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Legal Aspects of Climate Adaptation and the Economics of Resilience

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Abstract

Climate adaptation has moved from the margins of environmental policy to the centre of public law, economic governance and human-rights protection. Mitigation determines the magnitude of future change; adaptation determines how institutions, infrastructure, ecosystems and communities withstand change that can no longer be avoided. The legal challenge is distinctive because adaptation has no single metric equivalent to tonnes of greenhouse gases. Its effectiveness depends on place, timing, distribution, uncertainty and the avoidance of maladaptation. This study develops an integrated account of international, European Union and comparative adaptation law through the analytical lens of resilience economics. It examines duties to assess risk, plan under uncertainty, climate-proof investment, protect life and health, manage water and coasts, preserve ecosystems, regulate insurance and finance, allocate loss and enable participation. It argues that a legally adequate adaptation regime requires binding processes and reviewable outcomes: recurrent risk assessment, quantified objectives, transparent priorities, minimum protection standards, equitable finance, robust data, independent monitoring and remedies. Economic appraisal remains essential, but it must recognise catastrophic risk, irreversibility, distribution and the limits of monetary substitution. Resilience is therefore not a licence to normalise harm. It is a legal obligation to reduce vulnerability while preserving rights, ecological integrity and the capacity of future generations to choose.

Keywords: Climate adaptation, resilience economics, climate risk, disaster law, human rights, European Union law, infrastructure, insurance, water, nature-based solutions, maladaptation, loss and damage.

Adaptation as a Distinct Field of Climate Law

Climate law has long been organised around mitigation. The reduction of greenhouse-gas emissions offers a common unit, economy-wide pathways and relatively clear attribution to regulated activities. Adaptation is more fragmented. Heat, flood, drought, wildfire, erosion, ecosystem change and disease affect different territories through different exposures and vulnerabilities. The relevant decisions are embedded in planning, water, health, housing, agriculture, civil protection, insurance, finance and social welfare. International climate law nevertheless requires adaptation to be treated as an integral component of the response to climate change.[1,2]

Adaptation is not synonymous with emergency response. Prevention, preparedness, response, recovery and transformation occupy different points in the risk cycle. A warning

[1]United Nations Framework Convention on Climate Change, 9 May 1992, 1771 UNTS 107, arts 2–4.

[2]Paris Agreement, 12 December 2015, 3156 UNTS 79, arts 2(1)(b), 7, 8, 9 and 13.

system may reduce mortality during an event; land-use controls reduce exposure before the event; building standards reduce physical vulnerability; social protection improves the capacity to recover; managed retreat may transform an unsustainable settlement pattern. Legal analysis must identify which institution controls each stage and whether powers, finance and accountability are aligned.

The distinction between adaptation deficit and climate adaptation is important. Many existing losses arise because drainage, health services, ecosystems or housing are already inadequate under the present climate. Climate change magnifies that deficit and alters the probability distribution of future hazards. A lawful plan should therefore address current vulnerability while using forward-looking scenarios. Reliance on historical averages can constitute administrative irrationality where authoritative projections show that those averages no longer represent foreseeable conditions.

Adaptation also has limits. Some ecosystems cannot migrate or recover beyond physical thresholds. Some islands and coastal settlements may face unavoidable loss. Heat may exceed safe conditions for outdoor work. The Commission has recognised that physical limits constrain what adaptation can achieve.[3] Law should not use resilience language to justify continued exposure or to transfer responsibility onto households. It must define when protection is feasible, when transformation is required and how unavoidable loss is shared.

The Economics of Resilience

The economic case for adaptation begins with expected avoided loss, but a simple comparison of discounted costs and average benefits is incomplete. Climate risk is the interaction of hazard, exposure and vulnerability. An investment may produce benefits by reducing the probability of failure, the severity of damage, recovery time or cascading disruption. These benefits often accrue to persons other than the investor, which creates underinvestment. Flood defences, climate services, resilient grids and ecosystem restoration have public-good and network characteristics.

Uncertainty does not support inaction. It changes the design of action. Deep uncertainty about local precipitation, sea-level rise and compound events favours robust measures that perform acceptably across scenarios, flexible pathways that can be intensified when thresholds are reached and options that preserve future choice. Catastrophic tails deserve special weight because expected-value analysis can conceal low-probability losses of exceptional magnitude.[4] Public investment theory also recognises that governments can pool some project-specific risks, though correlated climate shocks limit that advantage.[5]

Discounting is particularly contentious. High rates diminish future avoided deaths, ecosystem losses and infrastructure damage, encouraging delay. Market rates may be unsuitable where benefits extend across generations and cannot be replicated by financial returns. Appraisal should disclose social discount rates, distributional weights and sensitivity to alternative climate scenarios. The Stern analysis treats early climate action as risk management rather than a prediction of a single optimal temperature path.[6]

Resilience produces option value and co-benefits. Wetlands can store floodwater, improve water quality, support biodiversity and cool urban areas. Heat-resilient housing can reduce mortality and energy poverty. Redundant infrastructure may appear inefficient in ordinary conditions but becomes valuable during systemic stress. Global assessments have found high returns from early warning, resilient infrastructure, dryland agriculture, mangrove protection and water resilience.[7] These estimates inform priority setting but do not replace rights-based minimum standards.

Distribution changes the economic result. A project that protects high-value property may score well in aggregate while abandoning low-income communities. Asset-value appraisal can reproduce existing inequality because wealthier districts contain more monetised value. Distributional weights, minimum-service standards and vulnerability indices correct part of this bias. Compensation must be real and accessible; hypothetical gains to society do not remedy an uncompensated loss of home, livelihood or culture.

International Adaptation Obligations

The UNFCCC requires States to formulate and implement measures facilitating adequate adaptation and to cooperate in preparing for climate impacts.[8] The Cancun Adaptation Framework elevated adaptation within the Convention process and established structures for planning, support and

[3]European Commission, Managing climate risks: protecting people and prosperity, COM(2024) 91 final.

[4]M L Weitzman, On Modeling and Interpreting the Economics of Catastrophic Climate Change, 91 Review of Economics and Statistics 1, 2009.

[5]K J Arrow and R C Lind, Uncertainty and the Evaluation of Public Investment Decisions, 60 American Economic Review 364, 1970.

[6]N Stern, The Economics of Climate Change: The Stern Review, Cambridge University Press 2007.

[7]Global Commission on Adaptation, Adapt Now: A Global Call for Leadership on Climate Resilience, 2019.

[8]United Nations Framework Convention on Climate Change, 9 May 1992, 1771 UNTS 107, arts 2–4.

knowledge.[9] National adaptation plans provide an iterative method for identifying medium- and long-term needs and integrating them into development planning.[10] These instruments establish process obligations whose value depends on implementation, finance and review.

Article 7 of the Paris Agreement recognises a global goal of enhancing adaptive capacity, strengthening resilience and reducing vulnerability. Adaptation action should be country-driven, gender-responsive, participatory and informed by science, Indigenous knowledge and local knowledge.[11] The Glasgow Climate Pact urged further work and finance, while the UAE Framework for Global Climate Resilience developed thematic and dimensional targets for the global goal.[12,13] The framework improves direction but does not create a single distributive formula for national responsibility.

Finance is a legal and practical fault line. Developing States may identify sound adaptation measures yet lack fiscal space, concessional capital, technical capacity or insurance access. Article 9 of the Paris Agreement and Convention principles require support that reflects differentiated responsibility and capability. Loans for projects that generate limited revenue can worsen debt vulnerability. Grants and highly concessional instruments are therefore especially relevant for public health, ecosystems, local planning and loss prevention in vulnerable States.

The Sendai Framework links climate adaptation and disaster-risk reduction through understanding risk, governance, investment and preparedness.[14] Its non-binding form does not eliminate legal significance. It supplies agreed standards against which domestic diligence, planning and international cooperation may be evaluated. The integration of climate and disaster systems also avoids parallel institutions that use inconsistent maps, thresholds and funding rules.

The ICJ advisory opinion of 2025 placed climate obligations within general international law, including prevention, due diligence, cooperation and State responsibility.[15] The ITLOS advisory opinion of 2024 characterised anthropogenic greenhouse-gas emissions as marine pollution for the purposes examined and articulated stringent due-diligence requirements under the law of the sea.[16] Together, the opinions strengthen the expectation that States assess foreseeable impacts, adopt adequate measures and update them with scientific knowledge. Adaptation does not discharge the separate duty to mitigate.

Loss and Damage, Responsibility and Solidarity

Adaptation reduces risk but cannot eliminate all loss. Article 8 of the Paris Agreement recognises the importance of averting, minimising and addressing loss and damage, including through early warning, emergency preparedness, slow-onset events, irreversible loss, risk insurance and resilience.[17] The legal distinction between adaptation finance and loss-and-damage support matters because the latter responds to impacts that prevention has not avoided. It also exposes disputes about responsibility, compensation and historic emissions.

Economic loss can be priced imperfectly; non-economic loss includes life, health, territory, culture, biodiversity, identity and social cohesion. Monetary compensation may assist recovery without restoring what was lost. Legal frameworks should therefore combine finance, relocation rights, cultural protection, ecosystem measures, documentation and guarantees against repeated exposure. Procedures must allow affected communities to define loss rather than accept categories created solely by donors or insurers.

State responsibility requires breach, attribution and the applicable rules of causation and reparation. The global, cumulative and temporally dispersed character of emissions complicates these elements but does not make them conceptually irrelevant. The ICJ opinion confirms that climate harm is not outside the law of responsibility.[18] Adaptation failures may also be more directly attributable than global temperature

[9]Decision 1/CP.16, The Cancun Agreements: Outcome of the work of the Ad Hoc Working Group on Long-term Cooperative Action under the Convention, FCCC/CP/2010/7/Add.1, paras 11–35.

[10]Decision 5/CP.17, National adaptation plans, FCCC/CP/2011/9/Add.1.

[11]Paris Agreement, 12 December 2015, 3156 UNTS 79, arts 2(1)(b), 7, 8, 9 and 13.

[12]Decision 1/CMA.3, Glasgow Climate Pact, FCCC/PA/CMA/2021/10/Add.1, paras 11–18.

[13]Decision 2/CMA.5, Global goal on adaptation, UAE Framework for Global Climate Resilience, FCCC/PA/CMA/2023/16/Add.1.

[14]Sendai Framework for Disaster Risk Reduction 2015–2030, UN Doc A/RES/69/283, annex II.

[15]International Court of Justice, Obligations of States in respect of Climate Change, Advisory Opinion of 23 July 2025, General List No 187.

[16]International Tribunal for the Law of the Sea, Request for an Advisory Opinion submitted by the Commission of Small Island States on Climate Change and International Law, Advisory Opinion of 21 May 2024, Case No 31.

[17]Paris Agreement, 12 December 2015, 3156 UNTS 79, arts 2(1)(b), 7, 8, 9 and 13.

[18]International Court of Justice, Obligations of States in respect of Climate Change, Advisory Opinion of 23 July 2025, General List No 187.

change: an authority may ignore a known flood map, fail to maintain a warning system or authorise development in a clearly dangerous zone.

Solidarity instruments distribute disaster cost without admitting international responsibility. They can mobilise resources quickly, but discretionary generosity produces uncertainty and unequal treatment. Rule-based triggers, pre-arranged finance, transparent allocation and independent audit improve predictability. International support should not require vulnerable States to surrender policy control or accept unsuitable private financial products.

Human Rights and Positive Duties of Protection

Climate impacts engage the rights to life, health, home, family life, water, property, culture, information, participation and an effective remedy. Recognition of a clean, healthy and sustainable environment by the UN General Assembly reinforces the normative setting.[19] Children face heightened and long-duration exposure, a concern elaborated in General Comment No 26 of the Committee on the Rights of the Child.[20] Rights analysis makes vulnerability legally visible rather than merely a variable in aggregate cost-benefit analysis.

The European Court of Human Rights has developed positive obligations in relation to foreseeable natural and technological hazards. Budayeva concerned failures in land planning, warning and emergency policies in the face of a known mudslide risk and resulted in a violation of Article 2.[21] Kolyadenko addressed a destructive flood linked to the operation and maintenance of a reservoir system and found violations of Articles 2 and 8 and of property protection.[22] M Özel concerned the effectiveness of the response to deaths caused by building collapse in an earthquake.[23]

These cases do not make the State an insurer against every disaster. They require a regulatory and operational framework proportionate to real and immediate risks within official knowledge and capacity. Climate attribution can strengthen foreseeability, but liability may arise without proving that climate change caused a particular event. It can be enough that authorities knew the site was exposed and failed to use available protective powers.

KlimaSeniorinnen confirmed that Article 8 encompasses effective protection against serious adverse climate effects and identified deficiencies in the Swiss regulatory framework and implementation.[24] Although centred on mitigation, its requirements concerning quantification, timely action, evidence and access to court influence adaptation governance. A State that adopts an adaptation strategy without measurable objectives, implementation arrangements or review may encounter similar accountability concerns.

Human-rights bodies have addressed displacement and culture. Teitiota recognised that climate conditions may, in sufficiently extreme circumstances, engage non-refoulement obligations, while finding no violation on the facts before it.[25] Billy and others found that Australia had inadequately protected Torres Strait Islanders from climate impacts affecting home, private life and culture.[26] Adaptation duties therefore include cultural continuity and participation, not only physical infrastructure.

The European Union Adaptation Constitution

EU adaptation law is dispersed across environmental, energy, health, agriculture, cohesion, internal-market and civil-protection competences. Articles 11 and 191–194 TFEU support environmental integration and climate action; Articles 168 and 222 address health and solidarity.[27] The Charter adds dignity, private life, property, children's interests, health protection, environmental integration and effective judicial protection.[28] Competence fragmentation makes coordination a constitutional requirement rather than an administrative preference.

[19]United Nations General Assembly Resolution 76/300, The human right to a clean, healthy and sustainable environment, A/RES/76/300, 28 July 2022.

[20]Committee on the Rights of the Child, General Comment No 26 on children's rights and the environment, with a special focus on climate change, CRC/C/GC/26, 22 August 2023.

[21]Budayeva and Others v Russia Apps nos 15339/02 and others, judgment of 20 March 2008.

[22]Kolyadenko and Others v Russia Apps nos 17423/05 and others, judgment of 28 February 2012.

[23]M Özel and Others v Turkey Apps nos 14350/05 and others, judgment of 17 November 2015.

[24]Verein KlimaSeniorinnen Schweiz and Others v Switzerland App no 53600/20, Grand Chamber judgment of 9 April 2024.

[25]Human Rights Committee, Ioane Teitiota v New Zealand, Communication No 2728/2016, CCPR/C/127/D/2728/2016, Views adopted 24 October 2019.

[26]Human Rights Committee, Daniel Billy and others v Australia, Communication No 3624/2019, CCPR/C/135/D/3624/2019, Views adopted 22 September 2022.

[27]Treaty on the Functioning of the European Union, arts 11, 168, 191–194 and 222.

Article 5 of the European Climate Law requires Union institutions and Member States to ensure continuous progress in enhancing adaptive capacity, strengthening resilience and reducing vulnerability. National adaptation strategies and plans must be regularly updated and informed by robust climate and vulnerability analysis, progress indicators and best available science.[29] The provision is programmatic in wording but supplies a binding direction and review standard.

The 2021 EU Adaptation Strategy organises action around smarter, faster and more systemic adaptation and stronger international engagement.[30] It promotes knowledge, climate-risk assessment, local action, climate-proof finance and nature-based solutions. The strategy is a Commission communication rather than a comprehensive adaptation code. Its influence therefore depends on integration into binding sectoral instruments, funding conditions and national administration.

The first European Climate Risk Assessment identified 36 major risks across ecosystems, food, health, infrastructure and the economy, with several requiring urgent action.[31] The Commission response allocated risk ownership among Union, national, regional and local levels and emphasised governance, planning, structural policy and financial resilience.[32] EUCRA makes inaction harder to justify because it provides an authoritative common evidence base. It does not eliminate the need for local assessment.

The Governance Regulation requires long-term strategies and reporting on adaptation, but the architecture remains less quantified than mitigation governance.[33] There is no adaptation equivalent of an economy-wide emissions cap. Legally meaningful progress therefore requires indicators for exposure reduction, resilience of essential services, heat mortality, water stress, ecosystem condition, warning coverage and recovery capacity. Indicators should measure outcomes, not merely expenditure or the number of plans adopted.

Risk Assessment, Data and Administrative Rationality

Adaptation begins with risk assessment. A competent assessment states the hazard, exposed persons and assets, vulnerability, time horizon, scenarios, confidence and possible cascading effects. It distinguishes current risk from projected risk and identifies data gaps. A map without assumptions can create false precision. Authorities should publish methods and uncertainty ranges so that affected persons and courts can understand the basis of prioritisation.

Climate information is a public infrastructure. The INSPIRE Directive supports interoperable spatial information, while environmental-information rights under Aarhus law provide access and review.[34,35] Data on heat, floods, fires, health and critical infrastructure often sit in separate institutions. Interoperability, common geospatial standards and stable public archives reduce duplication and allow cumulative analysis.

Risk data can itself create harm. Parcel-level maps may affect property value, insurance and credit. Health and mobility data may identify vulnerable individuals. The GDPR requires lawful purpose, data minimisation, security and appropriate safeguards.[36] Transparency should not expose sensitive security information or personal data unnecessarily. The solution is layered access, aggregation where sufficient and clear rules for beneficial reuse.

Administrative rationality requires decisions to engage with material risk evidence. A planning authority should not rely solely on a design storm derived from an obsolete historical period where updated projections are available. A regulator should explain why a selected scenario and safety margin are proportionate. Failure to confront a central scientific finding may render reasons inadequate even where legislation leaves broad discretion.

Attribution science estimates how climate change altered the probability or intensity of an event. It can inform loss assessment, standard setting and litigation, but it does not replace ordinary evidence of exposure and negligence. Adaptation

[28]Charter of Fundamental Rights of the European Union, arts 1, 7, 17, 24, 35, 37 and 47.

[29]Regulation (EU) 2021/1119 establishing the framework for achieving climate neutrality, OJ 2021 L 243/1, art 5, as amended by Regulation (EU) 2026/667.

[30]European Commission, Forging a climate-resilient Europe: the new EU Strategy on Adaptation to Climate Change, COM(2021) 82 final.

[31]European Environment Agency, European Climate Risk Assessment, EEA Report No 1/2024.

[32]European Commission, Managing climate risks: protecting people and prosperity, COM(2024) 91 final.

[33]Regulation (EU) 2018/1999 on the Governance of the Energy Union and Climate Action, OJ 2018 L 328/1, arts 15, 17 and 19.

[34]Directive 2007/2/EC establishing an Infrastructure for Spatial Information in the European Community, OJ 2007 L 108/1.

[35]Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters, 25 June 1998, 2161 UNTS 447, arts 4–9.

[36]Regulation (EU) 2016/679, General Data Protection Regulation, OJ 2016 L 119/1.

duties are primarily prospective. Waiting for event-specific attribution before correcting a known vulnerability confuses scientific explanation with legal foreseeability.

Floods, Water Scarcity and Drought

Water is the principal medium through which many climate impacts are experienced. EU water law combines ecological status, river-basin planning, flood-risk management and sectoral regulation. The Floods Directive requires preliminary assessment, hazard and risk maps and coordinated management plans.[37] Climate change should affect scenario selection, review and coordination across borders. Plans must guide land use and investment rather than remain descriptive documents.

The Water Framework Directive seeks to prevent deterioration and achieve good status through river-basin management.[38] The Court in Weser gave the prohibition of deterioration concrete effect at project level.[39] Adaptation cannot justify routine ecological degradation on the ground that new water storage or abstraction is useful. Derogations require strict conditions, alternatives and reasons. France Nature Environnement further illustrates the care required when temporary exemptions are invoked.[40]

Drought governance requires allocation before crisis. Legal systems should define ecological minimum flows, essential human use, agricultural and industrial priorities, emergency restrictions, abstraction monitoring and review. Vague ministerial discretion invites unequal enforcement and political bargaining. Tradable water rights may improve flexibility where rights are clear and ecological limits are enforced, but they can concentrate control and exclude small users.

The human right to water requires sufficient, safe, acceptable, physically accessible and affordable water. [41] Pricing can encourage conservation but must protect essential use. Increasing block tariffs, leakage control, metering, targeted support and industrial efficiency can align equity and conservation. Blanket subsidies may reward high consumption and deprive utilities of maintenance funds.

Transboundary basins demand cooperation, information exchange and joint contingency planning. Upstream retention, hydropower operation and abstraction affect downstream safety and ecosystems. Climate change increases variability and can expose weaknesses in fixed allocation treaties. Adaptive clauses, drought-sharing rules and joint scientific bodies reduce the risk that scarcity becomes interstate conflict.

Coasts, Oceans and Managed Retreat

Sea-level rise, erosion, salinisation and storm surge challenge legal assumptions of stable shorelines and permanent property boundaries. Coastal defence can protect dense settlements but shift erosion and create ecological loss. Accommodation uses elevation, floodable design and warnings. Retreat reduces exposure but affects property, local tax bases, culture and community continuity. A lawful strategy must compare pathways over time rather than approve isolated defences.

The Marine Strategy Framework Directive and the law of the sea connect adaptation with ecosystem condition.[42] The 2024 ITLOS opinion confirms stringent obligations concerning marine pollution from greenhouse gases.[43] The agreement on biodiversity beyond national jurisdiction adds tools for area-based management and environmental assessment in areas beyond national jurisdiction.[44] Coastal adaptation should not externalise harm into marine habitats.

Managed retreat requires clear triggers, fair procedures and durable finance. Compulsory acquisition engages property protection but can be justified in the public interest if lawful and proportionate.[45] Compensation based only on post-risk market value may leave households unable to relocate, while full repeated compensation can reward continued high-risk development. Prospective zoning, disclosure, time-limited occupancy and voluntary acquisition can reduce future conflict.

No-build zones and rolling easements preserve future space for shorelines and wetlands. They restrict development ex-

[37]Directive 2007/60/EC on the assessment and management of flood risks, OJ 2007 L 288/27.

[38]Directive 2000/60/EC establishing a framework for Community action in the field of water policy, OJ 2000 L 327/1.

[39]Case C-461/13 Bund für Umwelt und Naturschutz Deutschland eV v Bundesrepublik Deutschland, EU:C:2015:433.

[40]Case C-525/20 Association France Nature Environnement v Premier ministre, EU:C:2022:350.

[41]Committee on Economic, Social and Cultural Rights, General Comment No 15 on the right to water, E/C.12/2002/11, 20 January 2003.

[42]Directive 2008/56/EC establishing a framework for community action in the field of marine environmental policy, OJ 2008 L 164/19.

[43]International Tribunal for the Law of the Sea, Request for an Advisory Opinion submitted by the Commission of Small Island States on Climate Change and International Law, Advisory Opinion of 21 May 2024, Case No 31.

[44]Agreement under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction, 19 June 2023.

[45]European Convention on Human Rights, arts 2, 6, 8, 13 and Protocol No 1 art 1.

pectations before immediate danger materialises, making scientific evidence and transition periods important. Existing owners and recent purchasers may occupy different positions. Public authorities should avoid creating moral hazard through assurances that every property will always be defended.

Cultural and Indigenous interests require more than asset compensation. The Billy decision demonstrates that delay in protective measures can interfere with home, family life and culture.[46] Relocation planning should preserve collective decision-making, language, access to customary land and the possibility of return where feasible. Forced dispersal may constitute a second loss beyond the physical hazard.

Heat, Health, Housing and Labour

Extreme heat is a predictable public-health hazard affecting mortality, cardiovascular and respiratory illness, pregnancy, mental health and medication safety. Heat-health plans should define thresholds, warnings, outreach, hospital readiness, cooling access and post-event evaluation. The WHO has identified effective prevention measures and the need for coordinated governance.[47] Legal responsibility should be allocated before an emergency, not improvised during it.

Urban heat is uneven. Tree cover, building quality, occupation and access to cooling produce neighbourhood differences. Cooling centres provide emergency relief but do not replace housing renovation, shade, ventilation and public-space design. Planning law should protect ventilation corridors and mature trees, require heat-sensitive design and prevent adaptation measures from increasing rents or displacement.

Building codes based on historical weather may lock in unsafe indoor conditions. The recast Energy Performance of Buildings framework supports renovation and zero-emission buildings, but energy and adaptation objectives must be coordinated.[48] Airtight efficiency without summer comfort can worsen overheating. Standards should address passive cooling, solar gain, ventilation, resilience during power failure and the needs of medically vulnerable occupants.

Labour law must manage occupational heat through exposure thresholds, rest, shade, water, scheduling, acclimatisation and stop-work rights. Piece-rate pay and insecure status can discourage workers from using protections. Employers should assess climate risk as part of occupational safety duties, while public authorities set enforceable minimums. Migrant and outdoor workers require accessible information and protection from retaliation.

Energy resilience is a health issue. Heatwaves can coincide with electricity-system stress. Market reform strengthens consumer protection and long-term system design, but local continuity requires resilient distribution, demand management, storage and priority restoration for critical services.[49] Disconnection rules and social tariffs should account for medically necessary cooling.

Ecosystems and Nature-based Adaptation

Healthy ecosystems regulate water, stabilise coasts, reduce heat, protect soil and support food systems. Nature-based adaptation can deliver multiple benefits and avoid the lock-in associated with hard infrastructure. It is not automatically benign. Tree planting in unsuitable ecosystems, poorly designed wetlands or monocultures can damage biodiversity and water availability. Ecological integrity and local context determine performance.

The Habitats Directive requires appropriate assessment where a plan or project may significantly affect a protected site.[50] Waddenzee established a precautionary standard for authorisation.[51] Climate urgency does not displace these obligations. Adaptation projects should apply the mitigation hierarchy, assess cumulative effects and use restoration rather than offsetting as the default response.

The Nature Restoration Regulation creates binding restoration obligations and planning structures that can support adaptation.[52] Restoration targets should be linked with flood, drought, urban and agricultural plans. A restored floodplain has little protective value if later development occupies the residual risk zone. Governance must secure long-term land management and monitor ecological function, not only hectares treated.

[46]Human Rights Committee, Daniel Billy and others v Australia, Communication No 3624/2019, CCPR/C/135/D/3624/2019, Views adopted 22 September 2022.

[47]World Health Organization Regional Office for Europe, Heat and Health in the WHO European Region: Updated Evidence for Effective Prevention, 2021.

[48]Directive (EU) 2024/1275 on the energy performance of buildings (recast), OJ L, 2024/1275, 8 May 2024, repealing Directive 2010/31/EU with effect from 30 May 2026.

[49]Directive (EU) 2024/1711 and Regulation (EU) 2024/1747 on improving the Union electricity-market design, OJ 2024 L 2024/1711 and OJ 2024 L 2024/1747.

[50]Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora, OJ 1992 L 206/7, art 6.

[51]Case C-127/02 Waddenvereniging and Vogelbeschermingsvereniging, EU:C:2004:482.

Payment for ecosystem services can align private land management with public resilience, but additionality, permanence and distribution require control. Carbon-farming certification should not confuse temporary carbon storage with adaptation benefits or biodiversity quality.[53] Contracts should specify baselines, monitoring, reversal, land tenure and public access to essential data.

Maladaptation occurs when an intervention transfers risk, raises emissions, deepens inequality or reduces future options. Seawalls can increase erosion elsewhere; air conditioning can increase peak demand and waste heat; irrigation can exhaust aquifers; fire suppression can accumulate fuel. Legal appraisal should contain an express maladaptation test and require monitoring capable of triggering correction.

Critical Infrastructure and Essential Services

Infrastructure resilience is systemic. Failure of electricity can disable water, communications, health and transport; flooding of a digital node can disrupt finance and emergency coordination. Project appraisal that evaluates each asset independently misses cascading risk. Lifelines analysis focuses on service continuity and recovery rather than the physical survival of every component.[54]

The Critical Entities Resilience Directive requires national strategies, risk assessments and measures by identified entities across essential sectors.[55] NIS2 addresses cybersecurity and recognises the interaction of physical and digital threats.[56] Climate assessment should be integrated with these regimes so that entities do not maintain separate, inconsistent risk registers.

Climate-proofing guidance for 2021–2027 infrastructure links mitigation and adaptation assessment with Union funding.[57] The economic case favours life-cycle cost, redundancy, maintainability and safe failure over lowest initial price.[58] Procurement documents should specify performance under future conditions and allocate design, data and change risk clearly.

Standards need adaptive margins. Designing only for a median projection can produce early failure; designing every asset for the worst imaginable case can waste resources. Criticality, lifespan, reversibility, network alternatives and consequences of failure determine the safety margin. Modular upgrading and reserved space preserve options.

Public-private partnerships complicate accountability. Private operators may control assets while the State remains responsible for essential services and positive human-rights duties. Contracts should require risk disclosure, maintenance, emergency cooperation, audit, data portability and continuity on termination. Force-majeure clauses should distinguish genuinely exceptional events from foreseeable climate conditions that the operator was paid to manage.

Energy-system Adaptation and Climate Resilience

The energy transition is itself exposed to climate risk. Heat reduces thermal-generation efficiency and transmission capacity; drought constrains hydropower and cooling water; storms and wildfire damage networks; changing wind and precipitation patterns affect renewable output; sea-level rise threatens coastal terminals and substations. A mitigation asset that cannot operate under future conditions does not provide durable decarbonisation. Energy planning should therefore combine emissions pathways with physical-risk scenarios.

Electricity risk-preparedness law requires Member States to identify crisis scenarios, adopt preparedness plans and cooperate across borders.[59] Climate projections should inform those scenarios rather than appear as a generic background factor. Regional coordination is important because simultaneous heat, drought and low renewable output can affect interconnected markets, while uncoordinated export restrictions transfer scarcity to neighbours.

Resilience measures include network meshing, undergrounding where cost-effective, vegetation management, fire-resistant equipment, flood protection, storage, demand response, microgrids and black-start capability. No measure is universally superior. Undergrounding reduces wind exposure but raises cost and can complicate heat dissipation and repair. Distributed systems reduce dependence on central assets but increase coordination and cybersecurity needs. Regulators

[52]Regulation (EU) 2024/1991 on nature restoration, OJ 2024 L 2024/1991.

[53]Regulation (EU) 2024/3012 establishing a Union certification framework for permanent carbon removals, carbon farming and carbon storage in products, OJ 2024 L 2024/3012.

[54]World Bank, Lifelines: The Resilient Infrastructure Opportunity, World Bank 2019.

[55]Directive (EU) 2022/2557 on the resilience of critical entities, OJ 2022 L 333/164.

[56]Directive (EU) 2022/2555 on measures for a high common level of cybersecurity across the Union, OJ 2022 L 333/80.

[57]European Commission, Technical guidance on the climate proofing of infrastructure in the period 2021–2027, OJ 2021 C 373/1.

[58]OECD, Climate-resilient Infrastructure, OECD Environment Policy Paper No 14, 2018.

[59]Regulation (EU) 2019/941 on risk-preparedness in the electricity sector, OJ 2019 L 158/1.

should compare service continuity and recovery time across the full life cycle.

Cost allocation presents an intergenerational and regional problem. Current consumers may finance assets whose principal benefits arise decades later, while vulnerable regions require greater investment despite a smaller customer base. Regulatory asset bases, public grants and solidarity mechanisms should reflect beneficiaries, affordability and wider system value. Connection charges should not place the full cost of anticipatory resilience on the first clean project in an exposed region.

Emergency fossil generation may be temporarily necessary after a system shock, but resilience cannot become a route to permanent carbon lock-in. Preparedness plans should prioritise demand reduction, storage, interconnection and low-carbon firm capacity, define strict conditions for emergency derogations and publish post-event review. Adaptation and mitigation must be assessed together because measures that increase long-term emissions amplify the hazard the system is designed to withstand.

Public Budgets, Fiscal Risk and Local Government

Climate impacts create contingent public liabilities through emergency response, reconstruction, public insurance, guarantees, health expenditure and revenue loss. Conventional budgets often record these costs only after disaster, while prevention competes with visible current services. Fiscal-risk statements should disclose physical climate exposure, major guarantees, vulnerable public assets and the sensitivity of debt paths to repeated shocks. Transparency changes adaptation from exceptional spending into ordinary financial governance.

The revised EU economic-governance framework requires medium-term fiscal-structural planning and debt sustainability analysis.[60] Adaptation investment should be recognised as economically productive where it prevents larger future loss, but a general green label cannot remove the need for project quality. Fiscal rules should preserve incentives for maintenance and prevention while avoiding creative classification of ordinary expenditure as resilience.

National budgetary frameworks increasingly require attention to macrofiscal risk and medium-term planning.[61] Climate stress testing should use multiple hazards and correlated events. A flood can damage assets, reduce tax revenue and trigger public guarantees simultaneously. Central banks and fiscal councils can contribute analysis without deciding distributive priorities reserved to elected institutions.

The Recovery and Resilience Facility and cohesion funds provide substantial investment channels.[62,63] Their legal conditions should be used to prevent reconstruction of obsolete vulnerability. The do-no-significant-harm principle is necessary but not sufficient: funded projects should also demonstrate climate robustness, maintenance finance and consistency with territorial adaptation plans. Milestones should measure delivered protection rather than procurement alone.

Local governments control many adaptation levers but often have the weakest tax base and technical capacity. Unfunded mandates produce paper plans and unequal protection. Stable formula finance, shared technical services, open risk data and borrowing frameworks can support implementation. Allocation should reflect vulnerability and service responsibilities, not only population or project-readiness scores.

Intergovernmental responsibility must be explicit after disaster. Disputes over whether national, regional or municipal authorities should pay delay recovery and encourage strategic underinvestment. Pre-arranged cost-sharing, emergency advances and audit rules improve speed while preserving accountability. Central support may be conditional on enforcement of risk-sensitive land-use rules, but conditions should not punish communities for hazards they lack power or resources to manage.

Finance, Insurance and Corporate Governance

Adaptation finance suffers from weak revenue models and diffuse benefits. A flood barrier or heat-health system often protects public welfare without generating a user charge. Public finance, guarantees, land-value capture and resilience bonds can mobilise resources, but the funding source should match beneficiaries and ability to pay. Debt instruments are unsuitable where repayment depends on fiscal capacity already weakened by disasters.

The EU Taxonomy treats substantial contribution to adaptation through solutions that reduce physical climate risk without increasing risk elsewhere.[64] Delegated technical criteria

[60]Regulation (EU) 2024/1263 on the effective coordination of economic policies and on multilateral budgetary surveillance, OJ 2024 L 2024/1263.

[61]Council Directive 2011/85/EU on requirements for budgetary frameworks of the Member States, OJ 2011 L 306/41, as amended by Council Directive (EU) 2024/1265.

[62]Regulation (EU) 2021/241 establishing the Recovery and Resilience Facility, OJ 2021 L 57/17, as amended.

[63]Regulation (EU) 2021/1060 laying down common provisions for specified Union funds, OJ 2021 L 231/159, arts 9 and 73 and recital 10.

require robust climate-risk and vulnerability assessment for many activities.[65] Classification can improve investment discipline, but compliance should not become a generic consultant report detached from project design.

Cohesion rules integrate climate objectives and resilience into programme and project selection, while InvestEU supports sustainable investment.[66,67] Funding authorities should publish adaptation assumptions and monitor outcomes after completion. Expenditure labels do not establish resilience. A project may be counted as climate-related while remaining vulnerable to the hazards it is intended to address.

Insurance prices risk and finances recovery, but climate change threatens affordability and availability. Risk-based premiums encourage prevention where households can act and information is credible. They become punitive where tenants, low-income owners or legacy settlements cannot reduce exposure. Solvency regulation protects insurer capacity, yet public policy must also define coverage, disclosure, consumer protection and the boundary of public backstops.[68]

Public insurance and reinsurance should be conditional on risk reduction. Repeated unconditional rebuilding can entrench exposure. Deductible support, grants for property-level measures, community protection and prospective land-use reform can combine solidarity with prevention. Withdrawal of coverage requires notice, appeal and transition because insurance often determines mortgage access and property value.

Corporate reporting should explain material physical risks, adaptation expenditure, scenario assumptions and operational dependencies. CSRD rules provide a disclosure architecture, while due-diligence duties address environmental and human-rights impacts in value chains.[69,70] The 2026 amendments require attention to the current consolidated scope. Disclosure is not adaptation unless governance and capital allocation change.

Agriculture, Food Systems and Rural Resilience

Agriculture is exposed to heat, drought, flood, pests, soil degradation and water competition. Adaptation choices include crop diversity, soil cover, agroforestry, water efficiency, altered calendars, insurance and landscape restoration. Policy should avoid treating yield maximisation under a central forecast as resilience. Diversity and redundancy may lower average output in favourable years while reducing catastrophic failure.

The Common Agricultural Policy can finance adaptation through national strategic plans and conditionality.[71] Payments should reward measurable public goods and long-term soil and water function rather than practices in name only. Monitoring must distinguish income support from additional adaptation. Small farms need technical assistance and accessible procedures.

Drought insurance can stabilise income but create moral hazard if it subsidises water-intensive production in unsuitable locations. Index products reduce verification cost but create basis risk where the index does not match actual loss. Public subsidy should be linked with risk assessment, diversification and compliance with abstraction limits.

Food resilience extends beyond farms to processing, storage, transport, labour and trade. Strategic stocks can buffer temporary shocks but are costly and can distort markets. Competition and trade rules should permit proportionate emergency action without export restrictions that shift scarcity to more vulnerable countries. Food-security planning should include nutrition and affordability, not only aggregate calories.

Rural adaptation can create land conflicts where conservation, renewable energy, water storage and food production compete. Strategic environmental assessment is suitable for comparing cumulative demands before individual projects are authorised.[72] Participation must include tenants, seasonal workers and customary users whose interests may not appear in land registers.

Planning, Environmental Assessment and Participation

Land-use planning is the most direct means of preventing new exposure. It can reserve floodplains, manage coastal retreat, protect cooling corridors and direct growth toward serviced areas. Its benefits are politically difficult because avoided development is less visible than completed infrastructure. Clear statutory risk objectives and maps reduce pressure for case-by-case exceptions.

Environmental impact assessment requires consideration

[64]Regulation (EU) 2020/852 on the establishment of a framework to facilitate sustainable investment, OJ 2020 L 198/13, art 11.
[65]Commission Delegated Regulation (EU) 2021/2139 establishing technical screening criteria under the Taxonomy Regulation, OJ 2021 L 442/1.
[66]Regulation (EU) 2021/1060 laying down common provisions for specified Union funds, OJ 2021 L 231/159, arts 9 and 73 and recital 10.
[67]Regulation (EU) 2021/523 establishing the InvestEU Programme, OJ 2021 L 107/30.
[68]Directive 2009/138/EC on the taking-up and pursuit of the business of Insurance and Reinsurance, OJ 2009 L 335/1, as amended.
[69]Directive (EU) 2022/2464 as regards corporate sustainability reporting, OJ 2022 L 322/15, as subsequently amended.
[70]Directive (EU) 2024/1760 on corporate sustainability due diligence, OJ 2024 L 2024/1760, as amended by Directive (EU) 2026/470.
[71]Regulation (EU) 2021/2115 establishing rules on support for strategic plans under the common agricultural policy, OJ 2021 L 435/1.
[72]Directive 2001/42/EC on the assessment of the effects of certain plans and programmes on the environment, OJ 2001 L 197/30.

of climate vulnerability and major-accident and disaster risks where relevant.[73] Strategic environmental assessment addresses the earlier stage at which location and development pattern remain open.[74] Alternatives should include non-development, demand management, relocation and nature-based measures. An assessment that considers only how a project affects climate, but not how climate affects the project, is incomplete.

Aarhus rights require access to information, early participation and access to justice.[75] Adaptation plans make distributive choices about which places receive protection and which face retreat. Those choices demand participation before priorities are fixed. Technical models should be explained in accessible form, and communities should have resources for independent expertise.

Emergency urgency can justify accelerated procedures but not routine exclusion of participation. Pre-disaster frameworks can specify emergency powers, environmental safeguards, procurement controls and sunset clauses. Planning before the event allows faster lawful action afterwards. Permanent reconstruction decisions should not be taken under short emergency timeframes where alternatives can still be assessed.

Judicial review should test competence, evidence, reasons, equality, rights and consistency with binding plans. Courts need not select engineering designs to require an authority to address a central risk or explain departure from its own strategy. Effective remedies may include plan revision, reconsideration, interim protection or monitoring rather than automatic annulment of every measure.

Adaptation Litigation and the Standard of Review

Adaptation litigation often concerns omission rather than unlawful positive action. Applicants challenge delay in implementing plans, inadequate protection, discriminatory priority setting or approval of exposed development. The remedy sought may be institutional: appointment of a commission, adoption of milestones or recurrent reporting. Leghari is a leading example, using constitutional rights to require implementation of Pakistan's climate policy and creating a supervisory structure.[76]

The standard of review must account for technical complexity without collapsing into deference. Courts can examine whether risk assessment is current, whether vulnerable groups were considered, whether reasons engage with evidence and whether implementation mechanisms exist. A wide margin on the choice among lawful measures is compatible with strict scrutiny of persistent inaction.

Mitigation judgments also shape adaptation reasoning. Neubauer treated delayed mitigation as a threat to future freedom, while Urgenda connected foreseeable climate harm with positive duties under Articles 2 and 8 ECHR.[77,78] Adaptation cannot be used as a defence to inadequate mitigation because greater warming increases limits and residual loss. Conversely, ambitious mitigation does not excuse failure to prepare for impacts already locked in.

Causation should be matched to the claim. A challenge to a missing heat plan does not require proof that climate change caused a named death. It requires a foreseeable risk, a legal duty and inadequate action. Compensation claims may require stronger causal evidence. Declaratory and structural remedies can address systemic risk before individual injury occurs.

Standing rules determine whether diffuse and future risk is justiciable. KlimaSeniorinnen recognised association standing under specified conditions while rejecting the individual applicants for lack of victim status.[79] Domestic systems may permit broader public-interest standing. Whatever the model, procedural law should not make recurrent, scientifically established risk incapable of review merely because harm is probabilistic or shared.

Equity, Vulnerability and Just Resilience

Climate hazards are not socially neutral. Age, disability, income, health, housing tenure, occupation, migration status, geography and discrimination shape exposure and recovery. Vulnerability assessment should use disaggregated data without reducing individuals to static categories. People can face overlapping disadvantages and possess local capacities that central models overlook.

Just resilience requires recognition, distribution, participation and remedy. Recognition concerns whose knowledge and losses count. Distribution concerns protection, finance

[73]Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment, OJ 2012 L 26/1, as amended by Directive 2014/52/EU.

[74]Directive 2001/42/EC on the assessment of the effects of certain plans and programmes on the environment, OJ 2001 L 197/30.

[75]Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters, 25 June 1998, 2161 UNTS 447, arts 4–9.

[76]Leghari v Federation of Pakistan, Lahore High Court, WP No 25501/2015, Orders of 4 and 14 September 2015, PLD 2018 Lahore 364.

[77]Federal Constitutional Court of Germany, Order of 24 March 2021, 1 BvR 2656/18 and others, BVerfGE 157, 30.

[78]Urgenda Foundation v State of the Netherlands, Supreme Court of the Netherlands, 20 December 2019, ECLI:NL:HR:2019:2007.

and residual risk. Participation concerns power over priorities. Remedy concerns correction when institutions fail. A project can be technically effective yet unjust if it protects commercial districts by diverting water toward poorer neighbourhoods.

Minimum protection standards limit the ability of cost-benefit analysis to abandon groups with low monetised assets. Rights to life, health, water, home and non-discrimination establish a floor.[80,81] Above that floor, economic analysis can select cost-effective pathways. Equality may require different treatment of differently situated groups, including extra resources for accessible warnings, cooling, evacuation and recovery.

Adaptation finance should follow vulnerability as well as project readiness. Competitive calls often favour wealthy municipalities with technical staff, widening disparities. Formula funding, planning support and pre-approved project pipelines can improve access. Evaluation should track who benefits, who bears construction and displacement costs and whether protection remains effective over time.

Intergenerational equity requires pathways rather than one-off assets. A defence that is adequate for twenty years may create a sudden burden when it fails or becomes unaffordable. Authorities should disclose protection horizons, residual risks, upgrade triggers and funding responsibilities. Future residents should not inherit concealed liabilities.

Institutional Design and an Adaptation Compliance Framework

A coherent adaptation statute should establish objectives, institutional responsibility, recurrent national risk assessment, sectoral and local plans, finance, participation, monitoring and judicial review. It should define the relationship between ordinary planning and emergency powers. It should also require public bodies and regulated critical entities to assess physical climate risk within their mandates.

The planning cycle should begin with common scenarios and vulnerability analysis. Authorities should identify priority risks, protection standards and measurable outcomes; select measures through alternatives analysis; fund implementation; publish indicators; and revise plans after events or new science. Independent expert review can reduce optimism bias and political postponement.

Risk ownership must be explicit. A national ministry may own standards and finance, a municipality may control land use, a utility may operate infrastructure and a household may maintain property-level measures. Gaps appear when each assumes another actor will act. Statutory coordination duties, shared data and escalation procedures are therefore necessary.

Adaptation obligations should be proportionate to control, resources and consequences of failure. Essential-service operators require stronger continuity duties than ordinary businesses. Long-lived public infrastructure requires more conservative scenarios than reversible short-lived assets. Vulnerable households require assistance before behavioural obligations or insurance penalties are imposed.

Compliance requires more than publication of plans. Indicators should cover risk reduction, service downtime, avoided exposure, ecosystem function, warning reach, health outcomes, insurance protection and distribution. Audit bodies should assess whether expenditure produced additional resilience. Courts and ombuds institutions should have access to the evidence needed to review omissions.

The strongest legal model combines binding process with reviewable substantive floors. Numerical uniformity is impossible across hazards and territories, but complete discretion is equally inadequate. Continuous progress under Article 5 of the European Climate Law, rights-based minimum protection and sectoral standards can form the legal spine, while local institutions choose context-sensitive measures.[82] Polycentric governance permits experimentation within common accountability.[83]

Resilience is achieved when institutions can anticipate, absorb, recover and transform without sacrificing rights or transferring risk to those least able to bear it. The law should preserve that capacity through transparent foresight, fair allocation and enforceable correction. Adaptation policy then becomes neither a catalogue of projects nor an emergency reaction, but a durable structure of public responsibility.

[79]Verein KlimaSeniorinnen Schweiz and Others v Switzerland App no 53600/20, Grand Chamber judgment of 9 April 2024.

[80]European Convention on Human Rights, arts 2, 6, 8, 13 and Protocol No 1 art 1.

[81]Charter of Fundamental Rights of the European Union, arts 1, 7, 17, 24, 35, 37 and 47.

[82]Regulation (EU) 2021/1119 establishing the framework for achieving climate neutrality, OJ 2021 L 243/1, art 5, as amended by Regulation (EU) 2026/667.

[83]Elinor Ostrom, A Polycentric Approach for Coping with Climate Change, World Bank Policy Research Working Paper 5095, 2009.

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