal regions; smoke-protective infrastructure standard in fire-affected communities; integration with health system surveillance.

Drivers and barriers

Reinforcing feedbacks:

- **Fire stewardship recognition cascade.** Chapter 1 SA 8 drivers apply directly to air quality outcomes.[95]
- **Prescribed burning learning curve.** Each prescribed burn programme builds operational capacity for the next.
- **Smoke-protective infrastructure scaling.** Filtration and clean air centre cost declining as deployment scales.
- **Health surveillance integration.** Each documented health benefit strengthens political case for further investment.

Working against:

- **Climate-fire feedback.** Climate change is narrowing safe windows for prescribed burning.
- **Public smoke aversion.** Communities understandably oppose additional smoke from prescribed burns.
- **Liability frameworks.** Prescribed burning programmes face liability exposure when burns escape control.
- **Equity dimensions.** Smoke-protective infrastructure deployment lags in lower-income communities.

Where to act and what to watch

Priority geographies: US and Canadian fire-affected regions; Australia (operational model); Brazilian Amazon and Cerrado; Mediterranean Europe; Indonesian and Southeast Asian peatland fire regions; Russian boreal fire regions; Sub-Saharan African savannah fire regions (Chapter 1 SA 8 cross-reference).

Key actors: Indigenous land management institutions (Chapter 1 SA 8); national forest and emergency management agencies; air quality and public health agencies; smoke-protective infrastructure providers (residential filtration, clean air centres); insurance industry pricing fire risk; health surveillance integration networks; climate-fire research institutions.

Key risks: climate-fire feedback overwhelming stewardship capacity; equity exclusion of low-income communities from smoke protection; tokenistic Indigenous engagement without legal recognition (Chapter 1 SA 8); prescribed burn escapes generating political backlash; insurance industry retreat from fire-affected regions producing political stress.

Top progress indicators

Indicator	Quantification and target	Data source
Annual $PM_{2.5}$ emissions from wildfire globally and in priority regions	Target: 30% reduction in priority fire-managed landscapes by 2030 (cross-ref. Chapter 1 SA 8)	GFED; NASA FIRMS; Global Fire Atlas; State of Global Air wildfire attribution
Area under proactive, Indigenous-led fire stewardship (prescribed and cultural cool-burning)	Target: 100 million ha of fire-prone landscape under active early-season / cultural fire management by 2030 (cross-ref. Chapter 1 SA 8)	National fire agencies; savanna fire-management registries; Indigenous ranger and fire-steward programmes; FAO/national land-management datasets
Number of communities with operational smoke-protective infrastructure	Target: 5,000 fire-affected communities with operational smoke-protective infrastructure by 2030	EPA wildfire smoke programmes; equivalent national programmes; community air quality networks

Across these nine areas, five patterns recur: household energy is the largest single health lever; governance and monitoring is the operating system enabling everything else; health system integration is the amplifier on direct interventions; cross-Earthshot synergy is structural (every major air pollutant has its primary intervention point in another Earthshot); and agriculture and wildfire are the emerging frontiers for the air pollutants mainstream solutions do not address.

Chapter 3: Revive Our Oceans

The third Earthshot challenge sets a clear ambition to repair and preserve our oceans for future generations. In tipping point terms this means the recovery of marine ecosystems, fisheries and coastal communities by 2030. The tipping-point science is particularly well documented for oceans: marine protected area biomass recovery, fisheries Allee-effect thresholds, and the diffusion of community-led marine management have all been observed empirically across multiple jurisdictions.[7,66] Eleven solution areas are analysed below.

Solution areas

Solution area	Phase	How it Could Tip
High-quality marine protected area networks and OECMs for 30x30	Emergence → Acceleration (30×30 committed; biomass-spillover loop proven but coverage low).	Once protected areas visibly rebuild biomass that spills into fished waters, fishers become the constituency for more protection and the network self-expands.
Fisheries rebuilding, co-management and illegal fishing suppression	Emergence (Allee-threshold recovery demonstrated; ~half of stocks recoverable within a decade)	When rebuilt stocks demonstrably raise catch and income, effective management becomes self-reinforcing and recovery scales stock by stock.
Community-led locally managed marine areas	Acceleration (Apo-Island-to-Pacific diffusion across hundreds of communities).	Visible local recovery drives community-to-community diffusion until LMMAs become the regional norm.
Blue-carbon and coastal ecosystem restoration	Emergence (multi-Earthshot integrator; finance still early)	As blue-carbon markets and coastal-protection value mature, mangrove, seagrass and saltmarsh restoration becomes self-financing.
Climate-resilient reef systems and thermal refugia	Emergence (hardest near-term climate limit; assisted evolution experimental)	Identifying and protecting thermal refugia plus assisted evolution preserves seed-bank reefs that reseed recovery once warming stabilises.
Kelp forest and seaweed systems restoration	Emergence (trophic-cascade restoration + nascent seaweed economy).	Restoring predator control of urchins lets kelp rebound, while the seaweed economy creates market pull that funds further restoration.

Solution area	Phase	How it Could Tip
Sustainable aquaculture transformation	Emergence → Acceleration (aquaculture already exceeds capture supply).	As low-impact feeds and systems reach cost parity, sustainable aquaculture substitutes for wild capture and relieves pressure on stocks.
Integrated Sustainable Ocean Plans (100% approach)	Emergence (governance architecture adopted by early-mover nations).	When leading ocean states show whole-EEZ planning raises long-run value, sustainable ocean plans become the expected standard of national governance.
Pollution, nutrients and plastics: source-to-sea strategies	Emergence (UNEP plastics treaty pending)	A binding plastics treaty plus source-to-sea action reprices pollution upstream, cutting the ~80% of marine litter that originates on land.
Ocean finance mechanisms: blue bonds, debt swaps and blended finance	Emergence → Acceleration (scaled from ~zero in 2018 to ~$5bn in 2024).	As blue bonds standardise and a track record builds, ocean finance scales to unlock the solutions it currently bottlenecks
Clean shipping and ports	Emergence (2020 IMO sulphur cap shows global maritime regulation can tip).	Following the sulphur-cap precedent, IMO decarbonisation rules plus green-corridor demand makes zero-emission shipping the maritime default.

High-quality marine protected area (MPA) networks and OECMs for 30x30

What it is: protecting and properly enforcing the highest-value areas of the ocean through marine protected areas and other effective area-based measures, so fish and habitats recover and spill over into surrounding waters.

Why it matters and how it could tip

Well-designed and well-enforced marine protected areas produce a documented biomass–spillover–compliance reinforcing feedback: fish biomass inside the protected area grows (typically 4–7 times higher than equivalent unprotected waters within 5–10 years), individuals spill out beyond the boundary increasing nearby catches, fishers therefore support continued protection, and compliance strengthens further biomass recovery.[91,136]

The Kunming–Montreal Global Biodiversity Framework commits parties to protecting 30% of land and sea by 2030.[107] The decisive operational variable is quality: paper parks without management capacity deliver none of the tipping dynamics.

Current state and desired future

Current state: around 8.4% of the ocean is in MPAs; only around 2.9% is in highly or fully protected areas where extraction is restricted; most existing MPAs are paper parks with limited management capacity; High Seas Treaty (officially the BBNJ Agreement) now enforced, with 145 signatories supporting the protection of marine biodiversity in areas beyond national jurisdiction, covering two-thirds of the world's oceans.

Desired state: at least 30% of the ocean sits within ecologically representative, well-connected protected-area networks by 2030, with a substantial and rising share in highly or fully protected zones where extraction is restricted. Protection is genuinely governed, funded and enforced rather than "paper", so that biomass recovery inside reserves spills over into adjacent fished waters and builds the political constituency for further protection.

Drivers and barriers

Reinforcing feedbacks:

- **Biomass–spillover–compliance loop.** Recovery inside MPAs spills out, supporting fishers, who support protection.[136]
- **30x30 ratchet.** Kunming–Montreal commitment creates international peer pressure for designation and quality.[107]
- **Ecotourism revenue.** Recovered MPAs attract diving and tourism revenue, building local economic constituencies.
- **Scientific demonstration.** Each successful MPA strengthens evidence base, accelerating designation elsewhere.[91]

Working against:

- **Paper park risk.** MPAs without management capacity deliver no tipping dynamics; risk of designation theatre.
- **Boundary leakage.** Fishing pressure can intensify just outside MPA boundaries, undermining recovery.
- **Climate stress.** Warming, acidification and deoxygenation reduce recovery potential even with effective protection.
- **Equity displacement.** MPAs imposed without community consent generate non-compliance and political backlash.

Where to act and what to watch

Priority geographies: Coral Triangle (Indonesia, Philippines, Malaysia, Papua New Guinea, Solomon Islands); Western Indian Ocean (Mozambique, Tanzania, Kenya, Madagascar, Seychelles); Pacific Island states (Fiji, Palau, Marshall Islands); Mediterranean (under EU MSFD); Antarctic (CCAMLR); Caribbean (Mesoamerican Reef and CARICOM nations).

Key actors: national marine authorities and fisheries ministries; RFMOs; MPA management agencies (Great Barrier Reef Marine Park Authority, NOAA); satellite enforcement networks (Global Fishing Watch, OceanMind, Skylight); fishing communities and fisher organisations; conservation NGOs (WCS, TNC, WWF, Pew, Oceana); ocean finance institutions (Blue Nature Alliance, Bezos Earth Fund).

Key risks: paper park proliferation undermining 30x30 credibility; equity capture by ecotourism interests at the expense of fishing communities; climate-driven loss of recovery potential even in well-protected areas; greenwashing through low-quality OECM designations; under-funding of management capacity relative to expansion ambition.

Top progress indicators

Indicator	Quantification and target	Data source
Share of ocean under effective MPA or OECM protection	Target: 30% by 2030 (Kunming–Montreal); at least 10% highly/fully protected	Protected Planet (UNEP-WCMC); MPAtlas; Global Fishing Watch
Documented biomass recovery in protected sites	Target: at least 200 MPAs with documented biomass recovery (typically 4–7×) by 2030	Peer-reviewed marine biology; MPA News; WCS programmes
MPA management effectiveness verified by independent assessment	Target: at least 80% of MPAs with verified effective management by 2030	IUCN Green List; METT-4; protected area management evaluation networks

Fisheries rebuilding, co-management and illegal fishing suppression

What it is: rebuilding overexploited fish stocks by ending illegal fishing and managing catch together with the fishers who depend on it.

Why it matters and how it could tip

An estimated 35% of assessed marine fish stocks are overexploited; an estimated half of these can recover within a decade if management is effective.[92] The tipping mechanism is the Allee-effect threshold: below a critical biomass density, reproductive failure can lock stocks into collapse; above the threshold, rebuilding becomes self-propelling.[7]

Satellite-based vessel monitoring is bringing IUU fishing into accountability range for the first time; harmful subsidy reform under the WTO agreement provides the policy ratchet; co-management between fishers, scientists and regulators is operationally more effective than top-down rules.

Current state and desired future

Current state: around 35% of assessed stocks overexploited; harmful subsidies around $22 billion/year globally; IUU fishing estimated at 11–26 million tonnes/year (20–50% of reported catch in some regions).

Desired future state (2030): 90% of stocks fished at biologically sustainable levels (full SDG 14.4); WTO harmful subsidies agreement fully implemented; IUU fishing reduced by at least 50% from 2020 baseline through satellite monitoring and enforcement; fisheries co-management institutions operational in at least 50 countries.

Drivers and barriers

Reinforcing feedbacks:

- **Allee-threshold recovery.** Once biomass exceeds critical density, reproductive success accelerates rebuilding.[7]
- **Vessel monitoring transparency.** Satellite tracking makes IUU fishing visible and attributable.[66]
- **Subsidy reform ratchet.** WTO agreement creates legal framework; each compliance step builds international peer pressure. Kunming-Montreal Target 18, which commits parties to reduce incentives harmful to biodiversity by at least $500 billion a year by 2030, adds a second biodiversity-wide ratchet behind the same reform.
- **Co-management legitimacy loop.** Fisher participation improves compliance; better compliance improves outcomes; improvements attract further participation.

Working against:

- **Subsidy political constituencies.** Harmful subsidies support powerful fishing fleets and politically active coastal communities.
- **Discount-rate problem.** Recovery requires forgone catch in early years; political and financial discount rates undervalue future returns.
- **Climate stress.** Shifting species distributions complicate stock management.
- **Distant-water fleet politics.** Major distant-water fishing nations resist enforcement that constrains their access.

Where to act and what to watch

Priority geographies: West Africa (high IUU pressure from distant-water fleets); Southeast Asia (largest fisheries production, complex IUU patterns); Pacific Islands (tuna fisheries); North Atlantic and North Pacific (large industrial fisheries); Mediterranean (under EU Common Fisheries Policy reform); Andean and West African artisanal fisheries.

Key actors: national fisheries ministries; RFMOs (CCAMLR, WCPFC, ICCAT, IATTC, NEAFC); WTO; FAO; satellite monitoring providers; fisher organisations and cooperatives; sustainable seafood certification (MSC, ASC); food retailers driving sustainability standards.

Key risks: recovery failure where management lags; equity displacement of small-scale fishers by industrial interests; subsidy reform rollback; IUU displacement to less-monitored regions; greenwashing through low-quality sustainability certifications.

Top progress indicators

Indicator	Quantification and target	Data source
Share of marine fish stocks fished at biologically sustainable levels	Target: 90% by 2030 (full SDG 14.4)	FAO SOFIA; ICES; NOAA stock assessments
Volume of harmful fisheries subsidies eliminated under WTO agreement	Target: full $22 billion/year of harmful subsidies eliminated by 2030	WTO subsidy notifications; OECD support estimates
IUU fishing volume detected and intercepted	Target: at least 50% reduction in IUU from 2020 baseline by 2030	Global Fishing Watch; FAO port state measures; INTERPOL fisheries unit

Community-led locally managed marine areas

What it is: giving coastal communities the rights and tools to manage their own inshore waters — the locally managed marine area model that spread from Apo Island across the Pacific and Indian Ocean.

Why it matters and how it could tip

The locally managed marine area (LMMA) model has spread from Apo Island in the Philippines across the Pacific and Indian Ocean to hundreds of community-managed sites covering around 12 million hectares across at least 17 countries.[69] The diffusion-of-innovations dynamic is the same as in community forest governance: visible biodiversity and livelihood recovery in one site attracts neighbouring communities to adopt similar institutions.

The Earthshot Prize's global visibility is uniquely catalytic for this kind of peer-demonstration scaling, since community-led models scale through social proof rather than central programming.

Current state and desired future

Current state: around 1,000 LMMAs documented across the Pacific and Indian Ocean covering around 12 million ha; biomass and biodiversity recovery documented in around 70% of established LMMAs.[69]

Desired future state (2030): LMMA networks operational in at least 30 coastal countries; aggregate area exceeds 30 million ha; LMMAs formally recognised in national legal frameworks in at least 20 countries; community institution capacity sufficient to deliver durable management beyond donor cycles.

Drivers and barriers

Reinforcing feedbacks:

- **Demonstration-diffusion cascade.** Visible recovery attracts neighbouring community adoption.[69]
- **Community institutional learning.** Each new LMMA benefits from accumulated experience across the network.
- **Tenure recognition compounding.** Each formal recognition lowers political cost for the next.
- **Biodiversity-livelihood reinforcement.** Recovery delivers visible food security and income, sustaining community commitment.

Working against:

- **Donor dependency.** LMMAs initiated through external grants can collapse when donor cycles end.
- **Internal community conflict.** Benefit-sharing disputes within communities affect legitimacy.
- **External fishing pressure.** Industrial and IUU fishing outside LMMA boundaries can negate community-level gains.
- **Climate stress.** Warming reefs and shifting species reduce LMMA biological resilience.

Where to act and what to watch

Priority geographies: Pacific Island states (Fiji, Vanuatu, Solomon Islands, Palau, Marshall Islands); Coral Triangle (Indonesia, Philippines); Western Indian Ocean (Madagascar, Tanzania, Mozambique, Kenya, Seychelles); Caribbean (community-managed reefs in Belize, Honduras, Dominica); West Africa (community fisheries in Senegal, Cape Verde).

Key actors: coastal community institutions and traditional resource governance bodies; LMMA Network; national marine and fisheries ministries; conservation NGOs supporting community institutions (LMMA Network, Blue Ventures, SeaSense, Reef Check); ocean finance institutions providing blended capital; academic networks documenting outcomes.

Key risks: LMMA collapse when donor cycles end; equity capture by community elites; greenwashing through tokenistic community engagement; external industrial fishing pressure undermining community-level gains; climate-driven biological failure even with effective community management.

Top progress indicators

Indicator	Quantification and target	Data source
Number of community-led LMMAs operational globally	Target: 2,000 LMMAs covering 30 million ha by 2030	LMMA Network; Blue Ventures; Pacific Community SPC fisheries reporting
Share of LMMAs with documented biomass or biodiversity recovery outcomes	Target: 80% with documented recovery by 2030	Peer-reviewed marine biology; LMMA Network outcome database
Number of countries with LMMAs formally recognised in national legal frameworks	Target: at least 20 countries by 2030	FAO legal frameworks database; LMMA Network policy tracking

Blue-carbon and coastal ecosystem restoration

What it is: restoring mangroves, salt marshes and seagrass beds that store carbon, buffer storms and nurse fisheries.

Why it matters and how it could tip

Mangroves, salt marshes and seagrass beds sequester carbon at among the highest per-hectare rates on Earth (3–5 times tropical forest rates) while also providing storm-surge protection, nursery habitat supporting around 75% of commercial fisheries, and water quality benefits.[52]

The tipping mechanism is insurance industry repricing of natural infrastructure: insurers progressively recognise coastal ecosystems as flood-protection assets and price them accordingly, creating commercial incentives that operate alongside biodiversity and climate finance.[6,72,121]

Current state and desired future

Current state: around 35% of mangroves globally lost since 1980; salt marshes declining at around 1–2% per year; seagrass loss around 7% per year globally; restoration operational at landscape scale in lead jurisdictions but small relative to ongoing loss.

Desired future state (2030): net positive coastal ecosystem trajectory globally; at least 1 million ha of mangroves under restoration; salt marsh and seagrass restoration programmes operational in major coastal jurisdictions; insurance products incorporating natural infrastructure operational in at least 20 countries.

Drivers and barriers

Reinforcing feedbacks:

- **Insurance repricing loop.** Actuarial recognition of natural infrastructure creates commercial demand for restoration.[72]
- **Multi-Earthshot finance integration.** Blue carbon, biodiversity, fisheries and storm protection finance combine in single restoration projects.
- **Demonstrated co-benefit cost-effectiveness.** Coastal Nature-based solution cost-effectiveness exceeds grey alternatives by 2–5×.[6,121]
- **NDC integration ratchet.** Each NDC inclusion of blue carbon raises peer expectation for the next.

Working against:

- **Coastal development pressure.** Aquaculture, urbanisation and infrastructure continue to drive coastal ecosystem loss.
- **Land tenure complexity.** Coastal zones often have overlapping customary, state and private claims.
- **Climate-driven mortality.** Sea level rise and warming threaten restored ecosystems before recovery completes.
- **Carbon credit integrity.** Variable measurement and permanence challenges create credit quality concerns.

Where to act and what to watch

Priority geographies: Southeast Asian mangrove belt (Indonesia, Philippines, Vietnam, Bangladesh, Myanmar, Thailand); Caribbean and Mesoamerican Reef coastal systems; West African mangrove and salt marsh systems (Senegal, Sierra Leone, Nigeria, Cameroon); Pacific Island mangrove systems; US Gulf Coast restoration; Australian and Indian Ocean mangrove and seagrass systems.

Key actors: national coastal management agencies; insurance and reinsurance industry (Munich Re, Swiss Re, Zurich, Lloyd's); blue carbon credit standards (Verra VM0033, Plan

Vivo); coastal communities and Indigenous peoples; conservation NGOs (TNC, WWF, Conservation International, WCS); MDBs and ocean finance institutions.

Key risks: ongoing coastal development outpacing restoration; greenwashing through low-integrity blue carbon credits; equity displacement of coastal communities; climate-driven restoration mortality; insurance product limited to wealthy coastal jurisdictions.

Top progress indicators

Indicator	Quantification and target	Data source
Net mangrove area change globally and by region	Target: net positive global mangrove area by 2027; net positive in all major mangrove nations by 2030	Global Mangrove Watch; Mangrove Map Platform
Volume of insurance products incorporating coastal ecosystems as quantified flood-protection asset	Target: $25 billion cover by 2030	Geneva Association; reinsurer reports; parametric insurance market data
Blue carbon credit issuance from high-integrity restoration projects	Target: 50 $MtCO_2e$/yr by 2030 from ICVCM-aligned high-integrity projects	Verra; Plan Vivo; ICVCM Core Carbon Principles assessments

Climate-resilient reef systems and thermal refugia

What it is: helping coral reefs survive a warming ocean by protecting heat-tolerant reefs and the cooler refuges where they can persist.

Why it matters and how it could tip

Coral reefs are at the hardest near-term climate limit of any ocean ecosystem: at 1.5°C warming, 70–90% of coral reefs are projected to decline; at 2°C, more than 99% are projected to be lost.[4] Reef ecosystem services value is estimated at $36 billion/year in tourism, $11 billion/year in coastal protection.

The intervention combines refugia identification (mapping sites with persistent cool-water upwelling and lower thermal stress), refugia protection (ensuring those sites become source populations for downstream recovery), and assisted evolution (selective breeding of heat-tolerant coral genotypes). The Allen Coral Atlas has made refugia identification operational at global scale.[2]

Current state and desired future

Current state: around 50% of global reef cover lost since 1957; thermal refugia identified through Allen Coral Atlas and equivalent platforms but only partially protected; assisted evolution research at proof-of-concept stage in Australia, Hawaii and Florida.

Desired future state (2030): all identified refugia under effective protection; assisted evolution operational at scale in lead jurisdictions; reef restoration combined with refugia source populations recovering downstream sites; integration of reef climate adaptation into national adaptation plans in all coral-bearing nations.

Drivers and barriers

Reinforcing feedbacks:

- **Refugia source-population loop.** Protected refugia supply larvae for downstream recovery, scaling biophysical recovery beyond the refugia themselves.
- **Assisted evolution acceleration.** Each successful heat-tolerant genotype deployment generates evidence and scaling capacity.[4]
- **Tourism revenue defence.** Tourism-dependent governments invest in reef survival to protect economic base.
- **Climate adaptation finance pull.** Reef adaptation increasingly recognised in adaptation finance.[51]

Working against:

- **Climate stress overruns.** Even with refugia protection and assisted evolution, very high warming (above 2°C) likely overwhelms reef resilience.
- **Assisted evolution ethical and ecological risks.** Selectively bred coral may have other ecological costs; biosecurity risks in cross-region transfer.
- **Finance gap.** Reef adaptation finance lags far behind ecosystem service value at risk.
- **Local stressor compounding.** Pollution, sedimentation and overfishing weaken reef resilience to climate stress.

Where to act and what to watch

Priority geographies: Great Barrier Reef (Australia); Coral Triangle (Indonesia, Philippines, Papua New Guinea, Solomon Islands); Mesoamerican Reef (Mexico, Belize, Honduras, Guatemala); Western Indian Ocean (Maldives, Seychelles, Madagascar, Mozambique); Polynesian and Micronesian reefs; Florida Keys and Caribbean.

Key actors: coral reef nations; reef research institutions (AIMS, NOAA, Smithsonian); Allen Coral Atlas; reef restoration NGOs (Coral Restoration Foundation, SECORE, Reef Resilience

Network); tourism operators and dive industry; adaptation finance institutions (GCF reef adaptation programmes).

Key risks: climate overrun beyond adaptation capacity; ecological risks of assisted evolution; tourism overdependence creating reef burnout pressure; tokenistic reef adaptation in NDCs without sufficient finance; equity displacement of reef-dependent fishing communities by tourism interests.

Top progress indicators

Indicator	Quantification and target	Data source
Share of identified climate refugia under effective protection	Target: 80% of identified refugia under effective protection by 2030	Allen Coral Atlas; Protected Planet; reef monitoring networks
Volume of climate-resilient reef restoration deployment	Target: 1,000 ha/yr by 2030	Reef Resilience Network; AIMS; SECORE; NOAA Coral Reef Watch
Climate adaptation finance flowing specifically to reef nations	Target: $1 billion/year by 2030 for reef adaptation	GCF; Adaptation Fund; bilateral climate finance reporting

Kelp forest and seaweed systems restoration

What it is: recovering kelp forests and seaweed systems that have collapsed across much of their range, and the marine life they support.

Why it matters and how it could tip

Kelp forests support some of the most productive marine ecosystems on Earth but have collapsed across much of their global range – around 38% of global kelp forests have declined over the past 50 years – under combined pressures from warming, urchin overgrazing and reduced predator populations.

The trophic cascade tipping mechanism is well documented: sea otter recovery on the Pacific coast suppresses urchin populations, allowing kelp regrowth, which restores fish habitat and carbon sequestration.[66]

More broadly, marine rewilding works along a spectrum. In coastal and seabed systems, active reintroduction and restoration (e.g., sea otters, native oyster and shellfish reefs, seagrass and kelp) is central and feasible because the organisms are place-based and have been lost locally. In the open ocean and for mobile megafauna, recovery comes from removing pressure and protecting habitat, letting populations rebuild and recolonise through the MPA and fisheries solution areas. The recovery of great whales is the clearest ocean-scale example: as populations rebound, the "whale pump" redistributes nutrients that fertilise surface waters, raising productivity and carbon sequestration. This is a trophic-rewilding delivered through ending exploitation rather than through reintroduction.

The seaweed economy creates a commercial market pull for restoration expertise. Restoration combines direct methods (e.g., transplanting, green gravel seeding, and heat-tolerant strains) and trophic methods that rebuild the food web (e.g., urchin control and predator recovery, of which sea otters on the Pacific coast is only the best-known example). No single lever is sufficient; the appropriate mix of interventions is site-specific.

Current state and desired future

Current state: around 38% of global kelp forests declined over 50 years; sea otter populations recovered but still at fraction of historical range; global seaweed aquaculture around $14 billion/year and growing at around 6%/year.

Desired future state (2030): kelp restoration operational at landscape scale in priority regions (US West Coast, Norway, Japan, Australia, Korea, Chile); sea otter recovery extended; seaweed economy scaled with sustainability standards; carbon credit methodologies operational for kelp restoration.

Drivers and barriers

Reinforcing feedbacks:

- **Trophic cascade.** Otter recovery suppresses urchins, kelp recovers, fish habitat returns.[66]
- **Seaweed economy pull.** Commercial demand drives investment in seaweed cultivation expertise transferable to restoration.
- **Blue carbon credit pathway.** Emerging kelp carbon credit methodologies create finance for restoration.
- **Climate refugia identification.** Cool-water kelp persistence sites identified as priority restoration anchors.

Working against:

- **Climate stress.** Warming-driven kelp envelope contraction makes restoration in marginal zones less viable.
- **Urchin barren resilience.** Once established, urchin barrens resist kelp recovery even after urchin removal.

- **Seaweed cultivation displacement.** Industrial-scale seaweed aquaculture can compete with natural kelp habitat.
- **Carbon credit integrity.** Kelp permanence is shorter than mangroves, raising credit quality challenges.

Where to act and what to watch

Priority geographies: US Pacific coast (otter–urchin–kelp system); Norwegian and North Atlantic kelp forests; Japanese and Korean kelp ecosystems; Southern Australian Great Southern Reef; Chilean kelp coast; New Zealand kelp systems.

Key actors: Pacific coastal nations (US, Canada, Mexico, Chile); North Atlantic kelp nations (Norway, Iceland, UK, Ireland); Northwest Pacific (Japan, Korea, Russia); Australia and New Zealand; seaweed aquaculture industry; restoration research institutions (Marine Conservation Institute); Indigenous coastal communities with traditional kelp management knowledge.

Key risks: climate-driven restoration failure in marginal kelp zones; urchin barren persistence; greenwashing through low-integrity kelp carbon credits; ecological displacement of native kelp by industrial seaweed aquaculture; equity exclusion of small-scale seaweed harvesters.

Top progress indicators

Indicator	Quantification and target	Data source
Area of restored kelp forest globally	Target: 50,000ha restored cumulatively by 2030	Kelp Forest Alliance; Reef Life Survey; peer-reviewed kelp restoration databases
Global seaweed aquaculture production from sustainably certified operations	Target: $25 billion/year with at least 50% certified by 2030	FAO aquaculture statistics; ASC certification data
Documented trophic cascade outcomes in priority kelp regions	Target: at least 10 documented trophic cascade recoveries by 2030	Peer-reviewed kelp ecology; long-term ecological research networks

Sustainable aquaculture transformation

What it is: shifting fish and seaweed farming onto low-impact feeds, sites and species so it can feed people without degrading the ocean.

Why it matters and how it could tip

Aquaculture now exceeds capture fisheries in global seafood supply (around 122 million tonnes versus 92 million tonnes in 2022). Three transformations are tipping simultaneously: feed innovation (replacing fishmeal with insect protein, single-cell protein and algal sources); regenerative aquaculture (bivalve and seaweed farming that improves water quality); and certification standards (ASC, BAP) that progressively raise the floor on environmental performance.

Supply substitution from wild capture to sustainable aquaculture relieves pressure on overfished stocks if displacement effects are managed; bivalve aquaculture is structurally regenerative.

Current state and desired future

Current state: global aquaculture around 122 Mt/year with around 70% in Asia; around 17% of production is certified sustainable (MSC, ASC, BAP); fishmeal still represents around 14% of global wild catch use; bivalve and seaweed aquaculture growing at around 6%/year.

Desired future state (2030): sustainable certification covers at least 50% of major aquaculture species; fishmeal dependency reduced to below 5% of wild catch through alternative feed scaling; bivalve and seaweed aquaculture doubled; integration of aquaculture with marine spatial planning prevents conflict with conservation.

Drivers and barriers

Reinforcing feedbacks:

- **Certification standards ratchet.** ASC, BAP and MSC standards progressively raise the environmental performance floor.
- **Alternative feed learning curve.** Insect protein, single-cell protein and algal feed costs fall with scaling, displacing fishmeal.
- **Regenerative aquaculture cost loop.** Bivalve and seaweed farming earn revenue from ecosystem services beyond food.
- **Retailer demand pull.** Major retailers require certified sustainable seafood, driving supply transformation.

Working against:

- **Habitat conversion.** Aquaculture expansion (especially shrimp ponds) drives mangrove and wetland loss.
- **Disease and antibiotic use.** Intensive aquaculture remains a significant disease and antimicrobial resistance risk.
- **Wild seed dependency.** Some aquaculture species still depend on wild seed collection, pressuring source populations.

- **Greenwashing risk.** Low-integrity certification can mask continuing environmental damage.

Where to act and what to watch

Priority geographies: China (largest producer); Southeast Asia (Vietnam, Indonesia, Bangladesh); Norway and Scotland (salmon); Chile (salmon, mussels); Mediterranean Europe; Sub-Saharan Africa (Egypt, Nigeria, Ghana); India (carp and shrimp); North America Pacific Northwest (shellfish, salmon).

Key actors: major aquaculture producer nations; aquaculture industry (Mowi, Cermaq, Lerøy, Charoen Pokphand); certification bodies (ASC, BAP, MSC, GAP); retailers and food service driving demand standards; alternative feed industry (insect protein, single-cell protein, algal feed companies); aquaculture research institutions.

Key risks: mangrove conversion for shrimp ponds offsetting other restoration; disease and antimicrobial resistance from intensive operations; greenwashing through low-integrity certifications; smallholder exclusion through compliance burden; wild seed pressure on source populations.

Top progress indicators

Indicator	Quantification and target	Data source
Share of major aquaculture species production under credible sustainability certification	Target: at least 50% certified by 2030	ASC; BAP; MSC; FAO SOFIA
Volume of fishmeal substitution by alternative feeds	Target: at least 4 Mt/year alternative feed displacing wild-source fishmeal by 2030	IFFO; alternative feed industry reports; FAO
Production volume of regenerative aquaculture species (bivalves, seaweed)	Target: 40 Mt/year by 2030 (roughly doubling from current)	FAO SOFIA; FAO FishStat

Integrated Sustainable Ocean Plans (the 100% approach)

What it is: countries managing 100% of their national waters under a single sustainable ocean plan, rather than protecting only fragments.

Why it matters and how it could tip

The High-Level Panel for a Sustainable Ocean Economy has advanced the 100% approach: rather than protecting fragments of national waters, member states commit to sustainable management of 100% of their exclusive economic zones (EEZs). [39]

The governance tipping mechanism is institutional embedding: once an integrated plan is in national law, the cross-sectoral coordination it requires creates lock-in that survives political cycles.

Why it matters: MPAs safeguard the highest-value fragments, but most of a nation's waters, where fishing, shipping, aquaculture and offshore energy operate, lie outside them, and pressures there can undermine the protected core. The 100% approach is the container within which MPAs sit: one spatial plan that decides where strict protection goes and aligns it with every other use, so the two reinforce rather than compete.

Norway, for example, manages its whole exclusive economic zone through three integrated plans (Barents Sea–Lofoten, Norwegian Sea, North Sea–Skagerrak), each coordinating fisheries, petroleum, shipping and conservation on a shared scientific basis and designating "particularly valuable and vulnerable areas" — most notably the Lofoten–Vesterålen cod-spawning grounds, kept closed to petroleum. That is what "100%" means in practice: a single integrated plan for governing all national waters, with protected areas nested inside it.

Current state and desired future

Current state: around 20 nations committed; around 5 with operational integrated plans (Norway, Indonesia, Portugal, Kenya, Palau); global EEZ coverage around 30 million km² (around 8% of global EEZ).

Desired future state (2030): 40+ nations with operational Sustainable Ocean Plans covering at least 100 million km² (around 25–30% of global EEZ); cross-sectoral coordination mechanisms operational; integration with 30x30, blue economy finance and ocean adaptation.

Drivers and barriers

Reinforcing feedbacks:

- **High Level Panel demonstration.** Lead jurisdictions provide template and political momentum.[39]
- **Cross-sectoral coordination lock-in.** Once embedded in law, integrated planning resists political reversal.
- **Blue economy finance integration.** Sustainable Ocean Plans create the institutional architecture for ocean finance flows.
- **Peer ratchet through international networks.** Each new plan raises peer expectation for ocean-bordering nations.

Working against:

- **Institutional capacity gap.** Many coastal nations lack the cross-sectoral planning capacity to develop and implement plans.
- **Sectoral political resistance.** Fishing, shipping and offshore energy interests can resist integration.
- **Implementation lag.** Adoption is far easier than implementation; risk of paper plans.
- **Distant-water fleet exclusion.** EEZ-focused plans don't directly address distant-water and high-seas activity.

Where to act and what to watch

Priority geographies: lead jurisdictions (Norway, Indonesia, Portugal, Kenya, Palau, Fiji); next-wave priorities (Brazil, Chile, Mexico, South Africa, Vietnam, Philippines); Pacific Islands aligned with Blue Pacific 2050 strategy; Mediterranean under EU Maritime Spatial Planning Directive; Caribbean SIDS.

Key actors: member states of the High-Level Panel; national ministries of marine affairs and fisheries; UN Ocean Decade and IOC-UNESCO; ocean finance institutions; civil society networks supporting integrated planning (WRI Ocean, OECD); coastal communities affected by plan implementation.

Key risks: paper plan proliferation without implementation; political reversal under sectoral interest pressure; equity exclusion of small-scale and traditional ocean users; institutional capacity overrun; greenwashing through plans counted as ocean conservation without delivering substantive change.

Top progress indicators

Indicator	Quantification and target	Data source
Number of nations with operational Sustainable Ocean Plans	Target: 40 nations with operational plans by 2030	High Level Panel reporting; OECD ocean economy reviews
Share of global EEZ under integrated sustainable management	Target: 25–30% of global EEZ by 2030	Sea Around Us; UN Atlas of the Oceans; national maritime authorities
Cross-sectoral coordination effectiveness in lead jurisdictions	Target: documented coordination improvement in at least 20 jurisdictions by 2030	OECD ocean governance reviews; UNEP marine governance database

Pollution, nutrients and plastics: source-to-sea strategies

What it is: cutting the land-based pollution — plastics, nutrient runoff and chemicals — that causes most marine litter and coastal dead zones, at its source.

Why it matters and how it could tip

Around 80% of marine litter originates on land.[105] Marine plastic input is estimated at around 11 million tonnes/year and projected to triple by 2040 without intervention. Nutrient runoff from agriculture creates over 500 documented dead zones globally covering around 250,000 km².

There is a hierarchy here that the visibility of plastics can obscure. Nutrient pollution — the flow of nitrogen and phosphorus from agriculture and wastewater — drives the eutrophication and hypoxia behind dead zones. The biogeochemical-flows boundary for nitrogen and phosphorus is now among the most heavily exceeded of all the Planetary Boundaries (Richardson et al. 2023). Per unit, nutrients are arguably a larger systemic threat to ocean function than plastics, which are more conspicuous than they are damaging. This does not make plastics unimportant, but it argues for weighting interventions by systemic damage rather than public salience, and for giving nutrient source-management at least equal standing in this solution area.

The UNEP intergovernmental negotiating committee on plastic pollution is the most consequential ocean governance process under way globally.[113] Source-to-sea strategies bridge ocean and waste Earthshots.

Current state and desired future

Current state: around 11 Mt marine plastic input/year; around 500 dead zones; UNEP plastics treaty in active negotiation; EPR schemes operational in over 75 countries but with variable performance; microfibre filtration mandated only in some EU jurisdictions.[25]

Desired future state (2030): UNEP plastics treaty adopted with binding source-reduction provisions; marine plastic input reduced by at least 50%; nutrient pollution dead zones reduced through agricultural source management; microfibre filtration mandated in lead jurisdictions globally.

Drivers and barriers

Reinforcing feedbacks:

- **Treaty governance ratchet.** UNEP plastics treaty creates international legal framework propagating through national legislation.[113]
- **Source-reduction learning curve.** EPR and DRS systems gain efficiency with scaling, reducing per-unit cost of plastic capture.

- **Microfibre and microplastic policy ratchet.** France's washing machine filter mandate creates EU and global peer pressure.[25]
- **Cross-Earthshot integration.** Waste Earthshot (3) interventions deliver direct ocean benefits, scaling motivation across both.

Working against:

- **Treaty dilution risk.** Plastics-producing nations resist binding source-reduction targets.
- **Producer responsibility evasion.** Industry resistance to EPR scope and modulation.
- **Nutrient management political constituencies.** Agricultural runoff is politically protected by farming constituencies.
- **Plastic substitution risk.** Alternative materials may have other environmental costs.

Where to act and what to watch

Priority geographies: highest plastic-leakage countries (China, Indonesia, Philippines, Vietnam, Thailand, Egypt, Nigeria, Bangladesh, India); EPR lead markets (EU, Canada, parts of Latin America); microplastic policy lead (EU, US states, Canada); largest nutrient dead zones (Gulf of Mexico, Baltic Sea, East China Sea, Gulf of Oman).

Key actors: UNEP and member states negotiating the plastics treaty; national environmental and waste management authorities; plastics industry; EPR producer responsibility organisations; civil society plastics campaigns (Break Free from Plastic, OceanCleanup); agricultural extension and nutrient management agencies; consumer goods companies committing to packaging reduction.

Key risks: treaty dilution to non-binding voluntary commitments; substitution to materials with worse environmental footprints; cleanup-focused responses without source reduction; equity displacement of informal waste workers; greenwashing through low-integrity recycled content claims.

Top progress indicators

Indicator	Quantification and target	Data source
Marine plastic input	Target: at least 50% reduction from current 11 Mt/year by 2030	UNEP Marine Plastic Litter; Jambeck modelling; The Pew Charitable Trusts plastic flows
UNEP plastics treaty implementation status. This indicator also features in the Waste Earthshot, relevant to	Target: treaty adopted with binding source-reduction targets by 2027, transposed into national	UNEP INC; national plastic regulations registry

Indicator	Quantification and target	Data source
thresholds of upstream production and circularity. Its presence here in the Ocean chapter relates to marine-leakage production	law in at least 100 countries by 2030	
Area of marine hypoxic dead zones globally	Target: at least 25% reduction from current 250,000 km² by 2030	WRI; NOAA hypoxic zone monitoring; peer-reviewed marine science

Ocean finance mechanisms: blue bonds, debt swaps and blended finance

What it is: financing ocean protection at scale through blue bonds, debt-for-nature swaps, and blended finance that close the conservation funding gap.

Why it matters and how it could tip

Ocean finance has scaled from essentially zero in 2018 to around $5 billion in 2024 through blue bonds (Seychelles, Belize, Barbados, Gabon), debt-for-nature swaps and blended finance vehicles.[97,134] However, the estimated annual ocean conservation finance need is around $175 billion against current flows in the low single-digit billions. The creation of Marine Protected Areas (MPAs) is just the first step; without effective governance, enforcement, and effective capital-raising for these activities, ambitions are likely to fall short.

To achieve this, financing mechanisms need to be innovative and tactically deployed. While track-record investor-confidence loop is the main operational tipping mechanism here – with each successful issuance lowering perceived risk for the next, before rating agencies progressively rate the instrument class, and the addressable capital pool grows – this mechanism needs targeted financial innovation to have the desired effect at the emergence stage. Blended finance approaches are key, de-risking entry into new ocean markets, with debt swaps capable of tackling the constraints of highly-indebted nations; then, as emerging financial innovations reach maturity and a track-record exists, blue bonds can standardise and scale ocean finance.

Current state and desired future

Current state: around $5 billion ocean finance cumulative through 2024; around 15 blue bond and debt swap transactions; estimated need around $175 billion/year against current flows of low single-digit billions.

Desired future state (2030): ocean finance scaling to $20–30 billion/year (annual flow); around 50 blue bond and debt swap transactions cumulatively; ocean finance instruments rated by major rating agencies; integration with MDB ocean finance facilities.

Drivers and barriers

Reinforcing feedbacks:

- **Track-record investor confidence loop.** Each successful issuance reduces perceived risk for the next.[3]
- **Rating agency progression.** As deal volume grows, rating agencies develop frameworks reducing due diligence costs.
- **MDB facility scaling.** Each MDB ocean facility multiplies private capital catalytic effect.
- **Standardisation cascade.** Methodology and reporting standardisation reduces issuance friction.

Working against:

- **Outcome accountability gap.** Blue bond ocean outcomes can be hard to attribute and verify.
- **SIDS sovereign rating constraints.** Many ocean-priority nations have sovereign ratings that limit borrowing capacity.
- **Currency and political risk.** Ocean projects in Global South face currency and political risk premiums.
- **Greenwashing risk.** Ocean finance label can be applied to projects with weak ocean outcomes.

Where to act and what to watch

Priority geographies: Caribbean and Pacific SIDS (largest ocean-to-GDP ratios); West and East African coastal states; Indian Ocean island states (Seychelles, Mauritius, Madagascar, Comoros); Southeast Asian coastal states; Central and South American coastal nations (Belize, Ecuador, Colombia, Costa Rica).

Key actors: issuing sovereign nations; MDBs and DFIs (World Bank, IDB, ADB, IFC); rating agencies (Moody's, S&P, Fitch); institutional investors (pension funds, insurance companies, sovereign wealth funds); blue economy NGOs and finance facilities (Blue Nature Alliance, Ocean Risk and Resilience Alliance); legal and structuring advisors.

Key risks: outcome accountability gap producing greenwashing; sovereign rating constraints limiting access by priority nations; currency and political risk concentration in SIDS; standardisation lag relative to deal flow; equity exclusion if Global South coastal communities don't see benefits flow to local level.

Top progress indicators

Indicator	Quantification and target	Data source
Annual ocean finance flow by instrument type	Target: $20–30 billion/year by 2030	CPI; OECD; Blue Finance Initiative; World Bank Blue Economy Group
Number of nations with operational blue finance instruments	Target: 30 nations with operational instruments by 2030	World Bank Blue Bond Database; CBI Bond Database; CPI Global Landscape
Share of finance verified against blue economy principles	Target: at least 80% of finance verified against blue economy principles by 2030	IFC Blue Finance Guidelines; Ocean Risk and Resilience Alliance; third-party outcome verification

Clean shipping and ports: fuel standards, underwater noise, ballast water and zero-emission corridors

What it is: cleaning up shipping and ports through low-carbon fuels, quieter vessels, and controls on ballast-water invasive species and air pollution.

Why it matters and how it could tip

Shipping is responsible for around 3% of global CO_2 emissions, approximately 10% of global SO_2 emissions before the 2020 IMO sulphur cap (which delivered an estimated 77% reduction in shipping sulphur emissions), and significant cetacean noise pollution, ship strikes on whales, ballast water invasive species and scrubber washwater pollution.

The 2020 IMO sulphur cap demonstrated that global maritime regulatory tipping is achievable. Active IMO processes now address GHG intensity, cetacean noise, ship strikes, ballast water invasive species, and scrubber washwater. The 2050 GHG strategy commits to net-zero shipping by around mid-century.

Current state and desired future

Current state: 2020 sulphur cap operational; CII and EEXI operational since 2023; IMO 2023 GHG strategy adopted (targeting net-zero shipping by around 2050); ammonia, methanol and hydrogen pathways at early commercial stage; Maersk operates 12 dual-fuel methanol-capable vessels with around 25 more on order.

Desired future state (2030): GHG emissions from international shipping reduced by at least 20% from 2008 baseline; at least 5% of fuel from zero- or near-zero-emission sources; underwater noise standards adopted; ballast water management universal compliance; scrubber washwater discharge restricted in lead jurisdictions; zero-emission corridors operational on at least 20 routes.

Drivers and barriers

Reinforcing feedbacks:

- **IMO regulatory ratchet.** 2020 sulphur cap precedent and 2023 GHG strategy create regulatory momentum.
- **Lead jurisdiction port standards.** EU FuelEU Maritime, US ports, Singapore creating de facto global standards.
- **Alternative fuel learning curve.** Ammonia, methanol and hydrogen costs falling as production scales.
- **Corridor demonstration effect.** Zero-emission corridors prove commercial viability, accelerating broader adoption.

Working against:

- **Fuel availability constraint.** Zero-emission fuel supply chains are at early commercial stage; bunkering infrastructure incomplete.
- **Capital stock turnover.** Ships have 20–30-year lifespans; turnover slow without policy intervention.
- **Flag state evasion.** Open registry flag states can dilute regulatory effect.
- **Cost pass-through resistance.** Shipping cost increases pass to consumers; political resistance in lead-market jurisdictions.

Where to act and what to watch

Priority geographies: major shipping routes (Singapore–Rotterdam, Shanghai–Los Angeles, Persian Gulf–East Asia); port hubs (Singapore, Rotterdam, Shanghai, Los Angeles/Long Beach, Antwerp, Hamburg, Busan); cetacean migration corridors (US West Coast, Mediterranean, North Atlantic); island nations dependent on shipping.

Key actors: IMO and member states; major shipping companies (Maersk, MSC, CMA CGM, COSCO, Evergreen, Hapag-Lloyd); flag states (Panama, Liberia, Marshall Islands); port authorities; alternative fuel producers; cargo owners committing to clean shipping (Amazon, IKEA, Unilever).

Key risks: fuel-availability bottleneck constraining GHG strategy implementation; flag state evasion undermining regulatory effect; scrubber washwater displacement of air pollution to water; equity displacement of small shipping operators; unintended methane slip from LNG and methanol pathways; ship strike and underwater noise impacts on cetaceans remaining unaddressed.

Top progress indicators

Indicator	Quantification and target	Data source
GHG emissions from international shipping and carbon intensity	Target: at least 20% reduction from 2008 by 2030	IMO 4th GHG Study and updates; UMAS shipping tracker
Number of operational zero-emission shipping corridors	Target: 20 operational corridors by 2030	Getting to Zero Coalition; Global Maritime Forum; Clydebank Declaration tracking
Cetacean ship-strike incidents and underwater noise standards adoption	Target: 50% reduction in documented ship strikes; underwater noise standards adopted in at least 10 major shipping nations by 2030	IWC ship strike database; IMO noise reduction monitoring

Across these eleven areas, two patterns recur: ocean finance scaling is the binding constraint on most other solutions, and community-led management consistently outperforms equivalent state-managed alternatives where tenure and rights are secure.

Chapter 4: Build a Waste-Free World

The ambition of the fourth Earthshot challenge is to build a world where nothing goes to waste – where the leftovers of one process become the raw materials of the next. This Earthshot addresses the systems that produce, use, recover and dispose of materials. Approximately 40% of global waste ends in open dumps; food waste reaches 1.05 billion tonnes per year; construction and demolition is the largest single waste stream globally.[110,111] The tipping potential here is concentrated in regulatory and finance mechanisms that align upstream design choices with downstream recovery infrastructure. Eleven solution areas are analysed below.

Solution areas

Solution area	Phase	How it Could Tip
Policy, procurement and finance mechanisms (enabling layer).	Emergence (UNEP plastics treaty a potential global governance tipping point).	A binding treaty plus public-procurement demand activates the regulatory ratchet that unlocks other positive feedbacks.
Extended Producer Responsibility (EPR) and eco-modulated fees.	Acceleration (75+ country implementations).	As eco-modulated fees reprice products upstream, design-for-circularity becomes the profit-maximising choice and spreads across producers.
Circular construction materials and climate-adapted built environment.	Emergence (largest waste stream ~30%; early adoption).	When recycled-content and reuse standards plus embodied-carbon pricing take hold, circular construction undercuts virgin-material building.
Municipal waste infrastructure transformation.	Emergence (foundation for material recovery; trust-revenue loop).	Reliable collection builds the fee revenue that funds better service — a virtuous loop that makes formal waste systems self-sustaining.
Circular packaging materials and design.	Emergence → Acceleration (recycled-content mandates emerging).	Design-for-recyclability and recycled-content mandates pull material markets until circular packaging becomes the default format.
Reuse, refill and deposit return systems (DRS)	Acceleration (fastest-tipping instrument; PET collection	Deposit systems flip collection economics quickly, and once

Solution area	Phase	How it Could Tip
	>85% with DRS vs <40% without).	infrastructure is in place high return rates become the norm.
Organic waste prevention, composting and anaerobic digestion	Emergence (1.05bn t wasted annually; methane co-benefit)	Methane-linked climate finance makes diversion pay, and separate organic collection becomes standard municipal practice.
E-waste collection, circular electronics and repairability	Emergence (EU Right-to-Repair Directive 2024 as regulatory ratchet)	Once repair-network density crosses a threshold and right-to-repair rules bite, repair and reuse outcompete replacement.
Industrial symbiosis and eco-industrial parks	Emergence (the Kalundborg demonstration project is exceptional).	When a few firms' waste-to-input exchanges prove profitable, network effects cascade new exchanges across an industrial cluster.
Toxins: microplastics, microfibres, PFAS and pellet loss prevention	Emergence (EU PFAS restriction pending).	A sweeping PFAS/microplastic restriction sets a global precedent that designs persistent pollutants out of products upstream.
Textile and fashion circularity	Emergence (e.g. EU EPR regulation); re-use growing, fibre-to-fibre recycling still less than 1%	As textile EPR funds separate collection and guarantees feedstock, reuse becomes mainstream and fibre-to-fibre recycling scales until recycled fibre competes with virgin — decoupling clothing from virgin-material throughput

Policy, procurement and finance mechanisms

What it is: the regulations, public purchasing power and finance rules that set the conditions for every other circular-economy tipping point.

Why it matters and how it could tip

Policy is the highest-leverage solution area in the waste Earthshot because the regulatory ratchet activates the other tipping mechanisms in the chapter.[78] The UNEP intergovernmental negotiating committee on plastic pollution is the largest single global waste governance process under way.[113]

This is an enabling intervention rather than a material-flow solution. It does not affect a waste stream directly, but conditions whether other solution areas in this chapter can tip. Public procurement of recycled content, embodied carbon and reuse standards creates demand-side market pull that complements supply-side EPR fees. Finance flows from Multilateral Development Banks (MDBs) and climate funds determine whether the Global South investment gap in waste infrastructure can be closed.[111]

Current state and desired future

Current state: UNEP plastics treaty in active negotiation; EU Green Public Procurement framework operational across 27 member states; US Buy Clean operational at federal level and several states; municipal waste infrastructure financing gap estimated at $40–60 billion/year in Global South.

Desired future state (2030): UNEP plastics treaty adopted with binding source-reduction provisions; public procurement of circular materials standard across G20; waste infrastructure financing scaled to close Global South gap.

Drivers and barriers

Reinforcing feedbacks:

- **Treaty governance ratchet.** UNEP plastics treaty creates international legal framework propagating through national legislation.[113]
- **Public procurement demand pull.** Government buyers create early markets for circular materials at scale.[78,117]
- **Infrastructure finance cascade.** Each MDB waste facility scaling multiplies catalytic capital.[65,111]
- **Norm convergence across jurisdictions.** Lead-market policies create de facto international standards.[34]

Working against:

- **Treaty dilution risk.** Plastics-producing nations resist binding source-reduction targets.
- **Procurement implementation gap.** Standards on paper often lack enforcement and verification.
- **Finance political competition.** Waste competes with climate, health and infrastructure for limited concessional finance.
- **Regulatory complexity.** Cross-jurisdictional inconsistency creates compliance burden for global producers.

Where to act and what to watch

Priority geographies: EU as lead procurement and plastics treaty jurisdiction; major Global South economies needing waste infrastructure (India, Indonesia, Nigeria, Egypt, Bangladesh, Vietnam, Philippines); G20 economies as procurement scaling priority; SIDS particularly exposed to marine plastic.

Key actors: UN Environment Programme; national environmental and finance ministries; public procurement authorities; MDBs with waste sector facilities (World Bank, ADB, IDB, AfDB, EIB, EBRD); industry standards bodies (ISO, CEN); civil society advocacy networks (Break Free from Plastic, ZWE).

Key risks: plastics treaty dilution; greenwashing through unenforced procurement standards; finance allocation skewed to incinerators over circular alternatives; equity exclusion of informal waste workers; complexity costs burdening SMEs.

Top progress indicators

Indicator	Quantification and target	Data source
UNEP plastics treaty implementation status and binding source-reduction targets. This indicator is shared with Oceans Earthshot, where the relevant threshold is marine-leakage production. Here, the relevant threshold is upstream production and circularity.	Target: treaty adopted with binding source-reduction by 2027; transposed into national law in 100+ countries by 2030	UNEP INC; national environment ministry reporting
Share of major public procurement aligned with circular materials standards	Target: at least 75% of major public procurement using circular materials standards by 2030	OECD Green Public Procurement; EU GPP; Buy Clean tracker
Volume of concessional finance flowing to circular economy infrastructure in low- and middle-income countries	Target: $30 billion/year by 2030	CPI Global Landscape of Climate Finance; MDB Joint Reports; OECD DAC

Extended Producer Responsibility and eco-modulated fees

What it is: making producers pay for the end-of-life of what they sell, with fees scaled to how recyclable a product is, so design improves upstream.

Why it matters and how it could tip

Extended Producer Responsibility (EPR) shifts the financial cost of end-of-life waste management onto product producers, creating an upstream design-for-circularity incentive.[78] Over 75 countries now have EPR schemes; the EU Packaging and Packaging Waste Regulation and equivalents are extending coverage rapidly.

The decisive innovation is eco-modulated fees: lower fees for products designed for circularity, higher fees for problematic designs. The price signal flows directly into product design teams.

Current state and desired future

Current state: over 75 countries with EPR schemes; EU eco-modulation operational since 2021; recycling rates in EPR jurisdictions typically 30–50% versus 15–20% without EPR.

Desired future state (2030): EPR operational in all G20 economies across packaging, electronics, batteries, textiles and vehicles; eco-modulation standardised internationally; producer responsibility organisations covering at least 80% of consumer goods globally.

Drivers and barriers

Reinforcing feedbacks:

- **Design-for-circularity loop.** Eco-modulated fees flow directly into product design decisions, upstream of waste generation.[78]
- **PRO operational learning.** Each operational year reduces unit cost and improves outcomes.
- **International methodology convergence.** EU eco-modulation methodology spreading through trade-policy and standards bodies.[18,20,34]
- **Industry self-organising.** PROs allow industry-led implementation, reducing political resistance.

Working against:

- **Scope limitations.** Many EPR schemes cover only packaging; product scope expansion faces industry resistance.
- **Modulation gaming.** Producers can structure products to fit favourable fee categories without genuine circularity gains.
- **Cross-border free-rider risk.** Online cross-border sales evade national EPR systems.
- **Informal waste worker exclusion.** Formal EPR can displace livelihoods of informal waste workers without integration.

Where to act and what to watch

Priority geographies: EU as the global lead jurisdiction; Canada and Australia with provincial/state EPR systems; major Latin American economies (Brazil, Chile, Colombia, Mexico) with rapidly scaling schemes; India and South Asia; Sub-Saharan Africa (emerging schemes in Kenya, South Africa, Ghana).

Key actors: national environment ministries; Producer Responsibility Organisations (Citeo France, Der Grüne Punkt Germany); consumer goods companies (Unilever, P&G, Nestlé, PepsiCo, Coca-Cola); packaging industry; waste management industry; informal waste worker organisations.

Key risks: greenwashing through cosmetic eco-modulation; cross-border free-rider erosion; informal waste worker displacement; PRO governance capture by major brand owners; scope limited to packaging missing critical waste streams.

Top progress indicators

Indicator	Quantification and target	Data source
Number of countries with operational EPR schemes across major product categories	Target: full G20 coverage across 5 categories by 2030	OECD EPR Policy Database; UNEP EPR review
Documented improvement in product design-for-circularity in EPR-covered markets	Target: at least 50% of products in covered markets meeting design-for-circularity standards by 2030	Ellen MacArthur Foundation; PROs reporting; CDP Plastics
Recycling rate by product category in EPR jurisdictions	Target: at least 65% recycling rate in EPR jurisdictions by 2030	Eurostat; EPA Advancing Sustainable Materials Management; OECD waste indicators

Circular construction materials and the climate-adapted built environment

What it is: cutting the waste and embodied carbon of construction — the largest single waste stream — by reusing materials and designing buildings to last and adapt.

Why it matters and how it could tip

Construction and demolition is the largest single waste stream globally, approximately 30% of total solid waste.[111] Buildings and construction account for around 39% of global CO_2 emissions; embodied carbon is rising as the share of total building emissions.[117,135]

The demolition–construction loop captures materials from end-of-life buildings and recycles them into new construction at progressively higher quality. The World Green Building Council embodied carbon disclosure ratchet creates the information infrastructure that lets buyers differentiate circular from linear materials.

Current state and desired future

Current state: global C&D waste around 3.5 billion tonnes/year; embodied carbon disclosure mandatory in lead jurisdictions (Netherlands, France, Norway, UK GLA); circular construction materials at around 5–10% of new construction in lead markets.

Desired future state (2030): C&D waste recycled into high-value applications above 70% in lead jurisdictions; embodied carbon disclosure mandatory in all G20; circular construction materials at above 25% of new construction in lead markets.

Drivers and barriers

Reinforcing feedbacks:

- **Embodied carbon disclosure ratchet.** Each new disclosure mandate raises peer pressure and enables buyer differentiation.[135]
- **Buy Clean demand pull.** Public procurement specifies embodied carbon limits, creating early markets at scale.
- **Material passport infrastructure.** Digital material tracking through building lifecycles increases recovery potential.
- **Adaptation finance integration.** Climate-resilient infrastructure finance specifies durability and circularity criteria.[22,85,117]

Working against:

- **Capital stock turnover slow.** Buildings have 50–100-year lifespans; existing stock determines outcomes for decades.
- **Quality variability.** Recycled C&D materials have variable quality, raising structural and insurance challenges.
- **Land-use intensity of deconstruction.** Deconstruction requires more time and space than demolition; permitting frameworks lag.
- **Cross-jurisdictional fragmentation.** Material standards vary widely, limiting cross-border circular trade.

Where to act and what to watch

Priority geographies: EU under the Construction Products Regulation; California, Washington and other US Buy Clean states; Singapore Green Plan; UK net-zero carbon construction; Nordic countries; Australia and New Zealand; Japan and Korea retrofit programmes; rapidly urbanising Global South cities.

Key actors: national building regulators; public procurement authorities (Buy Clean coalitions); architecture and engineering firms (Architecture 2030, World GBC); construction material producers (cement, steel, glass, aggregates); developers and real estate investors; WGBC and national green building councils.

Key risks: greenwashing through low-integrity recycled content claims; structural safety concerns with low-quality recycled materials; equity displacement in rapid retrofit programmes; embodied carbon disclosure without enforcement; finance allocation skewed to new construction over retrofit and adaptive reuse.

Top progress indicators

Indicator	Quantification and target	Data source
C&D waste recycling rate (high-value applications)	Target: at least 70% high-value recycling in lead jurisdictions by 2030	Eurostat waste statistics; national building agencies; ISWA reports
Share of major jurisdictions with mandatory embodied carbon disclosure	Target: full G20 coverage by 2030	World GBC Building Policy Tracker; Architecture 2030; national building regulation databases
Embodied carbon of new construction in lead jurisdictions	Target: at least 40% reduction from 2020 baseline by 2030	World GBC; LETI; RICS; national disclosure data

Municipal waste infrastructure transformation

What it is: building reliable waste collection and sorting for the roughly two billion people who lack it, the foundation for all material recovery.

Why it matters and how it could tip

Reliable municipal solid waste collection is the foundation for all material recovery in household and commercial waste streams. Around 2 billion people globally lack access to formal waste collection; around 40% of global waste ends in open dumps or open burning.[111]

The trust-revenue feedback loop is the operational tipping mechanism.[111,60] Informal waste workers – estimated at 20 million globally, recovering approximately 60% of currently recycled material – are essential operational partners.

Current state and desired future

Current state: around 2 billion people without formal waste collection; around 40% of global waste in open dumps; municipal waste financing gap estimated at $40–60 billion/year concentrated in Global South cities.

Desired future state (2030): universal formal waste collection in cities above 1 million population; open dumping phased out in all G20 and major emerging economies; informal waste workers formally integrated into municipal systems with secure livelihoods; recycling rates above 50% in formal systems.

Drivers and barriers

Reinforcing feedbacks:

- **Trust–revenue loop.** Reliable collection builds participation, fees fund expansion.[65,111]
- **Informal worker integration dividend.** Formal integration retains existing recovery capacity while adding system reliability.[79,111]
- **EPR finance integration.** EPR fees provide sustained operating revenue beyond municipal budgets.
- **MDB facility scaling.** World Bank and equivalent waste facilities catalyse private capital.

Working against:

- **Municipal finance constraints.** Many Global South municipalities have limited fiscal capacity for waste investment.
- **Informal worker displacement risk.** Formalisation can displace livelihoods if not designed inclusively.
- **Incineration substitution.** Pressure to substitute open dumping with incineration risks long-term air pollution and material-recovery lock-in.
- **Tariff political resistance.** Waste fees face political resistance especially in informal settlements.

Where to act and what to watch

Priority geographies: South Asian megacities (Mumbai, Delhi, Dhaka, Karachi, Kolkata); Sub-Saharan African cities (Lagos, Kinshasa, Cairo, Dar es Salaam, Nairobi); Southeast Asian cities (Jakarta, Manila, Ho Chi Minh City, Bangkok); Latin American cities (Mexico City, Lima, Bogotá, São Paulo); SIDS particularly exposed to ocean plastic leakage.

Key actors: municipal governments; national environment and finance ministries; MDBs and DFIs financing waste infrastructure (World Bank, ADB, AfDB, IDB); informal waste worker organisations (WIEGO, AIW, GAIA, GroundWork); waste management industry (Veolia, Suez, Waste Management, Republic Services); EPR PROs.

Key risks: informal worker displacement; incineration lock-in displacing material recovery; equity displacement from informal settlements; municipal corruption and procurement integrity issues; over-capital-intensive solutions where labour-intensive informal-integration models are more appropriate.

Top progress indicators

Indicator	Quantification and target	Data source
Share of urban population with access to formal waste collection	Target: 100% urban access in cities above 1 million by 2030	UN-Habitat City Prosperity Index; What a Waste 2.0 updates; municipal waste departments
Number of cities with documented informal waste worker formal integration programmes	Target: 200 cities with formal integration by 2030	WIEGO; GAIA; AIW; municipal partnership databases
Share of global waste managed through sound systems (not open dumping or burning)	Target: at least 80% sound management globally by 2030 (from current around 60%)	UNEP GWMO; What a Waste 2.0

Circular packaging materials and design

What it is: redesigning packaging — recycled content, single materials and design-for-recyclability — so it can actually be recovered.

Why it matters and how it could tip

The materials a product is made from, and the way it is designed, largely determine whether it can be recovered. This area covers circular packaging materials and design, including recycled content, mono-material and design-for-recyclability choices, and innovative materials. Behavioural-and-infrastructural interventions (reuse, refill and deposit-return) are addressed in Solution Area 6.

The tipping mechanism for materials runs through design and demand: design for recyclability and convergence on a small set of recyclable mono-materials that make recovered packaging genuinely recyclable; recycled content mandates create a demand pull that pays for collection and reprocessing. The EU Packaging and Packaging Waste Regulation (PPWR), which sets recycled and recyclability requirements, provides the regulatory ratchet.[22]

Current state and desired future

Current state: the recycled content in plastic packaging is at roughly 10% globally and very uneven by polymer; design-for-recyclability is advancing but laminates and additives still leave much packaging unrecyclable in practice. The EU PPWR was adopted in 2025 with binding recycled-content and recyclability requirements; innovative materials (e.g., seaweed films, regenerated fibres, and bio-based polymers) are in pilots and early commercial use.

Desired future state (2030): recycled content at 30% or more in plastic packaging in lead markets; most packaging meeting design-for-recyclability criteria; recycled-content and recyclability mandates adopted in major economies beyond the EU; the most credible innovative materials reaching commercial scale in several packaging categories.

Drivers and barriers

Reinforcing feedbacks:

- **EU PPWR regulatory ratchet.** Binding reuse targets propagate through trade-policy and standards.[22]
- **Mono-material convergence and design standards.** As brands and recyclers converge on a small set of recyclable mono-materials, sorting and reprocessing economics improve across the whole system. .
- **Learning curve in recycled content and novel materials. Unit costs of recycled resins and innovative materials fall as production capacity** scales.
- **Brand recycled-content commitments.** Voluntary brand pledges (e.g. the Ellen MacArthur Foundation Global Commitment) create demand pull for recyclable design and recycled material.

Working against:

- **Virgin material price advantage.** Low virgin-plastic prices undercut recycled content unless mandates or carbon pricing close the gap.
- **Multi-material and additive complexity.** Laminates, additives and colourants leave many formats unrecyclable in practice even where collection exists.
- **Recyclate quality and supply.** Supply of recycled content is constrained and variable in quality, limiting closed-loop use.
- **Innovative materials risks.** New materials are promising but mostly experimental/pre-scale.

Where to act and what to watch

Priority geographies: EU under PPWR (binding recycled-content and design-for-recyclability requirements); UK (Plastic Packaging Tax); North America (recycled-content mandates in California and other states); Asia (Japan and Korea on design standards); Small Island Developing States (SIDS) as priority jurisdictions for packaging-material reduction.

Key actors: national environment ministries setting recycled content and recyclability rules; major retailers (e.g., Tesco, Carrefour, Walmart, ALDI, LIDL) and consumer goods companies (e.g., Unilever, Coca-Cola, Henkel, P&G); recyclers and reprocessors; materials innovators (Notpla, Circ, Colorifix);design and standards bodies (APR, CEFLEX).

Key risks: greenwashing through “recyclable” claims for formats that are not recovered in practice; recycled-content mandates outrunning recyclate supply; chemical-recycling claims displacing proven mechanical recycling without evidence.

Top progress indicators

Indicator	Quantification and target	Data source
Recycled content in plastic packaging	Target: 30% or more recycled content in lead markets by 2030	EU PPWR reporting; Ellen MacArthur Foundation Plastic Pact; CDP
Share of packaging meeting design-for-recyclability criteria	Target: large majority of packaging meeting design-for-recyclability criteria in lead markets by 2030	Ellen MacArthur Foundation; APR/CEFLEX design guidelines; CDP
Commercial scale of innovative circular materials	Target: innovative materials at commercial scale in three or more packaging categories by 2030	Eurostat; Ellen MacArthur Foundation; UNEP packaging flows

Reuse, refill and deposit-return schemes

What it is: keeping packaging in use through reuse and refill systems and recovering it for high-quality recycling through deposit-return schemes.

Why it matters and how it could tip

This is the behavioural-and-infrastructural element of packaging circularity, covering reuse and refill systems that keep packaging in service, and deposit-return schemes (DRS) that recover it for high-quality recycling. DRSs are the fastest-tipping individual instrument in the waste Earthshot, achieving operational maturity within two to five years of implementation.[40,77,122] PET collection rates exceed 85% in DRS countries against typically below 40% in equivalent jurisdictions without DRS.

The quality–revenue feedback loop makes the system self-financing: source-separated material is cleaner and commands higher recycled commodity prices, generating revenue that funds the deposit refund infrastructure.

Current state and desired future

Current state: reuse and refill at roughly 1–3% of consumer packaging globally, mature in some beverage markets (around 50% of beer in reusable bottles in Germany), with EU PPWR (2025) setting binding reuse targets; DRS operational in around 50 jurisdictions globally (most of EU, Canada, Australia, parts of US) with PET collection above 85% in DRS countries; UK DRS implementation delayed but in progress; rapid spread in 2023–2025 across European and Latin American jurisdictions.

Desired future state (2030): reuse and refill at 10–20% of consumer packaging in lead markets, with reuse infrastructure standard in major retail formats; DRS operational in all major economies and SIDS; coverage extended beyond beverages to other high-value priority materials; PET collection above 90% globally in DRS-covered markets.

Drivers and barriers

Reinforcing feedbacks:

- **Quality–revenue self-financing loop.** Clean source-separated material commands premium prices, funding infrastructure.[122]
- **Cross-jurisdictional learning.** Each new DRS implementation benefits from accumulated operational experience.
- **Reuse and return network effects.** As more retailers offer reuse, refill and deposit return, the behaviour becomes routine and convenient, encouraging further recruits.
- **Integration with municipal waste.** DRS reduces municipal waste stream contamination.

Working against:

- **Retail counter-resistance.** Some retailers resist take-back logistics; addressed through reverse vending machine deployment.
- **Material scope limitations.** Most DRS limited to PET, glass and aluminium; extension to other materials faces design challenges.
- **SIDS implementation challenges.** Small markets face minimum-volume economic challenges.
- **Deposit value erosion.** Inflation can erode deposit value if not regularly adjusted.

Where to act and what to watch

Priority geographies: lead markets (Germany, Nordic countries, Netherlands, Lithuania, Estonia, Ireland, Romania); rapidly expanding markets (UK, Spain, Portugal, parts of

Australia); developing implementations (Brazil, Mexico, Argentina, Chile); SIDS particularly exposed to marine plastic leakage.

Key actors: national environment ministries adopting reuse targets and DRS legislation; beverage and consumer goods companies (Coca-Cola, PepsiCo, Anheuser-Busch InBev, Heineken); retailers; reuse system operators (Loop, Algramo, Splosh); reverse vending machine manufacturers (Tomra, Sielaff, Repant); recyclers; circular economy NGOs (Reloop, CMI, UPSTREAM).

Key risks: deposit value erosion through inflation undermining return rates; retailer resistance to take-back logistics; scope limitations leaving major materials uncovered; equity exclusion of low-income consumers from deposits; informal waste worker displacement if not integrated.

Top progress indicators

Indicator	Quantification and target	Data source
Share of consumer packaging in reuse or refill systems	Target: 10–20% of consumer packaging in reuse or refill systems in lead markets by 2030	EU PPWR reporting; Reloop; UPSTREAM
Collection rate of beverage containers in DRS-covered markets	Target: at least 90% collection in DRS jurisdictions by 2030	National DRS operator reports; Eurostat; CMI
Material categories covered by DRS beyond beverages	Target: at least 10 jurisdictions with extended-scope DRS by 2030	Reloop; OECD; national environment ministries

Organic waste prevention, composting and anaerobic digestion

What it is: preventing food and organic waste, and turning what remains into compost or biogas instead of landfill methane.

Why it matters and how it could tip

Approximately 1.05 billion tonnes of food are wasted annually – around a third of all food produced.[110] Food waste accounts for around 8–10% of global GHG emissions; organic waste in landfills generates methane that contributes substantially to landfill emissions. Food waste is also a direct pressure on nature: a large share of agricultural land and the water use, fertiliser and habitat conversion behind it, is devoted to producing food that is never eaten. Halving food waste would therefore greatly ease demand for cropland and grazing land and the biodiversity loss that comes with expanding it, This links directly to the Nature Earthshot.

The nutrient feedback loop restores soil organic matter through composting, reducing synthetic fertiliser demand. Anaerobic digestion produces biogas, displacing fossil methane.[58] South Korea's household food waste source-separation programme demonstrates nation-scale tipping is achievable within a decade.

Current state and desired future

Current state: around 1.05 billion tonnes/year food waste; around 8–10% of global GHG emissions; South Korea, Switzerland and parts of EU with mandatory source separation; composting and AD at around 5–10% of organic waste in OECD, much lower in Global South.

Desired future state (2030): food waste halved from 2020 baseline (SDG 12.3); mandatory source separation in all G20 cities; landfill ban on biodegradable waste in lead jurisdictions; biogas displacing fossil methane in major heat and transport applications.

Drivers and barriers

Reinforcing feedbacks:

- **Source-separation tipping.** Once mandatory, source separation becomes routine within 2–3 years (South Korea evidence).
- **Methane finance integration.** Climate finance for methane reduction subsidises AD infrastructure.
- **Soil-carbon and fertiliser-displacement loop.** Compost displaces synthetic fertiliser, reducing emissions and improving soil.
- **Biogas commercial integration.** Biogas replaces fossil methane in heat and transport, generating commercial revenue.

Working against:

- **Source separation behavioural challenges.** Source separation requires sustained consumer behaviour; initial compliance often partial.
- **Contamination risk.** Compost and digestate contamination (microplastics, PFAS) limits agricultural application.
- **Cold-climate AD performance.** AD performance reduced at low temperatures, raising operational costs.
- **Land-use competition.** Energy crop-fed AD competes with food production.

Where to act and what to watch

Priority geographies: South Korea as operational model; EU under WFD revision; Singapore and Hong Kong with developed schemes; major US cities (San Francisco, Seattle, NYC) with mandatory composting; major Global South cities as next-wave priority (Bangalore, Cape Town, Lagos, Jakarta with pilot programmes).

Key actors: national environment ministries adopting source separation legislation; municipal waste authorities; food industry (retailers, processors, food service); food waste reduction NGOs (WRAP, ReFED, Champions 12.3); AD industry; agricultural producers using compost and digestate; methane finance institutions (CCAC, GMP).

Key risks: greenwashing through low-quality compost masking continued landfilling; contamination of compost stream limiting agricultural use; AD investment without source-separation infrastructure; energy crop displacement of food production; methane leakage from AD undermining climate benefits.

Top progress indicators

Indicator	Quantification and target	Data source
Food waste reduction against SDG 12.3 baseline	Target: 50% reduction by 2030 (SDG 12.3)	UNEP Food Waste Index Report; Champions 12.3 progress reports; national household waste surveys
Share of organic waste source-separated and composted or anaerobically digested in G20 cities	Target: at least 75% in G20 cities by 2030	ISWA; OECD waste indicators; municipal reporting
Methane emissions reduction from food and organic waste diversion	Target: at least 100 $MtCO_2e$/yr reduction by 2030 from current trajectory	UNFCCC national GHG inventories; GMI; methane finance reporting

E-waste collection, circular electronics and repairability

What it is: collecting the fastest-growing waste stream and keeping electronics in use longer through repairability and recovery of their valuable materials.

Why it matters and how it could tip

E-waste is the fastest-growing waste stream globally, with approximately $62 billion in recoverable resource value embedded annually.[59] Around 80% of e-waste is not formally collected.

The service-network tipping mechanism operates when repair shop density reaches a threshold at which repairing becomes more convenient than replacing. The EU Right-to-

Repair Directive (2024) requires manufacturers to make spare parts, repair information and software updates available.[27]

Current state and desired future

Current state: around 62 Mt e-waste/year globally; around 22% formally collected and recycled; EU Right-to-Repair Directive operational; US state right-to-repair laws spreading; e-waste recycling industry concentrated in Europe and East Asia.

Desired future state (2030): e-waste collection rates above 60% in lead jurisdictions; right-to-repair frameworks operational in all G20; circular electronics design (modular, repairable, software-upgradable) standard across major consumer electronics categories; e-waste recovery industry expanded to Global South.

Drivers and barriers

Reinforcing feedbacks:

- **Right-to-repair regulatory ratchet.** EU 2024 directive propagates through trade-policy and standards.[27]
- **Service-network tipping.** Repair shop density above threshold makes repair more convenient than replacement.
- **Critical materials recovery economics.** Rising critical materials prices improve e-waste recovery economics.[47,59]
- **Consumer behaviour shift.** Younger consumers increasingly value repairability and durability.

Working against:

- **Manufacturer resistance.** Planned obsolescence remains a profitable business model for some manufacturers.
- **Cross-border e-waste flows.** E-waste exports from rich to poor countries continue despite Basel Convention restrictions.
- **Informal recycling health risks.** Informal e-waste recycling exposes workers and communities to toxic materials.
- **Repair workforce constraints.** Trained repair technicians limited in number relative to demand.

Where to act and what to watch

Priority geographies: EU under Right-to-Repair Directive (lead jurisdiction); US states with right-to-repair laws (New York, Minnesota, California); informal e-waste hubs requiring formalisation (Ghana, India, Nigeria, China); rapidly digitalising emerging economies (Indonesia, Vietnam, Brazil, Mexico).

Key actors: national environment and consumer protection ministries; consumer electronics manufacturers (Apple, Samsung, Lenovo, Dell, HP); right-to-repair advocacy networks (iFixit, Right to Repair Europe, US PIRG); informal e-waste worker organisations; critical materials recovery industry; Basel Convention secretariat.

Key risks: manufacturer evasion of right-to-repair through software locks; continued e-waste export to Global South with weak environmental controls; informal recycling health impacts; equity exclusion of informal workers from formal systems; greenwashing through tokenistic repair offerings.

Top progress indicators

Indicator	Quantification and target	Data source
E-waste collection and recycling rate globally	Target: at least 60% formal collection in lead jurisdictions by 2030 (from current 22%)	ITU/UNITAR Global E-Waste Monitor; national EPR reporting
Number of jurisdictions with operational right-to-repair legislation	Target: full G20 coverage by 2030	Right to Repair Europe; iFixit policy tracker; national consumer protection agencies
Share of consumer electronics designed for repairability under formal scoring frameworks	Target: at least 75% of new consumer electronics meeting repairability standards by 2030	French Repairability Index; EU Ecodesign Directive reporting; consumer testing organisations

Industrial symbiosis and eco-industrial parks

What it is: linking co-located firms so one factory's waste becomes another's raw material, as pioneered at Kalundborg in Denmark.

Why it matters and how it could tip

Industrial symbiosis links co-located firms so that waste streams from one process become inputs to another. The classic case is Kalundborg in Denmark, where over 30 exchange relationships between a refinery, power station, gypsum board manufacturer and pharmaceutical company reduce material and energy waste across the cluster.[19]

The UNIDO Global Eco-Industrial Park Programme has scaled the model to over 50 sites across emerging economies.[118]

Current state and desired future

Current state: Kalundborg operational since 1972 with documented material, water and energy savings; UNIDO programme covers 50+ EIPs; National Industrial Symbiosis Programme in UK and equivalents in EU, Japan and Korea.

Desired future state (2030): industrial symbiosis standard practice in major industrial clusters globally; at least 200 documented EIPs with substantial inter-firm exchange relationships; integration with industrial transformation (Chapter 4 SA 7) and circular materials value chains.

Drivers and barriers

Reinforcing feedbacks:

- **Within-cluster network effects.** Each new exchange relationship makes additional ones more viable.
- **Resource cost pressure.** Rising material and energy costs improve symbiosis economics.
- **UNIDO programmatic scaling.** Standardised methodologies and capacity-building accelerate replication.[19,118]
- **Climate and circularity policy alignment.** EIPs deliver against multiple policy objectives simultaneously.

Working against:

- **Geographic concentration constraint.** Symbiosis works where firms are co-located; transferring waste over distance erodes economics.
- **Confidentiality and competition.** Firms resist disclosing waste streams to competitors.
- **Regulatory definition gaps.** Waste-to-input transfers face regulatory friction in many jurisdictions.
- **First-mover coordination cost.** Establishing symbiosis requires upfront coordination investment.

Where to act and what to watch

Priority geographies: existing industrial clusters in emerging economies (India, Indonesia, Vietnam, Thailand, China, Mexico, Turkey); EU industrial regions; UK industrial symbiosis programme; East Asian industrial clusters; Sub-Saharan African industrial development zones.

Key actors: UNIDO and equivalent international industrial development bodies; national industrial development agencies; industrial cluster operators and parks management; major industrial firms (steel, cement, chemicals, refining, food processing); circular economy and industrial symbiosis consultancies; research institutions.

Key risks: confidentiality concerns blocking exchange relationships; regulatory gaps treating waste-to-input as continued waste; over-reliance on one anchor firm whose closure can collapse the cluster; equity exclusion of SMEs from clusters dominated by large firms.

Top progress indicators

Indicator	Quantification and target	Data source
Number of operational eco-industrial parks with documented exchange relationships globally	Target: 200 operational EIPs by 2030	UNIDO Global EIP Programme; national industrial development agency reporting
Material and energy exchange volume in operational symbiosis clusters	Target: at least 10% of total material and energy throughput in EIP clusters delivered through symbiotic exchanges by 2030	UNIDO EIP performance assessment; individual cluster reporting
GHG and material savings attributable to industrial symbiosis	Target: at least 50 $MtCO_2e$/year in symbiotic savings by 2030	UNIDO; peer-reviewed industrial ecology research; national GHG inventories

Toxins: microplastics, microfibres, PFAS and pellet loss prevention

What it is: stopping persistent pollutants — microplastics, textile microfibres, PFAS and spilled plastic pellets — at source, because they cannot be cleaned up afterwards.

Why it matters and how it could tip

Persistent pollutants – microplastics, textile microfibres, per- and polyfluoroalkyl substances (PFAS), plastic pellet loss in the supply chain – require upstream prevention because remediation is effectively impossible at the relevant scales.[20,112] The European Chemicals Agency PFAS restriction under REACH, if adopted in its proposed scope, would be the largest chemicals regulatory action in history.

These pollutants matter because their harms are persistent. PFAs are called “forever chemicals” because they resist breakdown and bioaccumulate. They are now present in humans worldwide and linked to immune suppression, developmental and reproductive effects, thyroid disruption and some cancers. Microplastics and textile microfibres are similarly ubiquitous and can act as carriers for other toxins. Several of these substances are endocrine disruptors and have broad ecological toxicity across the food web. Large-scale clean is practically impossible. The only viable solution is to prevent their release.

The decisive design principle is class-based regulation: regulating substance classes rather than individual chemicals closes the substitution loophole.

Current state and desired future

Current state: ECHA PFAS restriction in regulatory development; EU microplastics restriction (intentionally added) operational from 2023; France washing machine microfibre filter mandate operational; US state-level PFAS bans accelerating; plastic pellet loss prevention under EU Council 2024 regulation.[26,28,68,119]

Desired future state (2030): class-based PFAS restriction adopted in EU and parallel jurisdictions; microfibre filtration mandatory for new washing machines globally; pellet loss prevention universal across plastics supply chain; intentionally added microplastics banned in major consumer products.

Drivers and barriers

Reinforcing feedbacks:

- **Class-based regulatory ratchet.** PFAS class restriction precedent sets template for other persistent chemical classes.[17,20]
- **Health evidence accumulation.** Each new health study strengthens regulatory mandate.
- **Substitute industry development.** Alternative materials industries scale as restrictions create market certainty.
- **Liability and insurance pressure.** Increasing litigation and insurance pricing creates corporate incentives to phase out persistent toxics.

Working against:

- **Chemical industry resistance.** Major chemical companies resist restrictions through political and legal channels.
- **Substitution chemistry gaps.** Some PFAS applications lack proven alternatives.
- **Regulatory definition complexity.** Defining the scope of substance classes raises legal challenges.
- **Cross-jurisdictional inconsistency.** Restrictions in lead markets can displace toxic chemical manufacturing to less-regulated jurisdictions.

Where to act and what to watch

Priority geographies: EU under ECHA REACH (lead jurisdiction for PFAS); US states with PFAS bans (Maine, Minnesota, California, Washington); manufacturing-export economies needing alignment (China, Japan, Korea, Taiwan); plastic pellet hub jurisdictions (Houston Ship Channel, Antwerp, Singapore).

Key actors: European Chemicals Agency; national environmental and chemical safety agencies; chemical industry (under both pressure and partial cooperation); textile and consumer goods companies; PFAS-affected community advocacy networks (PFAS-REACH coalition, Safer States, GAIA); insurance industry pricing PFAS liability risk.

Key risks: chemical industry political and legal challenge to class-based restrictions; substitute chemicals with similar persistence problems; equity exclusion of SMEs from compliance burden; cross-jurisdictional displacement to less-regulated economies; greenwashing through limited substance bans without addressing the full class.

Top progress indicators

Indicator	Quantification and target	Data source
Status of ECHA PFAS class restriction and equivalent jurisdictional restrictions	Target: ECHA restriction adopted with broad scope by 2027; equivalent restrictions in at least 5 major jurisdictions by 2030	ECHA REACH committee; national chemical regulation agencies; PFAS-REACH coalition tracking
Share of new washing machines globally with mandatory microfibre filtration	Target: at least 50% of new washing machines with filtration by 2030	ISO 4484 textile microfibre testing; national appliance standards; manufacturer reporting
Plastic pellet loss volume and pellet supply chain certification adoption	Target: at least 75% of plastics supply chain under pellet loss certification by 2030	Operation Clean Sweep; EU pellet regulation reporting; industry certification programmes

Textile and fashion circularity

What it is: keeping clothing, footwear and textiles in use for longer — through durable design, reuse and resale — and recovering their fibres at end of life, in place of the make-use-dispose model of fast fashion.

Why it matters and how it could tip

Textile-fibre production has roughly doubled since 2000 to over 110 million tonnes a year, yet globally less than 1% of textiles are recycled into new products; the rest is landfilled, incinerated or exported to countries with little capacity to process it. The EU alone discards around 5.2 million tonnes of clothing and footwear a year (about 12 kg per person). Around two-thirds of fibres are now synthetic, making textiles a leading source of the microfibre pollution addressed in solution area 10.

The tipping mechanism is regulatory, mirroring the Extended Producer Responsibility ratchet already driving packaging and e-waste. The EU's revised Waste Framework Directive (2025) introduces separate collection of textiles and EPR under which producers, including non-EU and e-commerce sellers, must fund collection, sorting and recycling, with fees eco-modulated against the impact of fast and ultra-fast fashion. Three reinforcing loops can then activate: EPR fees reprice durability and recyclability into design upstream; a resale and reuse market already growing faster than the wider apparel sector makes second-hand a default rather than a niche; and, as separate collection guarantees feedstock, fibre-to-fibre recycling scales from negligible volumes toward cost-competitiveness with virgin fibre.

Current state and desired future

Current state: over 110 million tonnes of fibre produced annually and rising; under 1% recycled fibre-to-fibre; EU separate textile collection and EPR beginning implementation from 2025; resale growing but still a small share of the market; fibre-to-fibre recycling largely pre-commercial.

Desired future state (2030): textile EPR with eco-modulated fees operational across the EU and adopted by other major markets; separate collection routine in high-income economies; reuse and resale a mainstream share of consumption; fibre-to-fibre recycling at commercial scale for dominant fibre types, so recycled content competes with virgin on cost.

Drivers and barriers

Reinforcing feedbacks:

- Design-for-circularity loop. Eco-modulated EPR fees flow into design decisions, rewarding durability, mono-materials and recyclability upstream.
- Resale normalisation. As second-hand platforms scale, buying and selling used clothing becomes socially default, lengthening product lifetimes.
- Feedstock–recycling loop. Separate collection creates reliable feedstock, letting fibre-to-fibre recyclers reach the volumes that lower unit costs.
- Peer-regulation ratchet. EU rules set a template that trading partners and other jurisdictions adopt to retain market access.

Working against:

- Ultra-fast fashion volumes. Business models built on ever-rising throughput can outpace circularity gains.
- Blended and contaminated materials. Mixed-fibre garments and trims are hard to recycle, limiting fibre-to-fibre yields.
- Export leakage. Used textiles exported as "reuse" can become unmanaged waste in importing countries.
- Cross-border e-commerce free-riding. Direct-to-consumer sellers outside a jurisdiction can evade EPR obligations.

Where to act and what to watch

Priority geographies: the EU as lead jurisdiction implementing textile EPR and separate collection; the UK and other European markets; major production hubs (Bangladesh, China, India, Vietnam, Türkiye) where design and manufacturing decisions are made; and East African and South Asian import destinations where exported textile waste accumulates.

Key actors: national environment ministries and the European Commission; Producer Responsibility Organisations; fast-fashion and apparel brands; resale and rental platforms; textile sorters and fibre-to-fibre recyclers; garment-manufacturing countries.

Key risks: eco-modulation gamed without genuine design change; "reuse" exports displacing waste to lower-capacity countries; recycling capacity lagging collection mandates and creating stockpiles; informal collection livelihoods displaced without integration.

Top progress indicators

Indicator	Quantification and target	Data source
Share of textiles reused or recycled rather than landfilled, incinerated or exported as waste (global, tracked by region)	Target: 50% of discarded textiles reused or recycled by 2030, in both major consumer and producer economies	Textile Exchange; UNEP; national waste statistics
Textile EPR coverage across major producing *and* consuming economies	Target: eco-modulated textile EPR operational in 15+ major economies spanning production hubs and consumer markets by 2030	OECD EPR Policy Database; UNEP
Fibre-to-fibre recycling rate (global)	Target: at least 10% by 2030 (from under 1% today)	Textile Exchange; Ellen MacArthur Foundation

Across these eleven areas, two patterns recur: regulatory ratchets in lead markets (EU EPR, Right-to-Repair, the PFAS restriction, the UNEP plastics treaty) drive upstream design change; informal sector integration is the operational requirement that determines whether formal systems can scale to dominant market share.

Chapter 5: Fix Our Climate

The ambition of the fifth Earthshot is to fix the world's climate by cutting carbon out of the global economy, halving emissions this decade and reaching net zero, while building resilience for the communities already living with its consequences. . The Emissions Gap Report 2024 found that 2030 emissions must be approximately 22 $GtCO_2e$ lower than current Nationally Determined Contributions to align with 1.5°C pathways.[109] The tipping-point science is most developed in this domain: solar PV has crossed a global tipping point, electric vehicles are crossing in leading markets, and several other transitions are approaching their thresholds.[71,73,93] Ten solution areas are analysed below.

Solution areas

Solution area	Phase	How it Could Tip
Clean electricity and flexible power systems.	Acceleration (renewables now cheapest in most markets).	Cheap renewables plus flexibility (storage, grids, demand response) make clean power self-propelling and cascade through every electrified end use.
Electrified mobility and Avoid-Shift-Improve transport.	Acceleration (EV cascade past its inflection point).	Battery cost curves and modal shift carry EVs to majority sales, and charging/demand feedbacks lock in the transition.
Sustainable cooling and the heat-mitigation nexus.	Emergence (largest mitigation–adaptation integration point).	Efficient, low-GWP cooling plus passive heat mitigation breaks the cooling–emissions doom loop before demand triples.
Methane abatement across fossil fuels, agriculture and waste.	Emergence → Acceleration (detection revolution + Global Methane Pledge).	Satellite detection makes leaks visible and cheap to fix, and benefits of near-term reductions in global warming make abatement the fastest self-justifying action.
Land-based mitigation: halt deforestation, restore ecosystems	Emergence (biophysical self-reinforcement + deforestation regulatory ratchet)	As restored ecosystems become self-sustaining and deforestation regulation bites, the land sink strengthens rather than erodes.
Heat pumps, deep retrofits and building sufficiency	Emergence → Acceleration (heat pumps crossing cost parity in leading markets).	Heat-pump cost parity plus tightening retrofit standards make efficient electrified buildings the default choice.

Solution area	Phase	How it Could Tip
Industrial transformation: net-zero steel, cement and chemicals	Emergence (lead-market / procurement feedbacks forming).	Green-procurement coalitions create guaranteed lead demand, driving green premiums toward zero and tipping heavy industry.
Systemic demand-side tipping: diets, sufficiency and circular materials	Emergence (contingent on supply-side conditions).	Once low-carbon options are affordable, accessible and attractive, norm-shift dynamics in food, fashion and materials become self-reinforcing.
Anticipatory action, adaptation finance and climate-resilient infrastructure	Emergence (consolidated adaptation enabler).	As early action visibly cuts losses and lowers financing costs, adaptation becomes self-propelling.
Durable carbon removal with stringent integrity rules	Emergence (decade-scale tipping case).	Integrity standards plus falling costs and compliance demand build a durable-removal market able to scale to net-zero requirements.

Clean electricity and flexible power systems

What it is: scaling the solar, wind, storage and flexible grids that have already passed their cost tipping point in most markets.

Why it matters and how it could tip

Solar

The current binding constraints are no longer technology or economics in lead markets but grid expansion, permitting reform and the clean energy investment gap in the Global South (Africa receives less than 2% of global clean energy investment despite hosting 60% of the world's best solar resources).[45,49] The electrification cascade extends through all other end uses.[21,74]

Current state and desired future

Current state: solar and wind around 30% of global electricity in 2024; renewables 80%+ of new capacity additions; global energy investment around $3 trillion/year with around $2 trillion going to clean energy; Africa receives less than 2% of global clean energy investment.

Desired future state (2030): renewables at 60%+ of global electricity in line with the International Energy Agency's (IEA) Net Zero Emissions (NZE) scenario; grid expansion at 2–

3× current rate; Global South clean energy investment scaling 3–5× from current levels; permitting reform unblocking deployment in lead markets.

Drivers and barriers

Reinforcing feedbacks:

- **Wright's Law learning curve.** Solar PV costs fell around 90% in the past decade; battery storage costs falling at similar rates.[7]
- **Electrification cascade.** Each electrified end use (transport, heating, industry) raises electricity demand and improves clean electricity economics.[21,74]
- **Lead-market policy ratchets.** EU Net-Zero Industry Act, US IRA, China renewables build-out propagating through trade-policy.[93]
- **Capital cost reduction loop.** As renewable track record builds, investor risk perception falls, lowering cost of capital.[3]

Working against:

- **Grid expansion lag.** Grid infrastructure lags renewable generation deployment in most markets.
- **Permitting bottlenecks.** Permitting cycles of 5–10 years constrain deployment speed in lead markets.
- **Global South capital cost premium.** Clean energy projects in Global South face 2–3× higher cost of capital than in OECD.
- **Fossil fuel political constituencies.** Fossil fuel-dependent economies resist transition pace.[71]

Where to act and what to watch

Priority geographies: China (largest clean energy build-out globally); EU under REPowerEU and Net-Zero Industry Act; US under IRA; India (rapidly scaling solar and wind); Sub-Saharan Africa (largest unmet investment opportunity); Southeast Asia (coal-dependent economies transitioning).

Key actors: national energy ministries and electricity regulators; grid operators (TSOs and DSOs); MDBs financing renewables in Global South; renewables industry; oil and gas majors transitioning (or not); institutional investors and infrastructure funds; mining industry providing critical materials (lithium, cobalt, nickel, rare earths).

Key risks: grid lock-in to centralised models inappropriate for Global South distributed needs; critical materials supply chain bottlenecks; just transition failures generating political backlash; fossil fuel asset stranding generating financial sector instability; capital allocation skewed to lead markets perpetuating Global South investment gap.

Top progress indicators

Indicator	Quantification and target	Data source
Share of global electricity from variable renewables (solar + wind)	Target: 60%+ by 2030 per IEA NZE scenario	IEA Renewables; IRENA; Ember Energy
Annual clean energy investment in Sub-Saharan Africa	Target: $200 billion/year by 2030 (from around $40 billion/year today)	IEA World Energy Investment; CPI Global Landscape; AfDB
Global grid investment ($bn/yr) and grid capacity additions (GW/yr)	Target: grid investment at $600 billion/year by 2030; grid capacity additions doubled from 2020 baseline	IEA Grids; IRENA; national TSO reporting

Electrified mobility and Avoid-Shift-Improve transport

What it is: switching transport to electric vehicles while avoiding unnecessary trips and shifting them to public and active travel.

Why it matters and how it could tip

Global electric car sales exceeded 17 million in 2024 (more than 20% of new car sales); the EV cascade is documented past its inflection point in China, Norway and several European markets.[48,71] Battery costs have fallen roughly 90% since 2010 and are projected to reach parity with conventional vehicles by 2026 in most segments.[14]

The Avoid-Shift-Improve framework recognises that the deepest decarbonisation requires reducing travel demand, shifting to lower-carbon modes (public transport, cycling, walking), and improving the efficiency of remaining vehicle travel.[58] Bus, two- and three-wheeler electrification has the largest near-term air quality co-benefit in the Global South.

Current state and desired future

Current state: around 17 million electric car sales in 2024 (20%+ of new sales); EVs around 40%+ of new sales in China and Norway; electric two- and three-wheelers dominant in some Asian markets; bus electrification accelerating in Latin American and Chinese cities.

Desired future state (2030): EVs at 50%+ of global new car sales per IEA NZE; mature public transport and active travel infrastructure in major cities globally; modal shift documented in lead jurisdictions; remaining ICE vehicles meeting tighter efficiency standards.

Drivers and barriers

Reinforcing feedbacks:

- **Battery learning curve.** Battery costs continue falling around 20% per doubling of manufacturing capacity.[14]
- **EV adoption network effects.** Charging infrastructure expansion makes EVs progressively more convenient.[48]
- **Manufacturer commitment cascade.** Major OEMs (Volvo, Ford, GM) committed to EV-only future, locking in capital allocation.
- **Lead-market regulatory ratchets.** EU 2035 ICE phase-out, UK 2030 ban, China NEV mandate creating de facto global standards.

Working against:

- **Charging infrastructure gap.** Charging networks lag EV deployment in most markets.
- **Grid capacity constraints.** Local grid capacity can constrain EV charging deployment in dense urban areas.
- **Critical materials supply.** Battery materials (lithium, cobalt, nickel, graphite) face supply concentration risks.
- **Equity dimensions.** EV adoption concentrated in higher-income segments; second-hand EV market still nascent.

Where to act and what to watch

Priority geographies: China (largest EV market and producer); EU under 2035 ICE phase-out; US under IRA; Norway (lead jurisdiction); India (electric two- and three-wheelers); Southeast Asia (electric bus and two-wheeler scaling); Latin American cities (bus electrification).

Key actors: national transport ministries; major auto manufacturers (BYD, Tesla, Volkswagen, Toyota, Hyundai, Stellantis); battery manufacturers (CATL, LG Energy Solution, Panasonic); charging infrastructure operators; city transport authorities; public transport operators; critical materials mining and processing industry.

Key risks: critical materials supply concentration risks; grid capacity constraints in dense urban deployment; equity exclusion of lower-income consumers from EV transition; charging infrastructure inadequacy in Global South; modal shift backsliding under suburban infrastructure path dependencies.

Top progress indicators

Indicator	Quantification and target	Data source
Share of global new car sales that are electric	Target: 50%+ by 2030 per IEA NZE	IEA Global EV Outlook; OEM sales reporting

Indicator	Quantification and target	Data source
Public transport ridership and modal share in major cities	Target: documented modal shift toward public transport, cycling and walking in at least 100 major cities by 2030	UITP; ITF; C40 transport metrics
Bus and two-/three-wheeler electrification rates in Global South cities	Target: 50%+ of new bus and two-/three-wheeler sales electric in major Global South cities by 2030	IEA Global EV Outlook; C40; ZEBRA partnership

Sustainable cooling and the heat-mitigation nexus

What it is: meeting rising cooling needs without driving emissions, through efficient equipment, low-warming refrigerants and passive design that keeps buildings and cities cool.

Why it matters and how it could tip

Cooling sits at the largest single mitigation–adaptation integration point. Heat-related mortality is around 489,000 deaths per year globally, projected to rise to approximately 3 million by 2050; cooling demand is projected to triple by 2050.[46,63]

The cooling–emissions doom loop – hotter conditions drive cooling demand, which drives electricity demand, which drives emissions, which drives warming – is measurable and accelerating. Three coupled tipping loops can break it: the Kigali Amendment HFC phasedown, passive–active substitution, and adaptation finance pull through specifying sustainable cooling criteria in procurement.[13,15,116] The Kigali Amendment is the agreement to phase down hydrofluorocarbons (HFCs), the potent warming gases used as refrigerants. Passive–active substitution means meeting comfort needs first through building design, shading and ventilation (passive measures) so that powered air-conditioning (active cooling) does less work. Procurement pull-through means large public and institutional buyers writing efficiency and refrigerant criteria into purchasing rules, using their combined buying power to shift the whole market toward sustainable equipment.

Current state and desired future

Current state: around 489,000 heat-related deaths per year globally; around 2 billion air conditioning units globally; cooling around 10% of global electricity demand; HFC phasedown underway under Kigali Amendment.

Desired future state (2030): Kigali Amendment HFC phasedown on track (80% phasedown by 2047); passive cooling design standard in new urban construction in hot climates; super-efficient air conditioning at 50%+ of new sales in lead markets; cool surfaces and urban heat reduction operational in 200+ cities.

Drivers and barriers

Reinforcing feedbacks:

- **Kigali Amendment ratchet.** HFC phasedown schedule creates regulatory ratchet for low-GWP refrigerants and efficiency improvements.
- **Passive–active substitution.** Passive cooling reduces baseline load by 20–40% to a level renewables can supply cleanly.[15]
- **Health adaptation finance pull.** Adaptation finance specifying sustainable cooling criteria scales the market.[13]
- **Lead-market efficiency standards.** Each new market efficiency standard creates demand for higher-performing equipment.

Working against:

- **Air conditioning demand surge.** AC ownership rising fast in Global South; risk of locking in high-emissions cooling.
- **Refrigerant transition cost.** Low-GWP refrigerants and equipment require capital investment producers resist.
- **Urban heat island compounding.** Built environment heat compounds outdoor temperature, raising cooling load.
- **Equity dimensions.** Around 1 billion people lack access to cooling for health and productivity.

Where to act and what to watch

Priority geographies: South Asia (largest population at heat stress risk: India, Pakistan, Bangladesh); Middle East (Gulf states with highest per-capita cooling); Sub-Saharan African cities under rapid AC uptake; Southeast Asia; rapidly urbanising heat-vulnerable cities globally.

Key actors: UNEP under Kigali Amendment; national environment ministries; AC manufacturers (Daikin, Carrier, LG, Samsung); refrigerant chemical producers; building regulators setting efficiency and passive design standards; city governments implementing heat action plans; health and adaptation finance institutions.

Key risks: AC demand surge locking in high-emissions cooling; refrigerant industry transition cost-pass-through to consumers; equity exclusion of those without cooling access from health protection; cool surface tokenism without addressing fundamental heat exposure; insufficient adaptation finance for heat-vulnerable populations.

Top progress indicators

Indicator	Quantification and target	Data source
HFC consumption phasedown against Kigali Amendment baseline	Target: 35% phasedown by 2030 (full Kigali schedule)	UNEP Ozone Secretariat; national HFC reporting
Sales-weighted average efficiency of new AC equipment in major markets	Target: doubling of efficiency from 2020 baseline by 2030	IEA Cooling; appliance efficiency standards databases; UNEP U4E
Number of cities with operational heat action plans and cool surface programmes	Target: 200 cities with operational integrated heat-mitigation programmes by 2030	C40; Cool Coalition; WHO heat action plan database

Methane abatement across fossil fuels, agriculture and waste

What it is: cutting methane — the fastest lever on near-term warming — from fossil fuels, agriculture and waste.

Why it matters and how it could tip

Methane is responsible for approximately 30% of current warming above pre-industrial levels; its short atmospheric lifetime (around 12 years) makes methane reduction the fastest available climate lever for limiting peak warming.[114] Up to 45% reductions are technically and economically feasible this decade, preventing approximately 0.3°C of warming by 2045.

The detection technology revolution (MethaneSAT, GHGSat, Carbon Mapper, Sentinel-5P TROPOMI) is making methane emissions from individual facilities visible globally, removing the information asymmetry that allowed non-compliance with voluntary standards.

Current state and desired future

Current state: global methane emissions around 580 Mt/year; oil and gas sector emissions around 80 Mt/year (around half technically abatable at low cost); agriculture around 150 Mt/year (largest source, hardest to abate); waste around 70 Mt/year. Global Methane Pledge signed by 150+ countries; EU Methane Regulation operational since 2024.

Desired future state (2030): 30% global methane reduction from 2020 baseline (Global Methane Pledge target); oil and gas sector emissions reduced 75%+; satellite monitoring of all major fossil fuel facilities operational; agricultural methane interventions scaling in lead jurisdictions.

Drivers and barriers

Reinforcing feedbacks:

- **Detection technology revolution.** Satellite-based methane monitoring removes information asymmetry that allowed non-compliance.
- **Global Methane Pledge ratchet.** 150+ country commitment creates international peer pressure for national action.
- **EU Methane Regulation.** Import standards on fossil fuel methane intensity create extraterritorial effect.
- **Low-cost abatement economics.** Around half of oil and gas methane abatement has negative cost (gas recovered exceeds abatement cost).[114]

Working against:

- **Agricultural methane complexity.** Enteric fermentation and rice methane harder to abate than fossil sources.
- **State-owned oil and gas.** Many major emitters are state-owned with limited political pressure for transparency.
- **Verification gap.** Bottom-up emissions inventories systematically underestimate actual emissions by 50–100%.
- **Methane finance gap.** Methane-specific finance limited relative to potential.

Where to act and what to watch

Priority geographies: major oil and gas producers (US, Russia, Saudi Arabia, Iran, China, Iraq, UAE, Kuwait); agricultural methane priorities (India, Brazil, US, China, Argentina); waste sector priorities (India, China, Indonesia, Nigeria); coal mine methane (China, India, Australia, Russia, US).

Key actors: national environment and energy ministries; oil and gas companies and their methane partnerships (Oil and Gas Methane Partnership 2.0); UNEP International Methane Emissions Observatory; Climate and Clean Air Coalition; satellite monitoring providers (MethaneSAT/EDF, GHGSat, Carbon Mapper); agricultural research institutions; waste sector operators.

Key risks: state-owned oil and gas company evasion; bottom-up inventory underestimation persistence; agricultural methane interventions creating perverse incentives (feedlot intensification displacing extensive grazing); methane offset credits with weak integrity; political reversal of Global Methane Pledge commitments.

Top progress indicators

Indicator	Quantification and target	Data source
Global methane emissions reduction from 2020 baseline	Target: 30% reduction by 2030 (Global Methane Pledge)	UNEP IMEO; national GHG inventories; satellite monitoring composites
Oil and gas sector methane intensity (kg CH_4/boe)	Target: at least 75% reduction in oil and gas sector methane intensity by 2030	OGMP 2.0; IEA Methane Tracker; satellite-validated facility emissions
Share of major fossil fuel facilities under satellite-based methane monitoring	Target: 100% of major facilities monitored by 2027	MethaneSAT; GHGSat; Carbon Mapper; UNEP IMEO

Land-based mitigation: halt deforestation, restore ecosystems

What it is: halting deforestation and restoring natural ecosystems and farmland soils to keep and draw down carbon.

Why it matters and how it could tip

Protection and restoration of natural ecosystems has total IPCC-assessed technical potential of 7.3 $GtCO_2e$ per year (range 3.9–13.1) plus 4.1 $GtCO_2e$ per year from agriculture, with around 30–50% available at costs below $20/$tCO_2e$.[53,58]

The solution area bridges directly to Chapter 1: every hectare of forest protected or restored is both a biodiversity asset and a carbon stock. The three coupled tipping mechanisms (commodity supply chain governance, community land tenure, carbon and biodiversity finance) are analysed in depth in Chapter 1 and applied here with climate framing.[66,82] The distinction from the Nature Earthshot chapter is the assessment criterion, not the activity. The Nature chapter focuses on biodiversity and ecosystem-integrity gains (its restoration areas, including peatland and wetland restoration in SA4), whereas this area focuses on mitigation tonnage and the deforestation-free-commodity regulatory ratchet — the same activities read against two different tipping tests.

Current state and desired future

Current state: tropical deforestation around 10 million hectares/year; land use change emissions around 4 $GtCO_2e$/year (around 8% of global emissions); restoration commitments under Bonn Challenge total around 230 million ha; carbon credit prices for high-integrity nature-based solutions around $10–40/$tCO_2e$.

Desired future state (2030): tropical deforestation halved from current; restoration delivering net-positive ecosystem trajectory globally; high-integrity nature-based carbon credit market at scale; integration with food system transformation reducing agricultural land-use pressure.

Drivers and barriers

Reinforcing feedbacks:

- **Commodity supply chain governance.** EUDR and equivalents close demand-side leakage (analysed in Chapter 1 SA 1).[82]
- **Restoration self-reinforcement.** Restored ecosystems generate biophysical feedbacks supporting further recovery (Chapter 1 SAs 3–4).
- **Carbon and biodiversity finance scaling.** Stacked finance improves restoration economics.[62]
- **Community tenure recognition.** Indigenous and community-managed lands deliver superior outcomes (Chapter 1 SA 7).[66]

Working against:

- **Carbon credit integrity challenges.** Variable credit quality undermines finance signal; high-integrity supply limited.
- **Permanence risk.** Climate-driven mortality and reversal undermine long-term storage.
- **Food system pressure.** Agricultural demand growth competes with restoration land.
- **MRV capacity gaps.** Monitoring, reporting and verification capacity inadequate in many priority jurisdictions.

Where to act and what to watch

Priority geographies: Amazon, Congo, Southeast Asian rainforests (largest carbon stocks at risk); African restoration belt (AFR100 priority landscapes); tropical peatland nations; community-managed lands globally (Chapter 1 SA 7 priorities).

Key actors: national forest and environment ministries; carbon market actors (Verra, Gold Standard, ICVCM); restoration finance institutions; commodity buyers and financiers (Chapter 1 SA 1); Indigenous federations; restoration NGOs; satellite monitoring providers (Global Forest Watch, PRODES).

Key risks: carbon credit integrity failures undermining finance signal; permanence failures through climate-driven mortality; equity capture by large landowners through PES; greenwashing through low-integrity offsets enabling continued fossil fuel emissions; moral hazard of CDR through nature offsets delaying mitigation.

Top progress indicators

Indicator	Quantification and target	Data source
Land-use change emissions	Target: at least 50% reduction in tropical deforestation by 2030 from current 10 Mha/yr	FAO FRA; Global Forest Watch; PRODES; UNFCCC LULUCF inventories
Volume of high-integrity nature-based carbon credit issuance	Target: 500 $MtCO_2e$/yr by 2030 from ICVCM-aligned projects	Verra; Gold Standard; ICVCM Core Carbon Principles; Berkeley Carbon Trading Project
Cross-cutting indicators on commodity supply (Chapter 1 SA 1) and community tenure (Chapter 1 SA 7) apply directly	See Chapter 1 indicators for detail	Cross-reference Chapter 1

Heat pumps, deep retrofits and building sufficiency

What it is: electrifying heating with heat pumps and cutting building energy demand through deep retrofits and smarter use of space.

Why it matters and how it could tip

Buildings account for around 21% of global final energy and 8–9 $GtCO_2$ emissions annually.[54] Heat pumps are 3–5 times more efficient than fossil fuel boilers at producing useful heat.[43]

Heat pump sales have grown rapidly (around 10 million units globally in 2022); the learning curve trajectory mirrors solar PV and lithium-ion batteries. The decisive constraints are split-incentives between landlords and tenants, electricity-to-gas price ratios, workforce training capacity, and building codes.

Current state and desired future

Current state: around 10 million heat pump sales/year globally; heat pumps installed in around 10% of European homes; deep retrofits at around 1–2% of building stock per year in lead markets; building emissions trajectory still rising in many economies.

Desired future state (2030): heat pump sales at 30–50% of new heating equipment in lead markets; deep retrofit rate accelerated to 3–5% of stock per year; new construction at net-zero embodied and operational carbon in lead jurisdictions; building electrification standard in new construction codes.

Drivers and barriers

Reinforcing feedbacks:

- **Heat pump learning curve.** Costs falling as manufacturing scales; performance improving.[43]
- **Lead-market regulatory ratchets.** EU Energy Performance of Buildings Directive, US IRA, equivalents driving heat pump deployment.
- **Retrofit financing innovation.** On-bill repayment, PACE financing, energy service models reducing upfront cost barriers.
- **Climate-driven cooling demand.** Heat pumps deliver both heating and cooling, improving economics.

Working against:

- **Split-incentive problem.** Landlord-tenant separation reduces incentive to invest in retrofits.
- **Electricity-gas price ratio.** Where electricity is 3–4× gas price, heat pump operating cost advantage erodes.
- **Workforce training gap.** Trained heat pump installers limited relative to deployment demand.
- **Building code lag.** Many jurisdictions still permit fossil heating in new construction.

Where to act and what to watch

Priority geographies: EU under EPBD revision; UK and Northern European heat pump leaders; US under IRA; China (largest heat pump market by units); Japan and Korea (mature markets); rapidly growing cooling-demand markets (India, Southeast Asia).

Key actors: national building regulators and energy ministries; heat pump manufacturers (Daikin, Mitsubishi, Bosch, Carrier); building developers and contractors; tenant and landlord organisations; energy efficiency finance institutions; trades training organisations; electricity utilities adapting to electrified demand.

Key risks: split-incentive failures limiting retrofit deployment; electricity-gas price ratios undermining heat pump economics; workforce constraints throttling deployment; tokenistic building codes without enforcement; equity exclusion of low-income tenants from retrofit benefits; embodied carbon in retrofit materials counted out of emissions accounting.

Top progress indicators

Indicator	Quantification and target	Data source
Heat pump share of new heating equipment sales in lead markets	Target: 50%+ in lead markets by 2030	IEA Heat Pumps; EHPA; national appliance sales data

Indicator	Quantification and target	Data source
Deep retrofit rate (% of building stock per year)	Target: 3–5% per year in lead jurisdictions by 2030	EU EPBD reporting; national building agency data; BPIE
Share of new construction in lead jurisdictions meeting net-zero operational carbon standards	Target: 100% in lead jurisdictions by 2030	World GBC; national building regulation reporting; LETI

Industrial transformation: net-zero steel, cement and chemicals

What it is: making heavy industry — steel, cement and chemicals — near-zero-carbon through cleaner production and using less material.

Why it matters and how it could tip

Often termed industrial decarbonisation, this solution area is framed more broadly because the deepest cuts come not only from cleaner production but from using less material — efficiency and circular substitution. Industry was responsible for around 9.2 $GtCO_2$ of direct emissions in 2022.[41,56] Hydrogen direct reduction iron (H2-DRI), electric arc furnaces, carbon capture for cement and electrified chemical processes are technically feasible but not yet cost-competitive at scale.

The primary tipping mechanism is green demand aggregation: buyer alliances (First Movers Coalition, SteelZero, ConcreteZero) and public procurement commitments (Buy Clean) create early markets at premium prices, enabling first-of-a-kind plants to be built. The EU Carbon Border Adjustment Mechanism prevents carbon leakage.

Current state and desired future

Current state: industrial emissions still rising in absolute terms; first commercial-scale green steel and cement plants under construction (HYBRIT, H2 Green Steel); First Movers Coalition has aggregated around $15 billion in green commodity commitments; EU CBAM operational from 2026.

Desired future state (2030): at least 30% of new steel and cement capacity using low-emission processes in lead markets; materials efficiency reducing demand by 10–20%; circular materials substituting around 30% of primary materials in selected applications; CBAM and equivalents creating global level playing field.

Drivers and barriers

Reinforcing feedbacks:

- **Green demand aggregation.** Buyer alliances create premium markets for first-of-a-kind plants.
- **Public procurement ratchet.** Buy Clean and equivalents create sustained demand for low-emission materials.
- **EU CBAM.** Prevents carbon leakage and creates extraterritorial pressure for industrial decarbonisation.
- **Hydrogen scaling.** As hydrogen production scales, costs fall, improving H2-DRI economics.

Working against:

- **Green premium.** Low-emission materials currently 20–50% cost premium; needs sustained buyer demand.
- **Capital intensity.** First-of-a-kind plants require multi-billion-dollar capital commitments.
- **Carbon leakage.** Without CBAM-equivalents in major markets, production can shift to less-regulated jurisdictions.
- **Materials efficiency under-investment.** Demand reduction often delivered cheapest but receives least policy attention.

Where to act and what to watch

Priority geographies: EU under CBAM and Net-Zero Industry Act; US under IRA; China (largest steel and cement producer); India (rapidly growing industrial economy); Japan and Korea (mature industrial economies); Middle East (low-cost green hydrogen potential).

Key actors: national industrial and energy ministries; steel, cement and chemical producers; buyer alliances (First Movers Coalition, SteelZero, ConcreteZero); public procurement authorities; hydrogen and renewable energy developers; CBAM administrators (EU Commission, equivalents); industrial trade associations.

Key risks: green premium under-funding limiting first-of-a-kind deployment; carbon leakage to less-regulated jurisdictions; hydrogen supply bottlenecks; equity exclusion of producer-country workers; greenwashing through low-rigour green commodity certifications; political reversal of CBAM under trade-policy pressure.

Top progress indicators

Indicator	Quantification and target	Data source
Share of new steel and cement capacity using low-emission processes in lead markets	Target: at least 30% by 2030	World Steel Association; Global Cement and Concrete Association; IEA

Indicator	Quantification and target	Data source
Volume of green commodity commitments through buyer alliances ($bn)	Target: $100B of cumulative commitments by 2030	First Movers Coalition; SteelZero; ConcreteZero; CDP
EU CBAM operational and equivalent measures in major importing economies	Target: at least 5 major economies with CBAM-equivalent measures by 2030	EU Commission; national trade ministries; carbon market platforms

Systemic Demand-side tipping: diets, sufficiency and circular materials

What it is: the shifts in diets, consumption and material use that amplify supply-side tipping points and lower the threshold for them.

Why it matters and how it could tip

This area is best read as a demand-side enabling-and-amplifying layer: it is based on the same tipping criteria as the physical-system solution areas, but it works largely by amplifying supply-side tips and lowering the threshold for them, rather than as an independent driver. Demand-side mitigation represents the largest total mitigation potential in the IPCC assessment but the least addressed in current policy: combined potential exceeds 23 $GtCO_2e$ per year by 2050 from food, transport, buildings and industrial demand reductions.[58] "Materials" means physical goods in the broadest sense, including the steel, cement, plastics, aluminium and textiles embodied in buildings, vehicles, products and packaging. "Sufficiency and circular" means meeting needs while using less materials and keeping them in use for longer through reuse, repair, sharing and recycling.

One research challenge is what extent that demand-side change tips on its own rather than following supply-side progress. The transition to electric vehicles was arguably largely supply-led, with falling battery costs and improving performance pulling demand. The evidence for demand-led tipping is real but narrower: examples including dietary shifts and reducing flying show social norm change reaching critical mass in a range from 10-43% adoption (centred around 25%), though often acting in addition to supply-side enabling conditions rather than in isolation.

Demand-side tipping operates through norm diffusion and choice architecture: when structural enabling conditions (affordable plant-rich food, safe cycling infrastructure, quality public transport, shared mobility) make sustainable choices the path of least resistance, social proof mechanisms can produce rapid adoption above the 10–43% critical mass threshold.[11,31,66]

Current state and desired future

Current state: dietary shift toward plant-rich foods documented in lead markets (UK plant-based around 7% of food spend); modal shift in select cities (Paris, Bogotá, Copenhagen); circular materials substitution at 5–10% in selected applications; demand-side policy remains a small share of mitigation portfolios.

Desired future state (2030): plant-rich dietary patterns standard in lead urban markets; modal shift documented in at least 100 major cities; circular materials substitution at 25%+ in selected applications; demand-side measures embedded in NDC frameworks.

Drivers and barriers

Reinforcing feedbacks:

- **Norm diffusion through social proof.** Above the 10–43% adoption threshold, social proof mechanisms drive rapid expansion.[11]
- **Structural enabling conditions.** Affordable plant-rich food, safe cycling infrastructure, quality public transport make sustainable choices easier.
- **Co-benefit framing.** Health, financial, and environmental benefits stack, accelerating adoption.[31]
- **Choice architecture in retail and procurement.** Default options and visible defaults drive measurable adoption shift.

Working against:

- **Cultural inertia.** Dietary and mobility patterns are culturally embedded and slow to change.
- **Industry resistance.** Meat, dairy and auto industries resist demand-shift policies.
- **Equity dimensions.** Healthy plant-rich food and active mobility infrastructure unevenly distributed.
- **Policy under-attention.** Demand-side measures rarely receive policy attention proportionate to their mitigation potential.

Where to act and what to watch

Priority geographies: high-income consumption-heavy economies (EU, US, UK, Canada, Australia); urbanising middle-income economies (China, India, Brazil, Mexico, Indonesia); city-level demand transformation programmes globally (C40 priority cities); food and mobility transformation lead cities (Copenhagen, Paris, Bogotá, Singapore, Tokyo).

Key actors: city governments and public procurement authorities (school meals, public sector catering, fleet); food retailers and food service; transport authorities and urban planners; manufacturers of plant-rich products; health and consumer protection agencies; behavioural science research networks; civil society advocacy organisations.

Key risks: industry political resistance blocking enabling policy; equity exclusion if sustainable consumption framed as individual virtue rather than structural enabling; greenwashing through symbolic gestures without systemic change; rebound effects offsetting demand reductions; technological-only framing displacing demand-side attention.

Top progress indicators

Indicator	Quantification and target	Data source
Plant-rich food share of food spend in lead consumption markets	Target: 25%+ in lead markets by 2030	Eurostat; FAOStat; retailer ESG reporting; Good Food Institute
Modal share of cycling, walking and public transport in major cities	Target: 60%+ modal share in at least 100 major cities by 2030	C40; UITP; ITF; city transport authority reporting
Share of materials demand met through circular sources (reuse, refurbish, recycled content)	Target: 25%+ in selected high-impact applications by 2030	Ellen MacArthur Foundation Circulytics; Circle Economy; sector-specific tracking

Anticipatory action, adaptation finance and climate-resilient infrastructure

What it is: replacing reactive, post-disaster spending with pre-agreed finance and resilient infrastructure that act on a forecast, before impact.

Why it matters and how it could tip

The prevailing norm in climate adaption finance is reactive: funds are mobilised after a flood, drought or storm has already done its damage. Anticipatory action is proactive: pre-agreed funds are released automatically when a credible forecast crosses an agreed trigger, enabling authorities and agencies to act in a window before impact. This reduces mortality and damage by 30–60% compared with post-event response in operational programmes.[32,50,76] Adaptation finance is approximately $50 billion per year against an estimated need of $300–500 billion by 2030.[108]

Climate-resilient infrastructure standards outline the structural requirements needed to withstand extreme weather events. Stricter standard such as the USA's ASCE 7 and the EU's Eurocodes can become globally implemented because multinational firms find it cheaper and easier to build to one standard rather than have multiple national/regional standards. This is nicknamed 'The Brussels Effect. A similar mechanism occurs in the way the insurance industry prices climate risk.[51,72,98,103] The three loops – anticipatory action, adaptation finance, and climate-resilient infrastructure, can engage together across all Earthshots.

Current state and desired future

Current state: anticipatory action operational in around 40 country programmes; adaptation finance around $50 billion/year against estimated need of $300–500 billion/year; climate-resilient infrastructure standards updates in EU, US and select major economies.

Desired future state (2030): anticipatory action standard in humanitarian and development programming, replicating, for example, the forecast-based financing that releases cash to households in Bangladesh ahead of monsoon flooding; adaptation finance scaled to $150–300 billion/year; climate-resilient infrastructure standards adopted in all G20; insurance industry climate risk pricing operational across major markets.

Drivers and barriers

Reinforcing feedbacks:

- **Anticipatory action cascade.** Each successful programme builds operational capacity and political support for the next.[32,50]
- **Adaptation finance scaling.** Track-record investor confidence loop applies to adaptation as to other climate finance categories.[108]
- **Climate-resilient standards ratchet.** Brussels Effect propagates standards through trade-policy.[103]
- **Insurance industry repricing.** Climate risk pricing creates commercial demand for adaptation investment.[72,98]

Working against:

- **Adaptation finance political competition.** Adaptation finance competes with mitigation finance for limited concessional capital.
- **Standards adoption lag.** Climate-resilient infrastructure standards adoption in Global South lags behind need.
- **Insurance coverage gaps.** Around 60% of climate disaster losses globally are uninsured.
- **Maladaptation risk.** Poorly designed adaptation can lock in vulnerability or displace risk to others.

Where to act and what to watch

Priority geographies: climate-vulnerable LDCs and SIDS; major Global South economies with significant climate exposure (India, Indonesia, Bangladesh, Pakistan, Egypt, Nigeria); EU and US under climate-resilient infrastructure standards updates; insurance industry hubs (Munich, London, Zurich, Hartford, Singapore).

Key actors: humanitarian organisations (IFRC, FAO, OCHA, WFP); national disaster management agencies; adaptation finance institutions (Adaptation Fund, GCF adaptation window, GEF LDCF and SCCF); reinsurance industry; infrastructure standards bodies (ASCE, ISO, CEN); climate risk modelling firms; adaptation NGOs.

Key risks: adaptation finance under-scaling against accelerating climate impacts; maladaptation through standardised approaches inappropriate to local context; insurance industry coverage gaps in Global South; equity exclusion of most vulnerable populations from adaptation investment; greenwashing through climate-resilient labelling without substance.

Top progress indicators

Indicator	Quantification and target	Data source
Annual adaptation finance flow ($bn/yr)	Target: $150–300 billion/year by 2030	UNEP Adaptation Gap Report; CPI Global Landscape; OECD DAC; MDB Joint Reports
Number of countries with operational anticipatory action programmes covering at least 50% of vulnerable population	Target: 80 countries by 2030 (from current around 40 with operational programmes)	IFRC; OCHA; FAO; Anticipation Hub
Climate-resilient infrastructure standards adoption in G20	Target: full G20 coverage by 2030	UNDRR; ASCE; national infrastructure standards bodies

Durable carbon removal with stringent integrity rules

What it is: scaling long-lasting carbon removal, under strict integrity rules, to neutralise the residual emissions that cannot be cut.

Why it matters and how it could tip

Carbon dioxide removal is needed in virtually all 1.5°C pathways to neutralise residual emissions from hard-to-abate sectors, but the IPCC is explicit that CDR cannot substitute for immediate, deep emissions reductions.[55] The IEA Net Zero scenario includes around 0.98 $GtCO_2$/yr of DAC removal by 2050, scaling from approximately 0.01 $MtCO_2$/yr today – a factor of around 100,000 increase in 25 years.[42,45]

The priority is supporting innovations that demonstrate genuine permanence and additionality, operate within governance frameworks preventing the moral hazard of CDR being used to delay mitigation, and avoid land, water and energy competition with other solutions.

Current state and desired future

Current state: DAC at around 0.01 $MtCO_2$/yr operational; enhanced weathering, BECCS, ocean alkalinity at pilot scale; Frontier coalition has committed around $1 billion to durable carbon removal procurement; ICVCM Core Carbon Principles operational for credit integrity.

Desired future state (2030): durable CDR at 30–70 $MtCO_2$/yr operational (per IEA NZE); ICVCM and equivalent integrity frameworks operational across the credit market; CDR governance frameworks preventing moral hazard substitution for mitigation; technology costs falling through learning curves.

Drivers and barriers

Reinforcing feedbacks:

- **Procurement-led pull.** Frontier and equivalent coalitions create demand for first-of-a-kind durable removal capacity.
- **Technology learning curves.** DAC and other technologies follow learning curves as deployment scales.[42]
- **Integrity frameworks ratchet.** ICVCM Core Carbon Principles raise credit quality floor.[55]
- **Net-zero corporate commitments.** Net-zero commitments drive demand for high-integrity removal credits.

Working against:

- **Moral hazard risk.** CDR can be invoked to justify delayed mitigation.
- **Cost.** DAC currently at \$400–1,000/tCO_2; learning curve needed to bring costs to \$100–200/tCO_2 by 2030s.
- **Land, water and energy competition.** Some CDR pathways (BECCS, enhanced weathering) have substantial resource requirements.
- **Permanence verification.** Long-term storage verification capacity limited.

Where to act and what to watch

Priority geographies: DAC operational sites (Iceland, US, Norway); BECCS lead jurisdictions (Sweden, UK); enhanced weathering pilots (US, Brazil); ocean alkalinity pilots; Frontier and equivalent procurement coalition geographies.

Key actors: durable CDR companies (Climeworks, Carbon Engineering, CarbonCapture, Heirloom, Lithos, Vesta); Frontier procurement coalition members (Stripe, Alphabet, Meta, Shopify, McKinsey); ICVCM and CDR integrity standards bodies; national climate and energy ministries setting CDR procurement frameworks; CCS infrastructure operators.

Key risks: moral hazard substitution of CDR for mitigation; cost curve disappointment leaving CDR at insufficient scale; resource competition with food, biodiversity and other land uses; integrity failures undermining market trust; greenwashing through low-integrity nature offsets framed as durable removal.

Top progress indicators

Indicator	Quantification and target	Data source
Operational durable CDR capacity globally	Target: 30–70 $MtCO_2$/yr by 2030 per IEA NZE	IEA DAC tracker; CDR.fyi; ICVCM operational tracking
Cost of durable CDR ($\$/tCO_2$) by technology pathway	Target: DAC below $\$200/tCO_2$ by 2030	IEA; CDR.fyi; National Academies CDR tracking
Share of durable CDR credits compliant with ICVCM Core Carbon Principles or equivalent integrity frameworks	Target: at least 95% of durable CDR credits ICVCM-compliant by 2030	ICVCM Core Carbon Principles; CDR.fyi credit ratings; third-party rating agencies (Sylvera, BeZero, Renoster)

Across these ten areas, five patterns recur: the clean electricity cascade is the master mechanism; phase-matched intervention is decisive; the just transition is a multiplier on durability rather than a constraint on speed; the Global South investment gap is the binding global constraint; and the moral hazard problem requires that CDR be governed as a complement to deep mitigation, not a substitute.

Synthesis: the five Earthshots as one system

The preceding five chapters treat each Earthshot in turn, analysing tipping dynamics and identifying where to act. This chapter steps back from the individual Earthshots and asks what surfaces when the chapters are considered together. The answer is that the five Earthshots are not five parallel programmes of work but a single system whose components are coupled at several distinct levels – through shared infrastructure, shared governance mechanisms, shared finance instruments, and shared risk patterns. Treating them as one system rather than five separate problems changes what counts as a high-leverage intervention.

Eight patterns emerge from the cross-chapter reading. The first three are structural mechanisms that operate across multiple Earthshots: the clean electricity cascade, the enablers of governance, finance, and monitoring, and mitigation–adaptation integration. The next three are operational principles that recur in different forms in different chapters: phase-matched intervention, the just transition as multiplier rather than constraint, and the role of coalitions and the Brussels Effect. The final two are persistent risks that The Earthshot Prize must guard against regardless of which solution area a nomination falls in: moral hazard, false circularity and greenwashing, and the Global South investment imperative.

1. The clean electricity cascade as the master mechanism

The single most important cross-cutting finding from the five chapters is that clean electricity is the enabling cascade for transitions across most other Earthshot domains. The mechanism is well established in the tipping-point literature: as renewable electricity becomes cheaper through learning-curve dynamics, it improves the economics of every electrified end use, which expands demand for clean electricity, which drives further deployment, which drives further cost reduction.[21,74] The cascade does not stop at the climate Earthshot. It extends through air quality (cleaner electricity means cleaner power-sector emissions and cleaner electrified transport, cooking and heating), through nature (the reduced land footprint of cheap energy reduces pressure on forests for biomass and on freshwater for hydropower extraction), through waste (the energy intensity of recycling and circular processes falls as electricity costs fall) and through oceans (electrified shipping and reduced fossil pollution at sea both depend on cheap clean electricity).

What this means in practice is that the highest-leverage clean electricity solutions are not simply those that add another solar farm or wind project in a market where renewables are already tipping. They are those that either accelerate the cascade where it is currently bottlenecked or extend it to populations and sectors it has not yet reached. Three bottlenecks recur across the chapters. First, grid expansion and permitting reform are now the binding constraint on renewable deployment in lead markets, with the IEA Net Zero Emissions scenario requiring grid expansion of roughly two-thirds of today's size by 2030 to enable the renewable build-out the climate trajectory requires.[45] Second, the clean energy investment gap in the Global South – Africa receives less than 2% of global clean energy investment despite hosting 60% of the world's best solar resources – means that even where the cascade is operating in China, Europe and North America, it is not yet operating globally.[49,109] Third, the electrification of hard-to-abate sectors (heavy freight, industrial process heat, long-duration heat for steel and chemicals) lags behind the electrification of cars and residential heating, with green hydrogen and electric process heat at first-of-a-kind commercial stage rather than at scale.[56]

Modelling by Nijsse and colleagues shows that coordinated policy mixes – mandates applied simultaneously across power, transport and heating – can bring forward tipping points in these sectors by two to eight years and significantly increase the likelihood of cross-sector cascades.[74] The mechanism is the same as in any tipping cascade: each successful tipping event lowers the activation threshold for the next, so the order of intervention matters and the simultaneity of intervention matters more. For The Earthshot Prize, the implication runs across both selection and support. In selection, it means recognising that solutions enabling cross-sector cascades – a single solution that simultaneously decarbonises electricity and depollutes urban air, or a single financing mechanism that closes the Global South investment gap across electricity, transport and cooling – are inherently more transformative than those that optimise within one sector. In support, it means the Prize can actively accelerate that potential once finalists are selected — brokering their connections with other solutionists, policymakers and markets in the leverage areas where cascades are most likely. The Prize could accelerate this cross-sector potential by supporting finalists' connections with solutionists, policymakers, and markets in high potential areas.

2. Enablers: governance, finance, and monitoring

A pattern that surfaces in every chapter is the distinction between direct intervention solutions and cross-cutting enablers. Direct interventions reduce a specific emission, restore a specific ecosystem, replace a specific polluting product. Enablers are the architectures that make direct interventions possible at scale. The pattern is most explicit in three solution areas analysed in the report: anticipatory action, adaptation finance and climate-resilient infrastructure in Chapter 5; air quality governance, monitoring and social tipping in Chapter 2; and climate-resilient health systems in Chapter 2. In each case the chapter explicitly identifies the solution as an operating system or amplifier on direct interventions rather than as a direct intervention. But the pattern is broader. Ocean finance in Chapter 3 plays the same role for marine conservation and restoration as adaptation finance plays for climate adaptation. Extended Producer Responsibility schemes in Chapter 4 play the same role for circularity as building codes play for industrial transformation. Land tenure and Indigenous rights in Chapter 1 are the foundational enablers for almost every nature solution area.

Three enablers cut across the chapters. Governance (Indigenous rights and tenure security, building codes, standards bodies, regulatory ratchets) determine what is permitted, what is required and what is enforceable. Finance (blended finance, blue bonds, adaptation bonds, the track-record investor confidence loop) determine what gets funded at what scale, on what risk-adjusted terms, and, through perverse subsidy and tax policy, what the harmful incumbent is paid to keep doing. Monitoring (satellite-based deforestation tracking, MethaneSAT, continuous emissions monitoring, low-cost air quality sensors, fisheries vessel monitoring) determines what is visible, what is attributable and what is accountable. The three enablers are not independent. Governance without monitoring is unenforceable.

Finance without governance is misallocated. Monitoring without governance produces data without consequences. When the three engage together they constitute the platform on which direct intervention solutions can scale; clustering finalists and encouraging collaboration between them is a direct opportunity for Earthshot to scale interventions by collectively addressing governance, finance, and monitoring needs.

The track-record investor confidence loop appears in four chapters and is worth naming explicitly because it is the dominant mechanism by which finance enablers tip. The loop works as follows: each successful financial instrument (a blue bond in the Seychelles, an adaptation bond in Barbados, a green bond for circular construction, a health adaptation finance product through the Green Climate Fund) generates outcome data; outcome data lowers perceived risk for subsequent issuances; rating agencies progressively rate the instrument class; investor due-diligence costs decline as track record accumulates; the addressable capital pool grows; deal flow increases; the next instrument issues on better terms. The loop tips when the instrument class becomes a standard rather than an innovation, and once tipped it scales rapidly. The same mechanism is operating for ocean finance (Chapter 3), circular construction finance (Chapter 4), adaptation finance broadly (Chapter 5) and health adaptation finance (Chapter 2). Earthshot nominations that scale these instrument classes – not by inventing new ones but by accelerating the track-record loop on existing ones – have particularly high leverage, as would the selection of complementary finalists and provision of support to collectively accelerate the track-record loop.

The finance enabler has a second face that the track-record loop does not capture: the redirection of finance that currently works against tipping. The most comprehensive assessment of the biodiversity financing gap finds that harmful agricultural, forestry and fisheries subsidies (estimated at $274-542 billion per year) are two to four times larger than all spending on biodiversity conservation[137]. UNEP"s broader accounting puts nature-negative flows at around $7.3 trillion (two-thirds of which comes from private capital) against only $220 billion for nature-based solutions (90% of which comes from public money)[114]. In tipping point terms, harmful subsidies raise the threshold that all solution areas need to cross, because the harmful incumbent is being paid to persist. This is why subsidy reform appears in this report as an enabler in multiple solution areas – agricultural subsidy reform in Chapter 1, the WTO fisheries subsidies agreement in Chapter 3, fossil fuel subsidy phase-out in Chapter 5 – and why the Kunming-Montreal Target 18 agreement (which commits parties to reducing harmful incentives by at least $500 billion per year by 2030 is among the most consequential commitments in support of the Earthshots. Reform is a political challenge beyond the gift of the Earthshot Prize, but the Prize can help by demonstrating that redirected money can produced better outcomes, and better monitoring can make harmful flows visible and attributable. Monitoring enablers have their own distinctive tipping dynamic: the democratisation of monitoring through cost reduction. The trajectory of low-cost air quality sensors documented in Chapter 3 is structurally identical to the trajectory of solar PV documented in Chapter 2: order-of-magnitude cost reductions over a decade, combined with quality improvements through standardised calibration protocols, bringing the technology from expensive specialist equipment to a tool available to community groups, schools and individual researchers. The same democratisation is occurring for satellite-based methane detection (MethaneSAT, Carbon Mapper, GHGSat), satellite-based deforestation tracking (Global Forest Watch, PRODES), and satellite-based fisheries monitoring (Global Fishing Watch). Each democratisation extends accountability capacity to communities and contexts previously without it, and each is creating the information cascade documented in China's 2013–2020 $PM_{2.5}$ reductions.[37] Clustering monitoring finalists across Earthshots represents a high-leverage opportunity, accelerating the democratisation of monitoring services through combined impact.

3. Mitigation–adaptation integration as a distinct solution class

The sustainable cooling solution area in Chapter 2 demonstrates a pattern that recurs across the chapters: the mitigation problem and the adaptation problem are sometimes the same problem at the system level, and solutions that treat them as one rather than as two deliver disproportionately larger benefits than the sum of separate mitigation and separate adaptation interventions. The cooling case is the clearest: rising heat drives cooling demand, cooling demand drives emissions, emissions drive warming, warming drives rising heat. This is a measurable, observed feedback loop – the cooling–emissions doom loop – and solutions that break it (passive cooling, efficient active cooling, refrigerant transition under the Kigali Amendment, district cooling, thermal storage) deliver mitigation and adaptation simultaneously through coupled tipping mechanisms.[13,15,116]

The pattern extends well beyond cooling. Nature-based solutions for coastal protection (Chapter 3) simultaneously sequester carbon, restore biodiversity, protect coastal communities from storm surge and provide nursery habitat for fisheries that support livelihoods. Climate-smart agriculture (Chapter 1, Chapter 5) simultaneously reduces emissions from cultivation, improves soil resilience to drought, increases yield stability under climate stress and protects farmer livelihoods. Circular construction materials (Chapter 4) simultaneously reduce embodied carbon in new infrastructure and produce more resilient buildings that perform better in extreme heat and storm events. Wildfire stewardship combining prescribed burning with Indigenous fire knowledge (Chapter 2) simultaneously reduces catastrophic megafire risk, improves air quality, protects biodiversity in fire-adapted ecosystems and supports Indigenous land governance.[95,106] Each of these is a mitigation–adaptation integration solution and each delivers more per unit of investment than equivalent single-purpose interventions.

There is a structural reason for the disproportionate returns. Single-purpose solutions are evaluated against a single benefit stream and must justify their costs against that stream alone. Mitigation–adaptation integration solutions are evaluated against multiple benefit streams simultaneously and their cost-effectiveness analyses look very different. A coastal mangrove restoration project that justifies itself on biodiversity grounds alone may not clear the cost–benefit threshold for biodiversity finance; the same project justified on combined biodiversity, carbon sequestration, storm protection and fisheries livelihood grounds clears the threshold easily and attracts finance from multiple sources. Recognising this class of solution explicitly and identifying clusters of finalists across the portfolio with mutually-reinforcing benefit streams, could maximise combined impact and tipping potential.

4. Phase-matched intervention across the portfolio

The ten climate solution areas in Chapter 5 span the full spectrum of tipping trajectory phases: clean electricity and electric vehicles are in acceleration; heat pumps and methane abatement are transitioning from emergence to acceleration; industrial transformation, demand-side tipping and carbon removal are in emergence. The same pattern holds across the other Earthshots. The Amazon Soy Moratorium and the Locally Managed Marine Area model are in stabilisation in their lead jurisdictions and in acceleration where they are diffusing; carbon credit market integrity is in emergence; deposit–refund schemes are in stabilisation in lead markets but emergence globally; Extended Producer Responsibility is in acceleration in lead markets and emergence elsewhere.[14,93]

Phase-appropriate interventions are essential. Emergence-phase solutions need R&D funding, demonstration projects, advance purchase commitments and market creation. Acceleration-phase solutions need deployment financing, mandates, grid and infrastructure investment, and workforce scale-up. Stabilisation-phase solutions need lock-in policies, institutional embedding and protection against political reversal. Funding acceleration-phase solutions with emergence-phase tools (R&D grants, pilots) wastes resources because the technology is already proven and what is needed is scale. Applying mandates and phase-out dates prematurely to emergence-phase solutions can trigger political backlash that sets back the transition. The phase-matching judgement is the single most consequential operational judgement in tipping-point intervention design.

The Earthshot Prize is structurally positioned to support solutions across all three phases. Emergence-phase nominations benefit from the Prize's ability to make speculative innovations visible to the philanthropic and corporate funders who can sustain them through the demonstration period. Acceleration-phase nominations benefit from the Prize's ability to attract policy and deployment finance attention through the credibility halo it confers. Stabilisation-phase nominations benefit from the Prize's ability to lock in political and institutional commitment through public recognition. But the support needs are different in each phase, and the assessment criteria should be different too. Emergence-phase nominations should be considered on, and supported to develop, their theory of change and the quality of their demonstration evidence; acceleration-phase nominations should be considered and supported on their scaling pathway and the proximity of their target tipping threshold; stabilisation-phase nominations should be considered for their durability against political reversal and their potential to extend the model to new jurisdictions.

5. The just transition as multiplier, not constraint

The just transition appears in every chapter, sometimes as an enabling condition, sometimes as a risk to be managed, sometimes as a moral imperative. Read together, these treatments converge on a single insight: the just transition is not a constraint on the speed of transition but a multiplier on its durability. When clean energy transitions impose costs on fossil-fuel-dependent communities without credible alternative pathways, the political resistance generated can stall or reverse the transition entirely.[14] When electric vehicles are accessible only to wealthy buyers and charging infrastructure is concentrated in affluent neighbourhoods, the tipping dynamic is confined to an elite segment and the political mandate for broader acceleration is undermined. When marine protected areas are imposed on coastal communities without their consent or benefit-sharing, compliance collapses and conservation outcomes deteriorate.[1,66] When waste management formalisation excludes informal sector workers whose livelihoods depend on the existing system, the formal system loses both legitimacy and operational capacity.[111]

The mechanism is the same in each case. Transitions that distribute costs and benefits unfairly generate political resistance that operates as balancing feedback against the transition itself. Transitions that distribute costs and benefits fairly generate political support that operates as reinforcing feedback. The just transition is therefore not a moral add-on to technical solutions but a structural component of their tipping dynamics. Earthshot nominations that embed just transition provisions – equitable benefit-sharing, worker transition support, universal access to clean alternatives, community ownership of clean energy infrastructure, free prior and informed consent in conservation, informal sector integration in waste systems – are not merely more ethical; they are more durable and more likely to trigger genuine system-level tipping than technically identical solutions that ignore equity.

Three operational corollaries follow. First, distributive design is part of solution design. A solar mini-grid programme that delivers electricity to a community is not the same solution as a solar mini-grid programme that delivers electricity and ownership stakes to the same community; the second has different tipping dynamics because it builds political constituencies that defend it. Second, the early adopters of a transition are often not the right populations for the transition's long-term political base. Affluent EV early adopters in California are not the constituency that will defend EV mandates through the political cycles required for full fleet turnover; that constituency is the working families who depend on the EV-related jobs and the urban populations who benefit from the air quality improvements. Designing transitions for the eventual political base from the outset, rather than letting that base emerge by accident, materially improves durability. Third, the just transition needs its own enabler. Worker retraining programmes, community ownership vehicles, informal sector integration mechanisms and FPIC protocols are not free; they require dedicated finance, dedicated institutional capacity and dedicated standards. Treating them as overhead on transition projects rather than as core programmes underfunds them and weakens the transitions they enable.

6. Coalitions and the Brussels Effect

Across all five chapters, the formation of coherent, ambitious coalitions emerges as one of the most powerful accelerators of positive tipping.[14,36] Pioneering, high-ambition small-group coalitions – buyer alliances for green steel, ZEV mandate coalitions among automakers, climate litigation networks, Extended Producer Responsibility coalitions, blue finance coalitions – can initiate self-propelling virtuous cycles of cooperation that others join once success is demonstrated. The Global Tipping Points Report 2025 specifically recommends that prizes identify and support emerging coalitions at or near their critical mass threshold.[93]

Coalitions matter because tipping dynamics in governance and market spaces are network phenomena. A single jurisdiction adopting a standard creates limited pressure on other jurisdictions to follow. A coalition of jurisdictions adopting a standard – particularly if the coalition includes large markets – creates strong pressure through three mechanisms simultaneously. First, supply chains adapt to serve the coalition's standards and then cannot easily serve different standards elsewhere, so non-coalition jurisdictions face higher compliance costs to remain different. Second, the coalition's standards become the reference point for future negotiations, displacing weaker alternatives from the policy menu. Third, the coalition's political success demonstrates that the standards are feasible, undermining the political economy resistance in non-coalition jurisdictions.

This is the dynamic that underpins what is variously called the Brussels Effect, the California Effect, or the lead-jurisdiction tipping mechanism. The EU Deforestation Regulation analysed in Chapter 1 is creating it for deforestation-free commodity supply chains.[62] The EU Carbon Border Adjustment Mechanism analysed in Chapter 5 is creating it for industrial decarbonisation.[56] The Kigali Amendment analysed in Chapter 5 created it for refrigerant transition. EU Extended Producer Responsibility schemes analysed in Chapter 4 are creating it for packaging and electronics. EU vehicle emission standards analysed in Chapter 2 are creating it for transport air quality. In each case the mechanism is the same: a lead jurisdiction sets a standard, supply chains adapt to serve it, the standard cascades outward through market integration.

For Earthshot, the highest-leverage coalition nominations have three characteristics. They include at least one large lead market that can drive supply chain adaptation. They have a credible standard or commitment with measurable compliance criteria. And they are at or near their critical mass threshold, where a small increment of additional commitment will produce a disproportionate increase in market power. Coalitions that are very small (one or two jurisdictions) have not yet reached critical mass and need patient support to grow; this is where Earthshot's convening power and storytelling can add particular leverage. Coalitions that are already at full market dominance need stabilisation support to prevent reversal but offer limited additional leverage. The narrow band of coalitions near but below critical mass is where Earthshot recognition and support can produce the largest marginal effect.

7. Three persistent risks: moral hazard, false circularity, and greenwashing

Three risks recur across the chapters in different forms. The first is moral hazard – the risk that the existence of a future solution becomes a justification for delayed action in the present. The clearest case is carbon dioxide removal in Chapter 5: the IPCC is explicit that CDR is needed in all 1.5°C pathways, but reliance on speculative future CDR to justify delayed mitigation today increases the risk of overshooting temperature limits and creates massive future obligations that may be technically impossible or economically devastating to fulfil.[55] The same pattern appears in other forms: climate-resilient health systems in Chapter 2 risk being invoked to justify reduced ambition on emissions reduction (the framing that we can adapt our way out of the air quality problem); adaptation finance in Chapter 4 risks being invoked to justify reduced ambition on mitigation finance; nature-based carbon credits in Chapter 1 risk being invoked to justify continued fossil emissions in other sectors.

The second persistent risk is false circularity – the risk that solutions framed as circular or sustainable in fact rely on accounting artefacts, displaced impacts or unproven assumptions. The clearest case is the voluntary carbon market integrity challenge analysed in Chapter 1 and Chapter 5, where independent analysis has found that a large proportion of existing forest-based offset credits do not represent real or permanent carbon removal. The same pattern appears for low-quality plastic recycling that exports waste to jurisdictions without infrastructure to handle it (Chapter 4); for biofuels that compete with food production and biodiversity (Chapter 5); for biomass co-firing that creates new $PM_{2.5}$ sources in place of old ones (Chapter 2); and for adaptation finance that is double-counted from mitigation finance flows (Chapter 5). The common element in all these cases is that the headline metric (credits sold, tonnes recycled, biofuel volumes produced, finance flows reported) does not capture the actual environmental outcome the metric is supposed to measure.

The third risk is greenwashing – the use of sustainability framing to enable rather than constrain harmful practice. Greenwashing differs from false circularity in that it is usually intentional rather than accidental. The patterns recur across the chapters: corporate net-zero plans that rely on offsets before direct emissions are eliminated; sustainable supply chain commitments that lack enforcement mechanisms; ocean conservation announcements that fail to follow through with management capacity or compliance monitoring; circular economy claims that depend on downcycling rather than genuine material recovery; air quality monitoring programmes that produce data that no one is accountable to act on.

8. The Global South investment imperative

The Global South investment gap appears in every chapter and is the single most binding constraint on global tipping in most solution areas. The headline number from Chapter 5 – Africa receives less than 2% of global clean energy investment despite hosting 60% of the world's best solar resources and around 17% of the global population – captures the scale of the gap for the clean energy transition.[49] But the gap is not specific to energy. It applies to adaptation finance (UNEP estimates a need of $300–500 billion per year by 2030 against current flows of around $50 billion);[108] to ocean conservation finance (estimated at $175 billion per year against current flows in the low single-digit billions);[97] to clean cooking finance (estimated at $4 billion per year against current flows below $1 billion);[44] to health adaptation finance (the WHO target is $11 billion per year against current flows of around $1 billion);[130] to circular economy infrastructure investment in low- and middle-income countries; and to nature-based solutions investment in tropical forest nations. The pattern is consistent: investment is concentrated in markets where the tipping is already occurring; the markets where tipping is most needed receive the least.

The mechanisms creating the gap are structural rather than coincidental. Three are particularly important. First, perceived investment risk in Global South markets is high because of currency volatility, political risk and limited investment-grade sovereign ratings; this raises the required risk-adjusted return for private capital and excludes projects that would be commercially viable on absolute terms. Second, transaction costs for small projects are disproportionately high because due diligence and structuring costs are roughly fixed regardless of project size; this excludes the small, distributed projects that are often the right form factor for Global South contexts. Third, capital is concentrated in financial centres with limited operational presence in Global South markets; this creates information asymmetries that translate into further risk premia. The combination is a market failure that does not self-correct.

Closing the gap requires three coordinated interventions, each of which appears as an enabling condition in multiple chapters. Concessional finance from multilateral development banks and development finance institutions is the primary mechanism for absorbing the perceived-risk premium that excludes private capital from Global South markets.[3] Blended finance vehicles that combine concessional and commercial capital reduce transaction costs by aggregating small projects into investible portfolios. Local capacity building – in regulatory institutions, in monitoring infrastructure, in domestic finance institutions, in technical workforces – reduces information asymmetries over time and progressively reduces the dependence on external concessional finance. The three together can produce the financial conditions under which the tipping dynamics already operating in lead markets can extend to the populations and regions where most of the world's population lives.

The implications reach across The Earthshot Prize's work. In selecting finalists, solutions that address the Global South investment gap – through innovative financing, technology adaptation for lower-income markets, or governance innovations that reduce perceived investment risk – carry particularly high leverage on global outcomes across every Earthshot, even where they are operational less mature than competing solutions in lead markets, because they tackle the harder and more consequential problem of extending positive tipping dynamics globally. In supporting finalists, the same logic points to helping Global South solutions de-risk, connect to finance and reach the scale at which they tip. And in communications, these are among the most powerful stories The Earthshot Prize can tell, because they talk about solutions rooted in lower-income markets that can help repair the planet for everyone.

Closing reflection

The five Earthshots are framed as separate challenges for a reason: each speaks to a distinct domain of environmental and human well-being, and the framing makes the scale of the work legible to publics, funders and policymakers who would otherwise find an undifferentiated planetary crisis difficult to engage with. The framing is doing important communicative work. But in reality, and by design, all five Earthshots are deeply interconnected, reflecting our global system and carrying a solution potential that necessarily cuts across solution areas, disciplines, and sectors. The same clean electricity cascade powers climate mitigation, urban air quality improvement, clean cooking access and electrified circular industry. The same monitoring democratisation enables air quality accountability, deforestation tracking, methane detection and fisheries enforcement. The same finance instruments scale ocean conservation, adaptation infrastructure and circular construction. The same enablers – governance plus finance plus monitoring – supports direct interventions across every Earthshot. The same just transition mechanisms determine the durability of transitions in every domain. The same moral hazards, the same greenwashing risks, the same Global South investment imperative apply across all five.

What this means for The Earthshot Prize is that the Prize's leverage is not the sum of its leverage on the five challenges separately. It is the product of its leverage on the cross-cutting enablers that operate across them. A solution that scales an enabler, that engages a cross-sectoral cascade, that embeds the just transition by design, that guards against moral hazard, and that addresses the Global South investment imperative is doing work in all five

Earthshots simultaneously even if it is formally categorised in one. The Prize's greatest contribution may be its capacity to identify and elevate such solutions – to use its public platform to make visible the solutions whose leverage operates across the architecture rather than within a single chamber of it.

That is the case for treating the Earthshots as one system. The chapter-by-chapter analyses in this report are the components; the cross-cutting synthesis in this chapter is the architecture; the combination is an operational picture for assessing, supporting, and connecting Earthshot finalists to maximise their tipping potential and accelerate their positive impact on an interconnected earth system. The picture is incomplete. New tipping mechanisms will emerge as the science evolves, new connectors will be identified as the chapters are read together by other readers with different framings, and the cross-cutting framework will need updating as the system itself changes. But the picture as it stands is sufficient to support the work that The Earthshot Prize is doing now, and the patterns it identifies will not change quickly. The five Earthshots are one system. Reading them that way is the most powerful analytical move available for assessing nominations, supporting finalists, and championing solutions to meet the scale of ambition the Earthshots themselves set out.

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Glossary

This glossary defines the technical terms and acronyms used in this report. Acronyms are also written out in full when first used in each chapter. Terms are listed alphabetically.

Term or Acronym	Definition
30x30	The Global Biodiversity Framework target of conserving at least 30% of the world's land and sea by 2030.
Accessibility	One of the three enabling conditions for a positive tipping point: the alternative must be practically reachable by the actors who need to adopt it.
Affordability	One of the three enabling conditions for a positive tipping point: the desired alternative must be cost-competitive with the damaging incumbent.
AFOLU	Agriculture, Forestry and Other Land Use. The set of human activities on land that emit or absorb greenhouse gases.
Agroforestry	Land-use systems that combine trees with crops or livestock on the same land, delivering food, income, biodiversity and carbon benefits together.
Anaerobic digestion	The breakdown of organic matter by microbes in the absence of oxygen, producing biogas (mostly methane) and a nutrient-rich residue.
Attractiveness	One of the three enabling conditions for a positive tipping point: the alternative must perform well enough, with sufficient social proof, that adopters are motivated to choose it.
Balancing feedback	A self-stabilising loop in a system that resists change and tends to keep the system in its current state.
BAT	Best Available Techniques. A regulatory benchmark, used widely in the EU, defining the cleanest economically viable production technology in a given sector.
BBNJ	Biodiversity Beyond National Jurisdiction. A 2023 UN treaty enabling the creation of marine protected areas and other conservation measures in the high seas.
BECCS	Bioenergy with Carbon Capture and Storage. Burning biomass for energy while capturing the resulting carbon dioxide for permanent storage.

Term or Acronym	Definition
Blended finance	The strategic use of public or philanthropic capital to mobilise private investment in projects with development or environmental benefits.
Blue bond	A debt instrument issued to finance ocean conservation, sustainable fisheries or marine protected area management.
Blue carbon	Carbon stored in coastal and marine ecosystems such as mangroves, salt marshes and seagrass beds, often per hectare among the most carbon-dense ecosystems on Earth.
Brussels Effect	The phenomenon where a large common market such as the European Union can unilaterally set global standards because multinational companies find it easier to adhere to a single set of rules worldwide than to manage different ones in different regions.
CDR	Carbon Dioxide Removal. Methods that remove CO_2 from the atmosphere and store it durably, for example through reforestation, BECCS or direct air capture.
CEMS	Continuous Emissions Monitoring System. Equipment that measures pollutant emissions from an industrial source in real time.
Circular economy	An economic model in which products, components and materials are kept in use as long as possible through reuse, repair, remanufacturing and recycling, designing out waste.
Co-benefit	A positive side-effect of an action taken primarily for another purpose – for example, the health gains from cutting fossil fuel use to reduce emissions.
DACCS	Direct Air Carbon Capture and Storage. Industrial technology that pulls CO_2 directly from the air for storage.
DRS	Deposit Return Scheme. A system in which consumers pay a small deposit on a beverage container and reclaim it when the empty container is returned for recycling or reuse.
E-waste	Electronic waste – discarded electrical and electronic equipment, ranging from phones to fridges. The fastest-growing waste stream globally.
Early opportunity signal	A statistical or observational signal that a system is losing the resilience of its current state and approaching a tipping point.
Eco-modulated fee	An EPR fee that varies according to the environmental performance of a product (for example, charging more for hard-to-recycle packaging).

Term or Acronym	Definition
eDNA	Environmental DNA. Genetic material shed by organisms into water, soil or air, used to detect species presence without direct observation.
EPR	Extended Producer Responsibility. Policy that makes producers financially and/or operationally responsible for the management of their products after consumer use.
EUDR	European Union Deforestation Regulation. EU law requiring that key commodities sold in the EU (such as beef, soy, palm oil, timber, cocoa and coffee) be demonstrably free of deforestation.
GHG	Greenhouse Gas. Gases such as carbon dioxide, methane and nitrous oxide that trap heat in the atmosphere.
$GtCO_2e$	Gigatonnes (billion tonnes) of carbon dioxide equivalent – a standard unit for comparing emissions of different greenhouse gases.
Hysteresis	A property of complex systems whereby reversing a change requires a larger intervention than the one that caused the original shift. Recovering a degraded ecosystem typically costs more than degrading it did.
Indigenous and community conserved area	An area of land or sea conserved by Indigenous Peoples or local communities through their own governance systems, often delivering biodiversity outcomes comparable to or better than state-managed protected areas.
Industrial symbiosis	The exchange of materials, energy or water between industrial facilities so that one's by-product becomes another's input.
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. The biodiversity counterpart to the IPCC.
IPCC	Intergovernmental Panel on Climate Change. The UN body responsible for assessing the science of climate change.
IUU fishing	Illegal, Unreported and Unregulated fishing. Fishing activity that breaks national or international rules, fails to report catch, or operates outside management arrangements.
IWRM	Integrated Water Resources Management. An approach that coordinates the development and use of water, land and related resources across a river basin.

Term or Acronym	Definition
Just transition	The principle that the move to a sustainable economy must protect the livelihoods of workers and communities tied to declining industries and ensure benefits are shared fairly.
Keystone species	A species whose role in an ecosystem is disproportionately large relative to its abundance – its presence or absence shapes the structure of the whole community.
LCOE	Levelised Cost of Electricity. The average lifetime cost of generating one unit of electricity from a given technology, used for like-for-like comparisons.
Leverage point	A place in a system where a small, well-targeted intervention can produce disproportionate change.
LMMA	Locally Managed Marine Area. A coastal or near-shore area whose conservation is led by the local community, often combining traditional and scientific knowledge.
MDB	Multilateral Development Bank. International financial institutions (such as the World Bank or African Development Bank) that fund development projects.
Moisture recycling	The atmospheric process by which water transpired by vegetation falls again as rain downwind, linking forest cover to regional rainfall.
MPA	Marine Protected Area. A designated area of ocean managed for the long-term conservation of nature; protection levels vary from highly protected (no extraction) to multi-use.
MRV	Measurement, Reporting and Verification. The procedures that make claims about emissions, removals or environmental outcomes credible and comparable.
MSW	Municipal Solid Waste. The mixed waste generated by households and similar small commercial sources.
Nature-based solution	Actions to protect, sustainably manage or restore ecosystems that deliver benefits for biodiversity, climate and people simultaneously.
NbS	Nature-based Solution (see entry above).
NDC	Nationally Determined Contribution. A country's self-set climate pledge under the Paris Agreement, updated every five years.

Term or Acronym	Definition
Negative tipping point	A threshold beyond which a system shifts abruptly to a less desirable state (for example, coral reef collapse, Amazon dieback).
Net zero	A state in which any greenhouse gas emissions remaining are balanced by an equivalent amount removed from the atmosphere.
NO_2	Nitrogen dioxide – a pollutant primarily from combustion (vehicles, power, industry) that harms health and forms secondary particulate matter.
O_3	Ozone. At ground level, a harmful pollutant that damages lungs and crops; it forms in the atmosphere from precursor pollutants including methane and NO_2.
OECM	Other Effective area-based Conservation Measure. An area achieving sustained biodiversity outcomes through means other than formal protected-area designation.
PES	Payments for Ecosystem Services. Schemes that pay land managers to maintain or restore services such as clean water, carbon storage or biodiversity.
PFAS	Per- and Polyfluoroalkyl Substances. A class of synthetic chemicals (sometimes called "forever chemicals") that are extremely persistent in the environment and increasingly regulated.
Phase-matched intervention	Aligning the form of support given to a transition with where it sits on its trajectory: emergence (demonstration and de-risking), acceleration (scaling investment and mandates), or stabilisation (locking in the new norm against reversal).
PM10	Particulate matter smaller than 10 micrometres across; coarser than PM2.5 but still inhalable and harmful.
PM2.5	Particulate matter smaller than 2.5 micrometres across. Fine particles that penetrate deep into the lungs and bloodstream and are the air pollutant most strongly linked to premature death.
Positive tipping point	A threshold beyond which reinforcing feedbacks become strong enough to drive self-propelling change towards a more desirable state.
PV	Photovoltaic. Solar technology that converts sunlight directly into electricity.

Term or Acronym	Definition
REDD+	Reducing Emissions from Deforestation and Forest Degradation. A UN framework that allows countries to be compensated for protecting and restoring forests.
Regime shift	A relatively rapid and persistent change in the structure and function of a system, often triggered by a tipping point.
Reinforcing feedback	A self-amplifying loop in a system, in which an initial change leads to further changes in the same direction.
Rewilding	Restoring ecosystems by allowing natural processes to recover, often including the reintroduction of native species.
RFMO	Regional Fisheries Management Organisation. An international body that manages shared fish stocks across national boundaries.
Secondary materials	Materials recovered from waste streams (recyclate) and used as feedstock in place of virgin raw materials.
Secondary PM	Particulate matter formed in the atmosphere from gaseous precursors (such as ammonia, sulphur dioxide and nitrogen oxides) rather than emitted directly.
SLCP	Short-Lived Climate Pollutant. Pollutants such as methane, black carbon and tropospheric ozone that warm the climate strongly but persist in the atmosphere for far less time than carbon dioxide.
Social tipping point	A threshold in a social system beyond which a new norm, behaviour or policy spreads contagiously and becomes dominant.
Tipping cascade	A sequence in which crossing a tipping point in one system triggers tipping in other connected systems.
Trophic cascade	An ecological knock-on effect through a food web, often triggered by the return or removal of a top predator.
Trophic rewilding	A form of rewilding that reintroduces species (typically large herbivores or predators) to restore food-web dynamics.
UNEP	United Nations Environment Programme. The UN body responsible for environmental matters.
VMS	Vessel Monitoring System. Satellite-based tracking of fishing vessels, used for enforcement and transparency.

Term or Acronym	Definition
WHO	World Health Organization. The UN agency responsible for international public health.
ZEV	Zero-Emission Vehicle. A vehicle, typically battery-electric or hydrogen-powered, that produces no tailpipe emissions.

Appendix A: Acronyms and Abbreviations

This appendix lists the acronyms used in the body of the report, grouped by domain for ease of reference. Where an acronym has a specific technical meaning in one Earthshot but a different general meaning elsewhere, both are noted. The glossary at the front of the report defines the broader conceptual terms (positive tipping point, reinforcing feedback, hysteresis, just transition) that are used across all chapters.

10. Climate and energy

Acronym	Expansion / meaning
AFOLU	Agriculture, Forestry and Other Land Use
BAT	Best Available Techniques
BECCS	Bioenergy with Carbon Capture and Storage
CBAM	Carbon Border Adjustment Mechanism (EU)
CCAC	Climate and Clean Air Coalition
CCS / CCUS	Carbon Capture and Storage / Carbon Capture, Utilisation and Storage
CDR	Carbon Dioxide Removal
CEMS	Continuous Emissions Monitoring System
CFD	Contract for Difference
DAC / DACCS	Direct Air Capture / Direct Air Carbon Capture and Storage
EPC	Energy Performance Certificate
EPBD	Energy Performance of Buildings Directive (EU)
EV / BEV / ZEV	Electric Vehicle / Battery Electric Vehicle / Zero-Emission Vehicle
FCDO	Foreign, Commonwealth and Development Office (UK)
GCF	Green Climate Fund
GHG	Greenhouse Gas
$GtCO_2$ / $GtCO_2e$	Gigatonnes of carbon dioxide (or CO_2-equivalent)
GW / TWh	Gigawatt / Terawatt-hour

Acronym	Expansion / meaning
GWP	Global Warming Potential
H2-DRI	Hydrogen Direct Reduction of Iron
HFC	Hydrofluorocarbon (refrigerant)
IEA NZE	International Energy Agency Net Zero Emissions scenario
IPCC AR6 WGI/II/III	Sixth Assessment Report, Working Groups I, II, III
IRA	Inflation Reduction Act (US)
LCOE	Levelised Cost of Electricity
LDC / SIDS	Least Developed Country / Small Island Developing State
LEZ / ULEZ	Low Emission Zone / Ultra-Low Emission Zone
LPG	Liquefied Petroleum Gas
LULUCF	Land Use, Land-Use Change and Forestry
MDB / DFI	Multilateral Development Bank / Development Finance Institution
MRV	Measurement, Reporting and Verification
NDC	Nationally Determined Contribution (Paris Agreement)
OGMP	Oil and Gas Methane Partnership
PAYG	Pay-as-you-go
PV	Photovoltaic (solar)
REDD+	Reducing Emissions from Deforestation and forest Degradation
TCO	Total Cost of Ownership
UNFCCC	United Nations Framework Convention on Climate Change

11. Air quality and health

Acronym	Expansion / meaning
AQG	Air Quality Guidelines (WHO)
AQI	Air Quality Index

Acronym	Expansion / meaning
BC	Black Carbon
CLRTAP	Convention on Long-range Transboundary Air Pollution
CO	Carbon Monoxide
EANET	Acid Deposition Monitoring Network in East Asia
EMEP	European Monitoring and Evaluation Programme
FIRMS	Fire Information for Resource Management System (NASA)
HAP	Household Air Pollution
HEI	Health Effects Institute
NH_3	Ammonia
NO_2 / NO_x	Nitrogen Dioxide / Nitrogen Oxides
NOAA	National Oceanic and Atmospheric Administration (US)
O_3	Ozone
$PM_{2.5}$ / PM_{10}	Particulate Matter under 2.5 / 10 micrometres
POPs	Persistent Organic Pollutants
PRTR	Pollutant Release and Transfer Register
SO_2 / SO_x	Sulphur Dioxide / Sulphur Oxides
TROPOMI	Tropospheric Monitoring Instrument (Sentinel-5P)
VOC	Volatile Organic Compound
WHO EMRO	WHO Regional Office for the Eastern Mediterranean
WMO	World Meteorological Organization

12. Nature, oceans and land

Acronym	Expansion / meaning
BBNJ	Biodiversity Beyond National Jurisdiction (treaty)
CBD	Convention on Biological Diversity

Acronym	Expansion / meaning
EUDR	EU Deforestation Regulation
FAO	Food and Agriculture Organization of the United Nations
FPIC	Free, Prior and Informed Consent
GBF	Kunming–Montreal Global Biodiversity Framework
GFW	Global Fishing Watch / Global Forest Watch (context-dependent)
IPLC	Indigenous Peoples and Local Communities
IUU	Illegal, Unreported and Unregulated (fishing)
LMMA	Locally Managed Marine Area
MPA	Marine Protected Area
NbS	Nature-based Solutions
OECM	Other Effective area-based Conservation Measures
PRODES	Brazilian deforestation monitoring programme (INPE)
REDD+	Reducing Emissions from Deforestation and forest Degradation
SDG	Sustainable Development Goal
TNFD	Taskforce on Nature-related Financial Disclosures
UNEP	United Nations Environment Programme

13. Waste and circular economy

Acronym	Expansion / meaning
DRS	Deposit-Refund Scheme
EEE	Electrical and Electronic Equipment
EIP	Eco-Industrial Park
EPR	Extended Producer Responsibility
ISWA	International Solid Waste Association
MSW	Municipal Solid Waste

Acronym	Expansion / meaning
PFAS	Per- and Polyfluoroalkyl Substances
PRO	Producer Responsibility Organisation
UNIDO	United Nations Industrial Development Organization
WEEE	Waste from Electrical and Electronic Equipment
WorldGBC	World Green Building Council

14. Adaptation and resilience

Acronym	Expansion / meaning
AA	Anticipatory Action
ARC	African Risk Capacity
ASCE	American Society of Civil Engineers
CCRIF	Caribbean Catastrophe Risk Insurance Facility
COP	Conference of the Parties (UNFCCC)
DRR	Disaster Risk Reduction
FbF	Forecast-based Financing
IFRC	International Federation of Red Cross and Red Crescent Societies
NAP	National Adaptation Plan
NCQG	New Collective Quantified Goal (climate finance, COP29)
OCHA	UN Office for the Coordination of Humanitarian Affairs
PCRIC	Pacific Catastrophe Risk Insurance Company
UNDRR	UN Office for Disaster Risk Reduction
WFP	World Food Programme

Note on the use of artificial intelligence

This report was prepared with the assistance of generative artificial intelligence (AI) tools, used in accordance with the University of Exeter's "Responsible use of AI in research" guidance and the University's Artificial Intelligence Policy (POL020), and consistent with established research-integrity principles, including those of the UK Research Integrity Office. This note is provided in the interests of transparency.

AI tools were used in a supporting role: to help draft and refine plain-language explanatory text, to improve the clarity and consistency of the writing, and to assist with structured editorial tasks such as incorporating reviewer feedback and organising and cross-checking the reference list and its citations. The substantive content of this report — the underlying scientific analysis, the evidence base, the assessment of solution areas, and the conclusions — is the work of the author and was not generated by AI.

In line with the University's guidance, all AI-assisted material was treated as draft output subject to critical review: the author checked, verified and where necessary corrected it, confirmed factual statements and references against their original sources, and retain full responsibility and accountability for the content of this report. AI is not credited as an author, as it cannot take responsibility for the work. No confidential, personal or special-category data, and no third-party material in breach of copyright or licence, was entered into AI tools, and their use was consistent with the University's information-classification and data-protection requirements. The environmental cost of AI was also considered, with these tools used selectively where they added genuine value rather than by default.
On this basis, the author is satisfied that AI has been used responsibly, transparently and in keeping with the University of Exeter's policy and the standards of research integrity expected of this work.

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