Chapter 20

Advanced Materials, Artificial Intelligence, and Sustainable Technologies for Energy and Environmental Engineering
ISBN: 978-9915-704-10-4
DOI: 10.62486/978-9915-704-10-4.ch20
Pages: 330-350

©2025 The authors. This is an open access article distributed under the terms of the Creative Commons Attribution (CC BY) 4.0 License.

Global Regulatory Frameworks and Sustainable Policy Approaches

Husnain Mukhdoom[1] ✉

[1]Famous Forum of Worldwide Collaborators. Lahore, Pakistan.

ABSTRACT

This article examines global regulatory frameworks and sustainable policy approaches, emphasizing the central role of regulation in addressing persistent market failures linked to long-term environmental, social, and technological risks. It analyzes how international treaties, soft-law instruments, and supervisory standards cascade into national and sectoral regulations, shaping sustainability outcomes across jurisdictions. The study compares major policy instruments—including command-and-control regulation, market-based mechanisms, disclosure-based policies, fiscal tools, and experimentalist governance—assessing their effectiveness, equity implications, and implementation constraints. Particular attention is given to sector-specific frameworks in climate and environmental governance, energy and industry transformation, sustainable finance and corporate disclosure, digital and artificial intelligence systems, and health and food systems. The article further explores regional regulatory approaches in the European Union, the United States, China, South Asia, Africa, Latin America, and the ASEAN–Pacific region, highlighting how state capacity, industrial strategy, and political economy influence policy design and enforcement. The analysis underscores that regulatory success depends less on aspirational targets than on institutional coherence, robust measurement, reporting and verification systems, enforcement capacity, and standard interoperability. Finally, the article outlines future scenarios toward 2035, arguing for adaptive, data-driven, and justice-oriented regulatory frameworks capable of managing emerging risks—particularly those associated with the growing environmental footprint of artificial intelligence—while ensuring durable and inclusive sustainability transitions.

Keywords: Global regulation; Sustainable policy; Climate governance; Regulatory instruments; Artificial intelligence impacts; Just transition

INTRODUCTION

Why Regulation Shapes Sustainability Outcomes

Markets are strong capital allocation mechanisms, but long-term social and environmental risks are chronically mispriced by the market. An example is climate change: harms that are decades old, which cut across boundaries and are full of profound uncertainty, which traditional discounting and incomplete information cannot readily represent.[1,2] The degradation of biodiversity is also under-priced since most ecosystem services are not priced until they fail, and invasive species and habitat destruction will be the diffuse costs that cannot be internalized by the individuals acting privately.[3] These failures are augmented by new digital externalities: AI and data-centers increase the energy and water demands growing with their size and not reported in forms helpful to decision-making, so under-incentivising efficiency and decarbonization of grids.[4] In those markets in which markets respond, such as consumer

pressure, investor activism, or voluntary standards, it has been found that the response is often incomplete or slow without clear signals of policy.[5]

There is regulation to rectify such failures: first, it charges or limits externalities through carbon taxes, emission trading, performance requirements, endangered-species safeguards, and product-stewardship requirements.[6] Second, it establishes guardrails to avoid high-probability harms (e.g., methane leaks, deforestation) and to deal with low-probability, high-impact risks (e.g., cascading ecosystem or power-system failures).[2,3] Third, it increases the rate of innovation diffusion through the reduction of the costs of adoption (auctions, tax credits), harmonization of infrastructures (grid codes, data and reporting standards) and provision of certainty which stimulates private investment.[7,8] Lastly, it would facilitate a fair transition through cost-sharing and benefits by worker, region, and supply chain, including through reskilling benefits, specific rebates, and community benefits, to make decarbonization a politically and socially sustainable transition.[9]

This chapter charts the world-system of sustainability regulation and demonstrates the way the international treaties, soft-law norms, and supervisory expectations trickle down into national and local regulations.[2,3] We evaluate the effectiveness of policy tools, including command-and-control, market-based, disclose, fiscal policies, and experimentalist, and compare them in terms of their effectiveness.[5,10] Then we examine regional differences in the European Union, United States, China, India/South Asia, Africa, Latin America and ASEAN/Pacific based on the influence of state capacity, industrial strategy and political coalitions on instrument choice.[8,11] The whole time, we pre-implementation realities implementation realities measurement, reporting, and verification (MRV); enforcement capacity; interoperability of standards; distributional design since results are dependent less on aspirational goals and more on institutional implementation.[5,7] We conclude with future directions to 2035 that are neither fast nor swift enough to drive but are balancing with the emerging risks of AI energy footprint, or the nature-related financial risks.[2,4]

Road map: section 3 elucidates some important concepts and governance prisms (polycentricity, precaution vs. innovation, policy feedbacks). Section 4 scans over the treaty layer and the institution layer. Part 5 explores sector schemes: climate, energy-industry, finance and disclosure, digital/AI, and food-health; making the choice of instruments to be quantifiable. Section 6 makes a comparison of instruments and provides a design matrix. Section 7 is case comparisons on a regional level. Section 8 deals with cross-border coordination, trade and standards interoperability. In Section 9, 10, and 11, there is information on justice, implementation, and adaptive regulation and continuous improvement metrics. The case studies are succinct and contrasting in section 12. Section 13 illustrates scenarios up to 2035. Sections 14 to 17 are topped off with practical recommendations, glossary, discussion prompts and resource guide.

Key Concepts & Analytical Lenses

Policy objective of sustainability is a combination of the environmental integrity, social equity and long term economic resilience. Environmental integrity poses the question of whether policy pathways should not exceed planetary limits and keep ecosystems across generations intact; social equity based on distributional outcomes and procedural fairness; long-term economic resilience based on structural change and adaptive capacity to shocks.[12] These three dimensions are complementary, yet tend to conflict in the short term, that is why sustainability policy is not only about what targets to achieve and what tools to use, but about how to design governance.[13]

This design space can be mapped with the help of regulatory typologies. Command-and-control standards impose definite limits or technological imperatives and cannot be dispensed with in case harms are acute, measurable, and demand certainty (e.g. ban on ozone-depleting substances). Internalized by market-based instruments, such as carbon pricing, tradable permits, and differentiated charges, market-based policies are effective in that they reduce externalities, but they are not costly since they require coverage, price paths, and complementary actions alleviating frictions between political economy.[10] Sustainability reporting (via disclosure-based regulation e.g. under emerging global baselines) is tried to discipline markets by information; in effect, only works best when comparable and audited disclosures are decision-useful and investors can act on them.[14] Co- /self-regulation and meta-regulation move focus of organizational systems, such as risk management, governance, and learning loops, which are subject to the supervision of the masses; their potential is flexibility, the danger is performative compliance without enforcement.[15] Experimentalist governance focuses on iterative goal-setting, benchmarking and revising across jurisdictions; it can speed up the learning in a state of uncertainty with accountability being preserved.[16] Lastly, polycentric governance acknowledges various decision centers including local, national, transnational that operate through norms and mutual adaptation instead of hierarchy; it is more consistent with commons problems of heterogeneous contexts.[13]

The binding tissue between instruments and levels is known as policy coherence. On a horizontal front, energy, industry, agriculture, finance, labor and environment ministries need to coordinate their efforts to ensure no whiplash (e.g., industrial competitiveness plans eroding emissions caps); on the vertical front, local-national-global connections have to coordinate to ensure there is no leakage and duplication.[12] Even though the term coherence does not imply uniformity, plausible national strategies tend to combine tools and arrange them, such as pilots, scaled standards, pricing, or coordinate with trade and innovation policy.[10]

Other criticism prisms enhance design decisions. Just transition lens foregrounds shares regional, sectoral, and worker distributional effects and has social dialogue and support policies (retraining, income support, place-based development) to climate and industrial strategies.[16] The precaution innovation lens describes decisions in the face of uncertainty: take action now to insure against irreversible damages but permits trial and error and spread of alternatives that are cleaner.[17,18] The feedbacks of policies and lock-in remind us that the present-day regulations condition the future coalitions, e.g. carbon pricing to finance visible benefits will be more popular, and infrastructure decisions may compromise the high-emissions paths.[10] Path dependence means that there is a need to utilize reform windows to re-route investment cycles and standards at the time of technological change or crisis.[16] The role of incumbents, new entrants, and organized labor, along with the role of the durable change to unite the plausible commitments with the transitional support and the open burden-sharing, is emphasized by the political economy of reform.[12]

Global Treaties & Institutions: The Rule-Setting Layer

MEAs offer anchor norms, targets and reporting structures which domestically based regulating bodies convert into national law. The UNFCCC and Paris Agreement provide long-term temperature objectives, nationally determined contributions (NDCs), transparency levels, and a five-year ambition cycle, which thoroughly incorporates domestic policy changes[12,16] in climate. The Kunming -Montreal Global Biodiversity Framework (GBF) is a document that outlines four goals and 23 targets of the Convention on Biological Diversity, now incorporates a continuously evolving system of monitoring to assess progress - an instance of target-and-

review governance, which now requires integration at the domestic level, primarily in land-use, finance, agriculture, and trade.[12,19]

Montreal Protocol on Substances that Deplete the Ozone Layer is one of the brightest examples of an adaptive treaty-making: non-compliance regime, technology switching schedule supported by finances, and binding control schedules. It applies this reasoning to HFCs in its Kigali Amendment; recent studies highlight the importance of lacing the fridge transition with an appliance efficiency standard to get the greatest climate gains- a lesson in how sectoral policies can be made consistent with the objective of treaties.[20] The Basel Convention on hazardous-waste governance has increased restrictions on the transboundary flows of plastic wastes; national governments are now implementing prior informed consent and quality standards, and tracking, which can be seen as examples of how treaty amendments can transform the global value chains when combined with domestic capacity.[18]

The interfaces of trade and investment become the precursors of sustainability. WTO regulations determine the policy space on carbon pricing, border adjustments, subsidies and product standards. With the spread of climate measures, the system is fumbling towards interoperability by design (common methodologies, due process, and transparency) to ensure a minimum number of frictions are not created at the cost of not pursuing decarbonization ambition, indicating that there is a need to improve the alignment between trade disciplines and climate/biodiversity ambitions.[10,12] Sustainability chapters are now incorporated in preferential trade agreements, and in some cases value-chain commitments; these need to be monitored, enforceable, and followed up domestically in addition to having a hortatory text.[16]

The social gaps in the sustainability governance are bridged by the labor and human rights. The principles that have triggered the national due-diligence regimes and reporting requirements are ILO just transition guidance and UN Guiding Principles on Business and Human Rights (UNGPs). However, it has been revealed that many companies are still talk-oriented and the disclosure in them is only thin, which indicates that enforceable obligations, supervisory ability, and enforceable backstop of liability are essential.[15] Integrating labor rights within climate-industrial policy (e.g. conditional subsidies, workforce transition alliances) makes it more legit and faster to adopt.[16]

Standard setting institutions transform general norms into technical specifications. The measurement, management, and assurance of energy, environmental, and circular-economy sectors, as well as of finance, rely on ISO/IEC standards, and the International standards board (ISSB) has published IFRS S1 and S2, a global standard of investor-centered sustainability disclosure all spillovers to risk management of corporates and capital allocation.[14] Disclosure regimes are based on comparability, assurance, and integration into financial supervision, otherwise they are likely to remain as box-ticking exercises.[14,15]

The soft law and compliance work simultaneously. Most of the treaty obligations are based on national transposition, peer review, transparency and mutual recognition as opposed to supranational enforcement. Hard sanctions can be replaced by sunset-plus-review clauses, learning-based stocktakes, watchdog transparency (registries, standardized reports), and making coalitions reform ready.[12,16] Polycentricity is relevant in this respect: cities, regions, and transnational networks tend to become more rapid than the national governments, which produces demonstration effects and closes the ratchet.[13] In situations with uncertain but potentially disastrous risks, precautionary design, in combination with innovation sandboxes and periodic reviews of evidence, is useful in helping treaties and standards navigate between

stagnation and blindly rushing ahead.[17,18] Overall, the rule-setting layer is effective when it is MEA-coherent, aligns disclosure, standards, and incentives, and it institutionalizes the process of learning and tightening by policy.[10,12]

Sector/Domain Frameworks: Where Rules Meet Real Economies

Climate & Environment

Policy goals: internalize environmental externalities, bend absolute emissions and biodiversity loss curves, and build climate resilience while safeguarding livelihoods. This means achieving timely, measurable reductions in greenhouse gases (GHGs), halting ecosystem degradation, and minimizing pollution across product life cycles.[12]

Core instruments

Emissions governance: the main tools of price-based motivators are cap-and-trade and carbon taxes. Cap-and-trade provides certainty of quantities, and allowances in the trade, taxes provide a stable marginal abatement incentive and recycling possibilities of revenue. Things are becoming more blurred with hybrid designs (price floors/ceilings in ETS; emissions-indexed tax credits). The use of offsets has to be limited to high-integrity credits that have conservative baselines, strong permanence, leakage protection, and a transparent project level.[10,21] MRV systems need to be digital-first: standardized protocol and 3rd-party verification and asset level data to facilitate audits and enforcement.

Natural capital: the rules of biodiversity net-gain (BNG) mandate ecological improvement of developments; no-deforestation supply-chain requirements associate compliance on imports with geolocation and geolocation; and watershed governance (watershed governance) combines permits, quality trading, and source-water protection compacts to align upstream land use with downstream water quality results.[22] Waste & circularity. Extended Producer Responsibility (EPR) causes producers to be economically and operationally liable to dispose of their goods at their end-of-life; eco-design establishes durability, reparability and quantity of recycled content criteria; right-to-repair policies allow access to parts, manuals, and diagnostics with no harm and a security risk and data protection.[23,24]

Implementation challenges. Abatement is undermined by too low price signals, limited coverage or enforcing these signals. The offset programs can be prone to excessive over-crediting in the absence of conservative baselines and independent verification.[21] Without ecological skills and expertise, data, and compliance capacity, local authorities in charge of watersheds and BNG may come to a halt.[22] The instruments of circularity demand product data (materials, chemicals of concern) that is interoperable and coordination among thousands of SMEs.

Equity considerations: carbon pricing may be retrogressive when the revenues are not recycled; equity-by-design implies that it has targeted subsidies of the form of rebates, rural mobility options, and low-income building retrofits. BNG must avoid green gentrification where funding is done on community stewardship and respecting tenure rights. The informal waste pickers should be incorporated in EPR programs through producer responsibility organizations based on the living-income contracts and safety standards. Metrics. Emissions: GHGs by absolute and intensity; price of allowance; tax coverage. Nature: hectares of habitat increase, richness of species, importation of deforestation. Circularity: rates of collection / recycling of each material, rate of repair, lifetime of the product, phase out of hazardous substances. Equity: proportion of the carbon-pricing revenues to the vulnerable groups; the scores of community participation.[10,23]

Energy & Industry

Policy goals: rapidly decarbonize power, electrify demand, scale firm low-carbon fuels, and transform materials industries (steel, cement, chemicals) while maintaining reliability and affordability.

Core instruments

Clean power deployment: technology-neutral or targeted auctions that have strong pre-qualification, performance insurance and bankable offtake use less money and less delivery risk, Renewable Portfolio Standards (RPS)/Contracts-for-Difference use more scale, grid codes and interconnection queue reform use more deliverability and minimize curtailment and flexibility markets (storage, demand response) use variable renewables.

Industrial decarbonization: performance targets (e.g., tCO 2 per ton of steel / cement) are ratched down with long lead-time visibility; hydrogen support targets upstream production standards and demand-side contracts; CCUS authorizes pore-space access, liability, and MRV and leaves support of hard-to-abate processes to governments.[25] Carbon leakage tools. Embedded-carbon costs to imports are equated by the border adjustment mechanisms, and a decarbonisation transition plans with time constraints ensure competitiveness, without disregarding price signals or contingent assistance on decarbonisation paths.[26]

Implementation challenges: under-bidding at auction, congestion in the supply chain may lead to non-delivery; backlog in the queue and sluggish network build-out strands the projects. The requirements of industrial standards (credible product-level MRV (e.g., low-carbon cement clinker ratios), harmonized definitions) are to prevent the problem of green protectionism.[25] The CBAM-type measures entail a high quality of embedded-carbon data and a sound customs administration.[26]

Equity considerations: design auctions that come with community benefits agreement and local hiring; safeguard the low-income consumers through special purpose bill credits. In the case of industry, pair standards together with just-transition compacts, reskilling, regional investment fund, and SME supplier enablement.

Metrics: levelized cost of electricity (delivered), price in an auction, average interconnection time; industrial emissions per unit of output; cost of hydrogen and its usage rates; CCUS capture rates and permanent storage; carbon-intensity differentials between domestic and imported good.[25,26]

Finance & Corporate Disclosure

Policy goals: align capital markets with sustainable outcomes by improving decision-useful transparency, curbing greenwash, and pricing climate- and nature-related risks in supervision.

Core instruments

Reporting baselines: the ISSB's IFRS S1/S2 create a global floor for investor-focused sustainability and climate disclosures (governance, strategy, risk management, metrics/ targets). Jurisdictions adopting double materiality expand scope to outward impacts alongside financial materiality. Taxonomies & labels. Decision-useful classifications (with "do no significant harm" and minimum safeguards) guide product labeling, disclosures, and public procurement; transition categories can crowd-in high-emitting sectors with science-based pathways.

Prudential/supervisory tools: climate scenario analysis and stress testing assess credit-

market vulnerabilities; stewardship codes formalize investor engagement escalation (Flood-tests and exploratory exercises are maturing toward capital frameworks).[27] Implementation challenges. Interoperability across standards (global baseline vs regional requirements), data gaps (Scope 3, private firms), and assurance capacity. Taxonomy usability for SMEs and banks is often low without simplified criteria and digital tags. Stress tests can become "model theater" if not linked to risk appetite, underwriting standards, and disclosure feedback loops.[27]

Equity considerations: avoid excluding MSMEs and emerging-market issuers by providing proportionality, simplified templates, and technical assistance; ensure transition finance reaches carbon-intensive regions to prevent stranded communities.

Metrics: disclosure coverage/assurance rates, taxonomy-aligned revenue/CapEx shares, portfolio-level financed emissions, scenario-consistent capital allocation, escalation outcomes in stewardship.[27,28]

Digital, Data & AI

Policy goals: unlock trustworthy sustainability data flows; manage AI's environmental footprint and systemic risks; and harden cyber-physical infrastructure as part of resilience.

Core instruments

Data & cross-border flows: establish sustainability "data rooms" with shared schemas; mandate interoperable emissions/energy data at asset and product level (digital product passports); ensure privacy/security via risk-based data protection. AI safety & sustainability. Require model-risk management, transparency on training data/limitations, and energy-use disclosures (training and inference). Encourage compute-efficient methods and siting powered by low-carbon grids.[4,29]

Cyber-resilience: critical-infrastructure standards (zero-trust, SBOMs, incident reporting), third-party risk rules for cloud and OT systems, and minimum encryption/authentication across supply chains. Implementation challenges. Sparse and non-comparable AI energy data and confidentiality claims limit accountability.[29] Product-level emissions data face fragmentation and IP concerns. Cyber rules can overburden SMEs without shared services and templates.

Equity considerations: prevent data monopolies by mandating access to public-interest datasets; ensure AI energy-cost pass-throughs do not disproportionately burden low-income users; include SME-friendly cyber compliance toolkits.

Metrics: share of assets/products with machine-readable emissions data; model energy per parameter/training run; percentage of critical entities meeting resilience benchmarks; incident response times.[4,29]

Health, Food & Biosafety

Policy goals: contain antimicrobial resistance (AMR), manage biosafety/biosecurity risks, and steer food systems toward nutrition, safety, and climate resilience.

Core instruments

AMR controls: integrated One-Health plans: prescription stewardship, surveillance, water/sanitation investments, and market-entry rewards for novel antimicrobials; procurement that favors access-oriented licensing. Biosafety standards. Risk-tiered lab and field protocols, gene-

drive governance, and incident reporting with independent oversight.

Food-system sustainability: sustainable input standards (fertilizer efficiency, pesticide risk), nutrition labeling, food-loss reduction mandates, and climate-resilient agriculture (soil health, water efficiency) paired with farmer extension. Implementation challenges. Financing gaps for AMR innovation and surveillance; fragmented food standards; limited biosafety capacity in low-resource settings.

Equity considerations: ensure equitable access to diagnostics and antibiotics, support smallholders through climate-smart extension and credit, and protect indigenous/community food systems. Metrics. Infection and resistance prevalence; antibiotic consumption intensity; food-loss rates; nutrition outcomes; farm-level emissions and water productivity.

Governance Models & Policy Instruments

Command-and-control: harms are acute and irreversible or they are priced in a poor way and therefore the harms they cause are clear and the guardrails are clearly indicated by bans, limits and performance standards. They suit best where performance can be measured, where tightening can be done in stages, and where flexibility in design is required (e.g. output-based allocations changing to absolute caps). There is the risk of technology lock-in where standards identify solutions directly, not results; overcome this by drafting outcome-based regulations and by ensuring that there are many ways of compliance.

Market-based: externalities are monetized by carbon pricing (taxes or ETS), tradable permits (renewable portfolio obligations, vehicle fuel-economy credits), differentiated tariffs, and congestion pricing and can promote cost-optimal abatement. This has been demonstrated by emerging results demonstrating that carbon pricing has provided quantifiable cuts when properly instituted even at small amounts and has complemented, rather than substituted, complementary policies to generate innovation, infrastructure, and equity.[10] Border adjustments have the benefit of safeguarding policy ambition against leakage, but entail effective embedded-carbon accounting and an effective domestic regime.

Information & disclosure: information asymmetries are minimized through corporate reporting, product labels, asset-level transparency, as well as open data. The ISSB standards (IFRS S1/S2) create a worldwide investor-centered standard; those jurisdictions which impose double materiality mandate disclosure of effects on both people and the planet in addition to financial materiality.[28] The lack of assurance of disclosure, comparability, and post-disclosure supervision is prone to transparency theater. Disclose assurance, enforcement, and supervision of capital markets.

Financial & fiscal: first-of-a-kind projects are de-risked with subsidies, tax credits, green public procurement, concessional/blended finance, and just transition funds and diffusion is hastened. Protect against windfalls through the competitive allocation (auctions), additionality tests and payout based on milestones. Observe the standards of low-carbon materials in order to establish the demand pull in the hard-to-abate sectors.

Collaborative/experimentalist: mobilized coalitions to deal with uncertainty through regulatory sandboxes, adaptive licensing, challenge prizes, and mission-oriented programs. Publish learning of pilots, make use of sunset and review clauses and scale what works. The use of experimentalist governance is bright in the situations when technologies and risks change rapidly (e.g., AI energy-use disclosures and model- risk controls).[4,29]

Institutional design: whole-of-government taskforces, cross-ministry action, arm-length implementation by independent regulators, stakeholder councils (labor, SMEs, communities) all help in reducing the friction in implementation.

Invest state capacity: digital permitting, MRV infrastructure, and local-government technical support.

Regional Approaches Comparative Perspectives

European Union

Strategic narrative: the European Green Deal aims to hard-wire climate-neutrality and circularity into the single market. The EU leans on economy-wide standards, product policy, and carbon markets to drive systemic change.

Flagship instruments: EU ETS (and ETS2 for buildings/road transport), Effort-Sharing Regulation, product eco-design and energy labeling, circular economy package (EPR for packaging/e-waste; right-to-repair trajectories), corporate sustainability due diligence and reporting, and the Carbon Border Adjustment Mechanism (CBAM) for leakage control.[26]

Strengths/weaknesses: strengths include rule-making capacity, market integration, and increasingly interoperable disclosures. Weaknesses are uneven national capacity, slow grid expansion, and compliance complexity for SMEs.

Spillovers: EU product and reporting rules are de-facto global standards for exporters; CBAM pushes trading partners toward better emissions accounting.[26]

United States

Strategic narrative: incentive-heavy industrial policy plus regulatory backstops. Federal tax credits and loans catalyze private investment, while EPA authority and state leadership handle standards and procurement.

Flagship instruments: long-duration tax credits for clean power, storage, hydrogen, CCS; EPA performance standards; state RPS/clean energy standards; federal and state procurement of low-carbon materials; transmission siting reforms.

Strengths/weaknesses: deep capital markets, innovation ecosystems, and demand-pull from procurement are strengths. Weaknesses include litigation risk, interconnection backlogs, and policy whiplash across administrations.

Spillovers: global clean-tech cost reductions and supply-chain diversification; competitive pressure on allied industrial policies.

China

Strategic narrative: dual-carbon goals guide a state-led transition, integrating ETS evolution with powerful industrial policy in clean tech manufacturing and grids.

Flagship instruments: national ETS expanding beyond power to heavy industry; large-scale renewables plus ultra-high-voltage transmission; local performance targets; data governance tightening with emerging sustainability data initiatives.

Strengths/weaknesses: strengths: speed/scale of manufacturing, grid build-out, and pilot-to-national policy diffusion. Weaknesses: data transparency, varied provincial enforcement, and coal reliance in power balancing.

Spillovers: cost leadership in solar, batteries, and EVs; global standard-setting in supply chains.

India & South Asia

Strategic narrative: energy-security-led transition, with rapid renewables growth, grid expansion, and an adaptation-forward agenda.

Flagship instruments: competitive auctions for solar/wind; green open-access and transmission corridors; renewable purchase obligations; green hydrogen and storage tenders; climate-resilient agriculture missions and sustainability finance frameworks.

Strengths/weaknesses: scale and auction experience are strengths; DISCOM finances, land/permits, and grid congestion remain bottlenecks.

Spillovers: regional power-pooling and standards for low-cost renewables in emerging markets.

Africa

Strategic narrative: universal energy access, resilience, and green industrialization anchored in mineral value chains and nature-based solutions.

Flagship instruments: IPP frameworks and renewable auctions, mini-grid regulations, clean-cooking standards, and land-use policies to protect high-value ecosystems. Nature- and climate-risk stress testing for banks is emerging (to price ecosystem loss and climate shocks).

Strengths/weaknesses: young markets with high marginal benefits from electrification; constraints include finance cost, utility creditworthiness, and transmission deficits.

Spillovers: innovation in distributed energy regulation; leadership on nature-risk financial supervision.

Latin America

Strategic narrative: protect natural capital, decarbonize grids already rich in renewables, and leverage critical minerals for a just industrial strategy.

Flagship instruments: deforestation controls linked to supply-chain due diligence; EPR and deposit-return systems; carbon-pricing pilots; green bonds and taxonomies.

Strengths/weaknesses: abundant renewables and biodiversity offsets potential; governance and enforcement gaps in frontier regions persist.

Spillovers: global supply-chain tightening for deforestation-risk commodities; growth in sustainable aviation fuel feedstocks and mineral processing.

ASEAN & Pacific

Strategic narrative: balance development and decarbonization with regional power trade,

common taxonomies, and climate adaptation for islands.

Flagship instruments: cross-border power trade frameworks; national and regional taxonomies to guide finance; coastal adaptation standards and disaster-risk financing; early AI-energy disclosure pilots as data-center hubs grow.

Strengths/weaknesses: dynamic manufacturing base and openness to standards cooperation; vulnerability to storms/sea-level rise and limited fiscal space.

Spillovers: interoperable taxonomies and digital product passports can reduce compliance friction for exporters.

Cross-Border Coordination, Trade & Standards Interoperability

Sustainability policy is now transnational just like supply chains, capital movements and data flows. Regulatory interoperability is a strategic capability, therefore. Three modes prevail, namely equivalence (admission of other rules that provide similar consequences), mutual recognition (admission of other conformity tests), and common baselines (co-established minimum standards). Equivalence and recognition can reduce duplicate testing, accelerate approvals, and reduce barriers to trade clean-tech, but they need reliable evaluation mechanisms and continuous peer review to prevent the risks of the race to the bottom.[30] In the areas of low political trust, it may be simpler to maintain common baselines, including aligned product safety or sustainability disclosure minima.[30]

Trade policy: the best-known example is the Carbon Border Adjustment Mechanism by the EU (CBAM) which is intended to impose price on embedded emissions of imports and counteract leakage as the free allowances of the EU ETS are lowered.[26,31] CBAM will be able to strengthen incentives to decarbonize overseas and facilitate domestic climate ambition, however, it will impose distributional and administrative issues on developing-country exporters and small importers. The coverage, default values, indirect emissions, and foreign carbon prices crediting are design-related characteristics that make or break CBAM to promote or trigger conflicts.[26,31]

Information & reporting interoperability: corporate sustainability reporting is also moving towards investor centric baselines, which have knock-on consequences on supply chains. With the alignment of the disclosure frameworks embraced by markets, assurance scopes and audit trails should be interoperable to ensure that the cost of compliance remains manageable.[32,33] Digital product passports (DPPs) that transport structured information (materials, repairability, emissions) throughout the life cycle of a product are maturing product-level traceability which can unlock the use of circular business models in the event that identifiers, data schemas, and access rights are coordinated across jurisdictions.[34,35]

Finance channels: money is also important in interoperability. In blended-finance platforms, which are based on multilateral development banks (MDBs), the mobilization of private capital occurs through the standardization of taxonomies, risk-sharing terms and verification rules across deals.[33,36] Partnerships and country platforms in the style of Just Energy Transition are effective when the disclosure, MRV, and eligibility requirements are compatible with the international standard to make concessional, commercial, and sovereign sources co-invest without individual due diligence.[33,36]

Justice, Inclusion & the Just Transition

Sustainable transition should provide answers to three distributive questions: who pays, benefits, and decision-makers. Relative prices, asset values, and employment opportunities are unevenly distributed in areas, industries, and even population groups due to industrial decarbonization. The burdens are, without intent, generally transferred to low-income earners, carbon-intensive regions, and workers with less easily portable skills and the gains are reaped by capital-intensive industries and workers with more high-skill labor.[9,37]

Distributional analysis: strong ex-ante analysis must measure impacts on households energy and stranded-asset risks, on workforce and it should disaggregate by gender and age and place to bring up inequities in the background.[9,37] The policy mix is then informed with credible evidence, such as the combination of price in carbon with gradual recycling of revenues and special support of industrial transition.

Design features: three levers dominate. First, households at risk are insulated by specific rebates and lifeline tariffs, and the decarbonization signalling to high-consumption users is maintained.[9] Second, sequencing plant retirement plans with reskilling and job-placement funds based on actual employer demand and supplemented by wage insurance or mobility support should be made available to women and young people who are burdened by care or have a credential penalty.[37] Third, legitimacy is anchored by community ownership and benefit-sharing the form of royalty streams, local equity interests, or community trusts, and redistributes the upside.[9]

Procedural justice: the early, ongoing and empowered forms of participation enhance sustainability: social consultation of unions and employer associations; local planning commissions with direct access to real budgets; and grievance systems that lead to conflict resolution before it develops.[37]

International fairness: CBAM need to be accompanied by transition assistance, including concessional finance, access to technology, and capacity building, to ensure the costs are not passed on to the producers and consumers in the developing countries.[26,31] The country platforms which could be a mix of the public and the private capital can be used to fund the transitions of coal-to-clean, grid investments and social protections with eligibility, MRV, and safeguards consistent with international standards.[33,36] The logic behind it is straightforward: matching domestic equity (in countries) and global equity (between countries) in such a way as to ensure that climate ambition grows not disintegrates.[9,37]

Implementation, Enforcement & Political Economy

Capability building: aspirational regulations require institutions that are resource endowed. There are three investments that can be done soon. First, individuals: the specialist regulatory personnel (economists, engineers) and professionalized inspectorates minimize backlog and enhance the quality of the rules. Second, MRVs systems: monitoring, reporting and verification at the facility, product and social levels should be modular in order to allow sectors to connect to a shared data backbone.[30,33] Third, digitalization: e-permitting, machine-readable disclosures, and API-based data exchanges can enhance compliance, reduce administrative discretion, and open up risk-based supervision to analytics.[34,35]

Enforcement toolkit: switch to a risk-based oversight as compared to the blanket inspection that directs resources to areas where the harms are most significant and compliance risks are the greatest. Alternate penalties with restorative enforcement e.g. enforceable undertakings which

remediate harm (e.g. habitat restoration, worker remediation) but do not eliminate incentives to self-report. Third party verification built into MRV (publicity through rotation of auditors, independence protection and public sums) scales are not privatized in the public interest.[30] In the case of cross-border value chains, certificates should be available in searchable, time-bound and auditable conformance registries by accepting accepted verifiers across jurisdiction.[34,35]

Political economy: reform runs into incumbency. The producers of carbon intensive, legacy producers and individual region blocks have the ability to unite to water down standards or glean rents. Three strategies help. (1) Sequencing: no-regret, no-compensation: initialize at no-regret; phase data quality as quality increases.[30] (2) Coalition-building: attract beneficiaries - clean-tech suppliers, finance, labor finding new employment, consumer groups, etc. - around foreseeable rules and investment channels.[33] (3) Credible commitment: lock-in with statutory targets and budgeted transition funds and independent oversight; align trade and procurement and disclosure rules with backsliding (making visible costs to firms and financiers).[26,31]

Controlling leakage and coordination issues: in the case of a domestic ambition endangering offshoring of emissions, introduce border policies with subsidies to partner nations to implement similar prices, MRV and technology. The acknowledgment of foreign carbon charges and high quality of offset has the ability of transforming trade friction into a convergence ladder.[26,31] Publicate default values and other methodologies to unwind little importer frictions although protecting against creative compliance.

Subnational role: experimentation of cities and provinces is ideal, such as the building code, distributed energy zoning, industrial symbiosis parks and circular-economy logistics. Experimentation (regulatory sandboxes, pilot waivers) and diffuse learning through playbooks and shared datasets should be licensed by national regulators. Make fiscal payments and purchases based on performance (e.g., verified emissions reductions, job quality indicators), not effort.[33] Templates and grid codes can be aligned throughout a region, which reduces transaction costs on developers and SMEs of projects.[34,35]

The through-line is doable: construct data-rich, risk-responsive institutions; implement fairly but visibly; connect domestic regulations to cross-border regimes to allow capital, technology, and accountability to scale. When done properly, implementation is not a cost burden but an investment vehicle coming to make sustainability regulations bankable projects and sustainable political alliances.[30,33]

Measuring Impact & Adaptive Regulation

A good sustainability policy begins with a theory of change connecting inputs (funding, staffing, data infrastructure) to actions (rulemaking, permitting, enforcement), outputs (licenses issued, disclosures filed, kilometers of grid upgraded), outcomes (reduced emissions intensity, increased resilience), and, finally, impacts (avoided climate damages, increased biodiversity, social inclusion). Visualizing this chain at the beginning of the chain presupposes assumption, aligns agencies, and trade-offs are legible.[38]

There should be a limited number of KPIs and indicators that are similar and relevant to decisions. On climate, pegged to intensity of emissions (e.g., tCO 2e/MWh; tCO 2e/ton of steel) and absolute emissions paths. To be resilient, avoidance of track downtime, time taken to restore services, and asset level risk scores, which are a combination of hazard, exposure, and vulnerability. Nature measures are capable of matching area metrics (hectares of conservation,

no-deforestation compliance) with biodiversity outcome measures (species abundance, habitat connectivity). Social indicators are to be tracked in terms of affordability, quality of jobs, and involvement (e.g. share of community-owned projects), with equity integrated as opposed to being added. The choice of KPIs that can be calculated using high-frequency operational data will minimize such lags between signal and policy adjustment.[39]

Regulation can be evolved by adaptive cycles: write sunset clauses, which activate reviews, periodically audit performance (e.g. after every 2436 months), and test new technologies, business models or MRV techniques with regulatory sandboxes before going to scale or codifying them.[40] Pivot prescription to outcome-based controls (e.g. performance standards) where possible so as to incentivize innovation whilst maintaining safeguards.[38]

Adaptation is built on a strong learning infrastructure: data collaboratives to exchange information on an asset-level (grids, buildings, supply chains), open APIs to standardize submissions (emissions, product passports, grid interconnection status), and independent evaluation to prevent self-assessment bias and regulatory capture. In the rapidly relevant fields, AI and digital infrastructure, transparent energy and water KPIs are the most important to align the innovation with climate objectives.[4]

CASE OF STUDY

Power Sector Auctions in Emerging Economies

Context: as FITs gave way to competitive procurement, many emerging economies adopted technology-specific auctions to accelerate renewables while lowering costs.

Instrument mix: reverse auctions with pay-as-bid or uniform pricing, pre-qualification (land, permits, grid-connection evidence), bid bonds, and realization penalties. Complementary policies include standardized PPAs, grid code updates, and local content rules tied to industrial strategy.[41,42]

Results so far: auctions reliably delivered steep tariff declines and volume at pace where pipeline quality, PPA bankability, and grid readiness were credible. Where interconnection lagged or curtailment risk was high, realized capacity fell below awards; underbidding and concentration risks emerged when pre-qualification was weak or lot sizes were oversized.[41] Targeted design—e.g., zonal caps, ceiling prices, and milestone-based securities—mitigated failures while preserving competition.[42]

Equity impacts: tariff reductions improved affordability, but local content rules produced mixed outcomes unless paired with skills and supplier enablement. Community benefit schemes and land safeguards helped reduce siting conflicts.

Lessons: auctions are powerful if embedded in a policy mix: bankable PPAs, timely grid expansion, and realistic penalties. Periodic design reviews prevent lock-in and address market concentration.[41,42]

Corporate Climate Disclosure & Investor Stewardship

Context: the post-2020 surge in climate reporting norms (e.g., TCFD-aligned frameworks and their successors) reshaped how firms quantify transition and physical risks, while investor stewardship moved from awareness to escalation.[43,44]

Instrument mix: baseline reporting on governance, strategy, risk management, and metrics/

targets; transition plans with near-term capex and scope-coverage milestones; stewardship codes and coalition engagements; escalation ladders (vote against, file resolutions, reallocate capital).

Results so far: evidence shows private engagements can improve ESG practices and reduce downside risk; climate proposals have become more targeted and data-driven.[43,44] Yet greenwashing risks persist where metrics are unaudited, targets exclude Scope 3, or scenario use is cosmetic.

Equity impacts: better disclosure supports workforce transition planning and supplier enablement, but costs can burden SMEs without proportionality and interoperability. Lessons. Mandatory decision-useful disclosure plus credible stewardship drives progress; add assurance, scope-inclusive targets, and escalation protocols to deter greenwashing and align capital with real-economy decarbonization.[44]

Circular Economy via EPR (Packaging/E-waste)

Context: EPR shifts end-of-life responsibility and financing from municipalities to producers, spurring design changes and improving collection/recycling for packaging and e-waste.[6,45]

Instrument mix: producer Responsibility Organizations (PROs), modulated fees (eco-modulation by recyclability/toxicity), take-back obligations, eco-design standards (repairability, recycled content), and litter-prevention schemes. Integration with informal waste sectors via registration, safe-work standards, and price floors builds inclusivity.[6]

Results so far: where fee signals are strong and enforcement credible, EPR improved collection rates and nudged design-for-recycling. Weak data and fragmented standards, however, limited comparability and cross-border trade in secondary materials.[45]

Equity impacts: formalizing informal collectors raises incomes and safety, but requires transition support and access to PRO payments. Fee design must avoid regressive pass-through to consumers.

Lessons: pair EPR with eco-design rules, common data standards, and market development for recycled outputs; use adaptive reviews to refine fee modulation and prevent perverse incentives.[6,45]

Future Outlook to 2035: Scenarios & Strategic Inflection Points

Convergence: by the early 2030s, major jurisdictions align on disclosure baselines, digital product passports, and carbon accounting; auction and transmission planning co-evolve; EPR interoperability lowers costs; AI governance internalizes energy/water impacts. Finance scales through blended vehicles and transition-finance taxonomies; policy risk premia fall. Diffusion of green tech accelerates, shaving emissions intensity across power, industry, and mobility.[4,38]

Patchwork: progress is mixed: regional clubs advance standards but create compliance complexity. Auction design improves but grid bottlenecks persist; disclosure quality rises unevenly; investor stewardship pushes laggards case-by-case. EPR advances in some markets; leakage and waste trade remain problematic. Adaptive regulation becomes essential to manage divergence.[41,45]

Backlash: political reversals stall carbon policies; reporting is diluted; data standards fragment; AI-driven energy demand collides with decarbonization pathways, raising emissions and public costs. Investment slows as policy uncertainty widens risk premia.[4]

Watch items: critical minerals supply and recycling economics; AI × climate interactions (demand management vs rebound); adaptation finance for infrastructure hardening; supply-chain resilience in grids and clean-tech manufacturing.[45]

Build interoperability: (reporting, product passports, EPR data) to cut friction. Invest in regulatory capacity MRV systems, grid planning, competition oversight, independent evaluators. Hone just-transition compacts reskilling, place-based investment, affordability shields. Institutionalize adaptive cycles—sunset clauses, scheduled reviews, sandboxes linked to outcome-based rules.[40] Target KPIs that matter—emissions intensity, resilience performance, biodiversity outcomes, and distributional metrics—to keep policy aimed at real-economy change.[39]

CONCLUSIONS

For governments: design coherent mixes that combine standards, markets, and information; embed equity-by-design (affordability, worker transition, participation); fund capacity (regulators, grid operators, data systems); and mandate machine-readable reporting with assurance to strengthen accountability.

For business: integrate policy risk into strategy; publish credible transition plans with capex-backed targets across Scopes 1–3; enable suppliers (toolkits, financing, data sharing); and monitor operational energy/water footprints of digital systems—including AI—against science-based thresholds.

For finance: use stewardship escalation ladders (vote, file, re-allocate) and time-bound engagement to close performance gaps; expand transition financing for hard-to-abate sectors; and apply robust taxonomies that prevent greenwashing while rewarding real emissions intensity improvements.

For civil society & academia: scale monitoring (citizen science, watchdog analytics), curate evidence syntheses for policymakers, and co-design participatory processes that legitimize transitions and improve uptake.

Across contexts, the through-line is adaptive regulation: pick KPIs that track what matters, build feedback loops that learn in public, and revise rules on schedule. That's how regulatory frameworks remain legitimate, lower compliance costs over time, and deliver durable sustainability impacts.

Discussion Questions & Applied Assignments

Seminar prompts

When do disclosure-only regimes work, and when do they fail? Consider incentives, comparability, auditability, and enforcement spillovers. What's the fairest way to design a carbon border measure? Discuss equity, exemptions, use of revenues, and compatibility with trade rules. Which policy mix best accelerates industrial decarbonization in your country? Weigh standards, pricing, procurement, finance, and just transition supports.

Applied assignment

Draft a two-page policy memo proposing a regulatory sandbox for a climate-tech or circularity

use case. Specify objectives, eligibility and governance, consumer and environmental safeguards, data/MRV requirements, exit criteria, and success metrics (e.g., cost per ton abated, time-to-permit, SME participation).

Further Reading & Resource Guide

UNFCCC Paris Agreement; Convention on Biological Diversity; OECD Regulatory Policy Outlook; IEA Net Zero Roadmap; World Bank State and Trends of Carbon Pricing; IFRS/ISSB S1–S2; GRI Standards; ILO Guidelines for a Just Transition; Ellen MacArthur Foundation Circular Economy Handbook; PRI Active Ownership 2.0.

Open data: WRI Climate Watch; World Bank World Development Indicators (including environment/climate series).

BIBLIOGRAPHIC REFERENCES

1. Rennert K, Errickson F, Prest BC, Rennels L, Newell RG, Pizer WA, et al. Comprehensive evidence implies a higher social cost of CO_2. Nature. 2022;610(7933):687–92. https://doi.org/10.1038/s41586-022-05224-9

2. Intergovernmental Panel on Climate Change (IPCC). Climate Change 2023: Synthesis Report of the IPCC. 2023. https://doi.org/10.59327/IPCC/AR6-9789291691647

3. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). Thematic Assessment Report on Invasive Alien Species and their Control. 2023. https://doi.org/10.5281/zenodo.7430682

4. de Vries A. The growing energy footprint of artificial intelligence. Joule. 2023;7(10):2191–4. https://doi.org/10.1016/j.joule.2023.09.004

5. Christensen HB, Hail L, Leuz C. Mandatory CSR and sustainability reporting: Economic analysis and literature review. Rev Account Stud. 2021;26(3):1176–248. https://doi.org/10.1007/s11142-021-09609-5

6. Mallick PK, Salling KB, Pigosso DCA, McAloone TC. Designing and operationalising extended producer responsibility under the EU Green Deal. Environ Chall. 2024;16:100977. https://doi.org/10.1016/j.envc.2024.100977

7. Bergquist P, Warshaw C. How climate policy commitments influence energy systems and the economies of US states. Nat Commun. 2023;14:4850. https://doi.org/10.1038/s41467-023-40560-y

8. Meckling J, Benkler A. State capacity and varieties of climate policy. Nat Commun. 2024;15:9942. https://doi.org/10.1038/s41467-024-54221-1

9. Stark A. Just transitions' meanings: A systematic review. Soc Nat Resour. 2023;36(12):1849–71. https://doi.org/10.1080/08941920.2023.2207166

10. Döbbeling-Hildebrandt N, Miersch K, Khanna TM, Bachelet M, Bruns SB, Callaghan M, et al. Systematic review and meta-analysis of ex-post evaluations on the effectiveness of carbon pricing. Nat Commun. 2024;15:4147. https://doi.org/10.1038/s41467-024-48512-w

11. Guy J, Shears E, Meckling J. National models of climate governance among major emitters. Nat Clim Chang. 2023;13(2):189–95. https://doi.org/10.1038/s41558-022-01589-x

12. Dzebo A, Shawoo Z, Browne J. Policy coherence for sustainable development: Concepts, methods, and practice. Annu Rev Environ Resour. 2025;50. https://doi.org/10.1146/annurev-environ-111523-102337

13. Gatto A. Polycentric and resilient perspectives for governing the commons: Strategic and law-and-economics insights for sustainable development. Ambio. 2022;51:1786–802. https://doi.org/10.1007/s13280-022-01719-x

14. Hummel K. An overview of corporate sustainability reporting: Harmonization, assurance and the ISSB baseline. Sustain Account Manag Policy J. 2024;15(6):1–25. https://doi.org/10.1080/17449480.2024.2312145

15. Rogerson M, Scarpa F, Snelson-Powell A. Accounting for human rights: Evidence of due diligence in EU-listed firms' reporting. Crit Perspect Account. 2024;99:102716. https://doi.org/10.1016/j.cpa.2024.102716

16. Haderer M. Climate governance experiments: Design, delivery and learning in sustainability transitions. J Environ Policy Plan. 2023;25(4):495–513. https://doi.org/10.1080/15487733.2023.2186078

17. Reins L. Innovation, precaution, and sustainable development in EU environmental law. J Environ Law. 2025. https://doi.org/10.1093/jel/eqaf032

18. Alaranta J. Precautiously circular: Perspectives on the application of the precautionary principle in European Union waste and chemicals regulation. Eur J Risk Regul. 2023;14(1):14–30. https://doi.org/10.1017/err.2022.37

19. Hughes AC. The post-2020 Global Biodiversity Framework: How did we get here, and where do we go next? Integr Conserv. 2023;2(1). https://doi.org/10.1002/inc3.16

20. Park WY, Shah N, Vine E, Blake P, Holuj B, Kim JH, et al. Ensuring the climate benefits of the Montreal Protocol: Global governance architecture for cooling efficiency and alternative refrigerants. Energy Res Soc Sci. 2021;76:102068. https://doi.org/10.1016/j.erss.2021.102068

21. Badgley G, Freeman J, Hamman JJ, Haya B, Trugman AT, Anderegg WRL, et al. Systematic over-crediting in California's forest carbon offsets program. Glob Chang Biol. 2022;28(13):4383–95. https://doi.org/10.1111/gcb.15943

22. Thornhill I, Prendergast-Miller M, Rampling T, et al. Using past planning practice to inform biodiversity net gain in England. Ecol Solut Evid. 2025;6:e70021. https://doi.org/10.1002/2688-8319.70021

23. Pruess JT, Garrett RD, et al. Potential effectiveness of extended producer responsibility: An ex-ante policy impact analysis for plastic packaging waste in Belgium, France, and Germany. Resour Conserv Recycl. 2025;219:108297. https://doi.org/10.1016/j.resconrec.2025.108297

24. Ozturkcan S, Rehmani M. The right-to-repair movement: Sustainability and consumer welfare

considerations. J Macromark. 2024;44(2):233–48. https://doi.org/10.1177/20438869231178037

25. Algers J, Toktarova A, Wangel J, Rootzén J. Steel decarbonization—from optimization to transformation. Annu Rev Environ Resour. 2025;50:1–27. https://doi.org/10.1146/annurev-environ-111523-101851

26. Bye B, Nesbakken R. EU's Carbon Border Adjustment Mechanism (CBAM) and its industrial effects. Clim Policy. 2025;25(6):823–40. https://doi.org/10.1080/14693062.2025.2557236

27. Alogoskoufis S, Carbone I, Cœuré B, Giuzio M, Kesaniemi J, Parisi L, et al. Climate stress testing. Annu Rev Financ Econ. 2023;15:659–90. https://doi.org/10.1146/annurev-financial-110921-101555

28. Mezzanotte FE, D'Ignazio A, Tiscini R. Corporate sustainability reporting: Double materiality, risk and governance. J Public Aff. 2024;24(1):e29058. https://doi.org/10.1080/14735970.2024.2319058

29. Masanet E, Lei N, Koomey J. To better understand AI's growing energy use, analysts need a data revolution. Joule. 2024;8(9):2427–36. https://doi.org/10.1016/j.joule.2024.07.018

30. Lang A. Regulatory "reliance" in global trade governance. Eur J Risk Regul. 2024;15(1):1–20. https://doi.org/10.1017/err.2023.73

31. Morone P, Alfino A. Impact of the EU Carbon Border Adjustment Mechanism on the Global South. Discov Sustain. 2025;6:315. https://doi.org/10.1007/s43621-025-01131-x

32. Castillo Delgadillo VM, Castro Huarac JJ, Salim M. Real options for IFRS-S1 and S2 mandatory disclosures: A valuation framework. J Risk Financ Manag. 2025;18(10):540. https://doi.org/10.3390/jrfm18100540

33. Zeng W. Climate finance and new multilateral development banks. Clim Policy. 2024;24(10):1455–71. https://doi.org/10.1080/14693062.2024.2442004

34. Zhang A, Zhang X, Liu Y. Digital product passport for sustainable and circular supply chain management: A structured review of use cases. Int J Logist Res Appl. 2024. https://doi.org/10.1080/13675567.2024.2374256

35. Chaudhuri A, Kumar S, Gunasekaran A. Impact pathways: Digital product passports for electronics supply chains. Int J Oper Prod Manag. 2025. https://doi.org/10.1108/IJOPM-01-2024-0012

36. Bazbauers AR, Renzaho AMN. The multilateral development banks and rural climate finance. Adm Soc. 2025. https://doi.org/10.1177/10704965241305842

37. Wang X, Lo K. Just transition: A conceptual review. Energy Res Soc Sci. 2021;82:102291. https://doi.org/10.1016/j.erss.2021.102291

38. Peñasco C, Díaz Anadón L, Verdolini E. Systematic review of the outcomes and trade-offs of ten types of decarbonization policy instruments. Nat Clim Chang. 2021;11(3):257–65.

https://doi.org/10.1038/s41558-020-00971-x

39. Zis TPV, Psaraftis HN, Reche-Vilanova M. Design and application of a key performance indicator (KPI) framework for autonomous shipping in Europe. Mar Transp Res. 2023;4:100095. https://doi.org/10.1016/j.martra.2023.100095

40. Chen GKH, Rauter T, Yang EZ. Designing regulatory sandboxes. J Risk Financ Manag. 2025;18(1):1–20. https://doi.org/10.1080/25741292.2025.2570954

41. del Río P, Kiefer CP. Academic research on renewable electricity auctions: Taking stock and looking forward. Energy Policy. 2023;173:113305. https://doi.org/10.1016/j.enpol.2022.113305

42. Ehrhart K-M, Ott M, Seifert S, Wang R. Combinatorial auctions for renewable energy—Potentials and challenges. Energy Policy. 2024;186:113988. https://doi.org/10.1016/j.enpol.2024.113988

43. Barko T, Cremers M, Renneboog L. Shareholder engagement on environmental, social, and governance (ESG) performance. J Bus Ethics. 2022;179(4):1063–94. https://doi.org/10.1007/s10551-021-04850-z

44. Kolasa T, Kamiński J. Institutional investors and the fight against climate change. Corp Gov Int Rev. 2024;32(5):1003–22. https://doi.org/10.1111/corg.12620

45. OECD. Global plastics outlook: Economic drivers, environmental impacts and policy options. OECD Publishing; 2022. https://doi.org/10.1787/de747aef-en

FINANCING

None.

CONFLICT OF INTEREST

None.

AUTHORSHIP CONTRIBUTION

Conceptualization: Husnain Mukhdoom.
Data curation: Husnain Mukhdoom.
Formal analysis: Husnain Mukhdoom.
Drafting - original draft: Husnain Mukhdoom.
Writing - proofreading and editing: Husnain Mukhdoom.