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Research Book Title :Geopolitical and Climate-Risk-Aware Supply Chains using Graph Analytics, Digital Twins and Scenario Intelligence

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Abstract:

Global supply chains are increasingly exposed to compound disruptions in which geopolitical rivalry, trade controls, extreme weather, infrastructure fragility and financial volatility interact across multiple supplier tiers and transport corridors. This book develops an integrated research architecture for making such networks more visible, testable and adaptive through graph analytics, digital twins and scenario intelligence. The framework links supplier and infrastructure topology with geospatial climate information, trade and energy signals, causal inference, regime-aware forecasting, graph machine learning, robust optimization and reproducible data engineering. It treats resilience as a measurable capability to anticipate hazards, identify structural chokepoints, simulate cascading effects, qualify substitutes, reroute flows and govern high-impact decisions under uncertainty. Ten research themes and five methodological chapters connect geopolitical exposure and climate nonstationarity to statistical explanation, predictive intelligence, scalable digital-twin systems and sectoral governance. Applications are framed for manufacturing, agriculture, energy, transport, finance, telecommunications and public infrastructure across South Asia, Europe, Africa and the Americas. The resulting outputs include multi-layer supply-chain graphs, climate-adjusted vulnerability scores, causal evaluation protocols, hazard-aware forecasts, scenario libraries, digital-twin stress tests, resilience optimization frontiers and auditable governance artefacts. The book therefore provides a research platform for firms, policymakers and scholars seeking to redesign globally connected supply systems for continuity, adaptability and accountable decision-making.

Keywords

geopolitical risk, climate risk, supply-chain resilience, graph analytics, digital twins, scenario intelligence, multi-tier suppliers, network centrality, climate hazards, trade disruption, critical infrastructure, logistics corridors, causal inference, nonstationarity, graph neural networks, geospatial analytics, hydrological risk, predictive intelligence, robust optimization, MLOps, trustworthy AI, public-private governance

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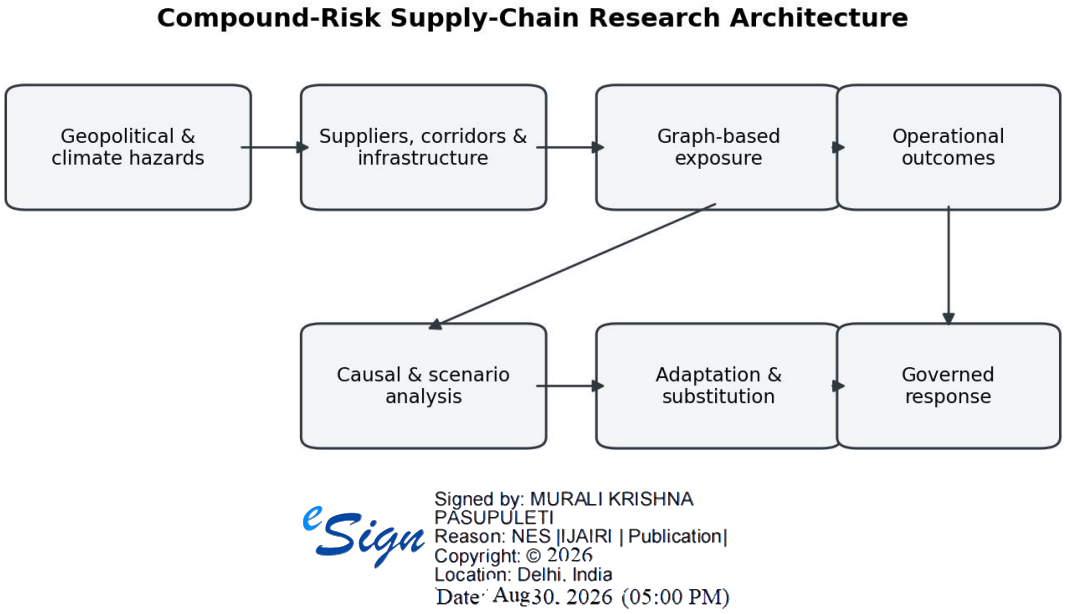
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Chapter 1. Foundations of Geopolitical and Climate Risk, Network Uncertainty and Supply-Chain Research Design

The first chapter establishes a systems view of supply-chain risk in which geopolitical restrictions, climate hazards and infrastructure dependencies are represented as interacting sources of uncertainty. The research design distinguishes hazard from exposure, vulnerability from adaptive capacity, and first-tier visibility from deeper network dependence. Supplier and corridor graphs provide the structural layer; geospatial and climate information provides the hazard layer; scenario logic represents conditions that cannot be inferred reliably from history alone. The resulting conceptual architecture supports research across products, firms and regions without assuming that the same nominal shock produces the same operational consequence everywhere (Pasupuleti 2026b, pp. 59–84; Pasupuleti 2026m, pp. 118–142; Pasupuleti 2026o, pp. 143–165; Pasupuleti 2026q, pp. 1–30).

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Methodologically, the chapter moves from construct definition to multi-layer graph construction, climate-sensitive location analysis and scenario-based stress testing. It treats data provenance and boundary choice as part of validity because supply-chain models can change materially when lower-tier suppliers, shared infrastructure or regional hazard information are omitted. Outputs include a compound-risk taxonomy, a supplier-corridor graph, climate-adjusted vulnerability metrics, scenario design rules and a research protocol for comparing South Asian, European, African and American supply systems (Pasupuleti 2026j, pp. 29–59; Pasupuleti 2026d, pp. 114–141; Pasupuleti 2026l, pp. 106–133; Pasupuleti 2026s, pp. 134–160).



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Figure 1.1 Compound-Risk Supply-Chain Research Architecture

Construct	Operational meaning	Indicative measures	Strategic use
Compound exposure	Joint dependence on policy-sensitive jurisdictions and climate-exposed locations	Jurisdiction concentration; hazard exposure; critical-input share	Prioritize graph mapping and scenario review
Network criticality	Structural importance of suppliers, facilities, routes or infrastructure	Centrality; bridge dependence; community concentration	Identify hidden chokepoints and shared failure points
Substitutability	Ability to replace an input, route, facility or service within technical and time limits	Qualification time; switching cost; route alternatives	Estimate realistic recovery options
Climate sensitivity	Degree to which heat, flood, drought or other hazards impair capacity or access	Hazard intensity; downtime; recovery time; adaptation status	Guide adaptation, inventory and location decisions
Scenario robustness	Performance of a strategy across plausible geopolitical-climate futures	Service loss; cost range; constraint violations; recovery time	Select options that survive multiple regimes

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Governance capacity	Ability to make traceable cross-functional decisions under stress	Decision rights; auditability; escalation speed	Translate analytics into accountable action

Table 1.1 Core Constructs for Compound Geopolitical and Climate Supply-Chain Risk

1.1 Compound Geopolitical-Climate Risk, Strategic Interdependence and Supply-Chain Exposure

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The analytical starting point is strategic interdependence, weaponized dependencies, policy-sensitive market access and the distinction between exposure and vulnerability. In this subsection, those concepts are treated as connected mechanisms rather than as independent risk labels. The supply-chain significance lies in how they alter feasible relationships among firms, jurisdictions and infrastructure providers, thereby changing both the cost and the reversibility of strategic commitments. A useful model separates observable exposure from deeper vulnerability and asks whether alternatives are technically substitutable, legally available and operationally reachable within the disruption horizon. That distinction prevents a high supplier count from being mistaken for genuine resilience. The conceptual boundary also matters for comparative research because the same nominal exposure can create different consequences when institutions, logistics capacity or financing conditions differ across regions. The supplied corpus provides relevant foundations for this systems-oriented interpretation (Pasupuleti 2026l, pp. 106–133; Pasupuleti 2026q, pp. 1–30). In Compound Geopolitical-Climate Risk, Strategic Interdependence and Supply-Chain Exposure, this lens is operationalized through construct mapping, event taxonomies, policy-intensity coding and comparative institutional analysis. The resulting conceptual target is a firm-level geoeconomic exposure register that links external restrictions to products, suppliers, customers, finance and data infrastructure.

Methodologically, the subsection uses construct mapping, event taxonomies, policy-intensity coding and comparative institutional analysis. These methods are selected because the research problem mixes observable outcomes with policy- and

climate-sensitive uncertainty, so no single predictive score can establish mechanism and decision quality at the same time. The design therefore states identification assumptions before estimation, separates training from evaluation where machine learning is used, and subjects optimization outputs to hard operational and governance constraints. Particular attention is paid to missing relationships, endogenous policy responses, structural breaks and uneven data quality across jurisdictions. Robustness is evaluated through alternative specifications, sensitivity tests and explicit failure conditions rather than through fit statistics alone. This disciplined separation of explanation, prediction and action is consistent with the methodological resources in the supplied corpus (Pasupuleti 2024g, pp. 90–111; Pasupuleti 2024c). For Compound Geopolitical-Climate Risk, Strategic Interdependence and Supply-Chain Exposure, diagnosis explicitly links strategic interdependence, weaponized dependencies, policy-sensitive market access and the distinction between exposure and vulnerability. The prescribed workflow is to define the shock class; map affected countries, technologies and contractual links; identify direct and indirect dependencies; record substitution options; update exposure after policy changes. Evaluation reports exposure indices, dependency maps, policy-event chronologies, escalation rules and board-level risk dashboards before strategic use.

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The operational workflow is sequential: define the shock class; map affected countries, technologies and contractual links; identify direct and indirect dependencies; record substitution options; update exposure after policy changes. The principal capability created is a firm-level geoeconomic exposure register that links external restrictions to products, suppliers, customers, finance and data infrastructure. By retaining data versions, assumptions, model states and approval records, the pipeline leaves an auditable path from evidence to strategic action and makes later review possible after conditions change. Global applicability is examined through export-oriented South Asian firms, European manufacturers facing technology controls, African resource-linked value chains and American multinationals operating across competing regulatory blocs. The comparison uses common constructs but allows local thresholds, data availability and governance overlays to vary, avoiding the assumption that institutional diversity is measurement noise. Research outputs comprise exposure indices, dependency maps, policy-event chronologies, escalation rules and board-level risk dashboards. Together, these artefacts support repeated stress testing, executive

decision review and cumulative research across cases (Pasupuleti 2026l, pp. 106–133; Pasupuleti 2024c).

1.2 Multi-Tier Supply-Chain Graphs, Concentration and Climate-Sensitive Chokepoints

A rigorous treatment of the topic begins with multi-tier production networks, centrality, bridge dependence, common-cause failure and the difference between supplier count and effective diversification. Theoretical reasoning focuses on the mechanism by which an external constraint is transmitted into firm behaviour, rather than assuming that country-level risk automatically predicts operational outcomes. This requires attention to contractual structure, supplier relationships, digital dependencies and the option value of alternative configurations. The analysis therefore distinguishes structural dependence, strategic choice and residual uncertainty, making it possible to ask which vulnerabilities can be redesigned and which must instead be buffered. The framework is intentionally relational: a location or supplier becomes critical because of its place in a broader network, not because of an isolated attribute. Such framing supports cross-border comparison while preserving institutional differences that affect adaptation costs (Pasupuleti 2026t, pp. 36–83; Pasupuleti 2021f, pp. 26–50). In Multi-Tier Supply-Chain Graphs, Concentration and Climate-Sensitive Chokepoints, this lens is operationalized through graph construction, concentration measures, community detection, path redundancy and scenario-based node or edge removal. The resulting conceptual target is a topology-aware resilience model that detects hidden concentration and shared lower-tier dependencies.

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The explanatory and decision logic is built from graph construction, concentration measures, community detection, path redundancy and scenario-based node or edge removal. Implementation begins by specifying what each method is allowed to claim: descriptive models organize exposure, causal designs test mechanisms, predictive models estimate future states, and optimization models search within a constrained action space. Assumptions about comparators, stationarity, data completeness and institutional stability are documented because fragmentation can invalidate relationships learned in quieter periods. Validation is therefore regime-aware and includes checks on calibration, subgroup performance and sensitivity to omitted or

uncertain links. Where evidence is weak, the output is downgraded from recommendation to scenario input. The cited sources support this emphasis on methodological fit, uncertainty and controlled use of advanced analytics (Pasupuleti 2024m, pp. 173–192; Pasupuleti 2026l, pp. 106–133). For Multi-Tier Supply-Chain Graphs, Concentration and Climate-Sensitive Chokepoints, diagnosis explicitly links multi-tier production networks, centrality, bridge dependence, common-cause failure and the difference between supplier count and effective diversification. The prescribed workflow is to integrate supplier-master data with logistics and infrastructure relationships; reconcile entity identities; create a multiplex network; compute structural measures; validate critical nodes with operating teams. Evaluation reports tier-visibility ratios, critical-node rankings, route redundancy, cascade paths and network intervention portfolios before strategic use.

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In practice, the research pipeline should integrate supplier-master data with logistics and infrastructure relationships; reconcile entity identities; create a multiplex network; compute structural measures; validate critical nodes with operating teams. This design produces a topology-aware resilience model that detects hidden concentration and shared lower-tier dependencies, linking analytical output to a defined management process rather than leaving results as stand-alone reports. The implementation records when information was known, who validated material assumptions and which constraints shaped the final option set. Application across automotive and electronics clusters in South Asia, cross-border industrial ecosystems in Europe, mineral-to-processing chains in Africa and North American regional production networks provides a test of portability: models are expected to preserve conceptual meaning while adapting to regional data and institutional conditions. The resulting deliverables include tier-visibility ratios, critical-node rankings, route redundancy, cascade paths and network intervention portfolios. These can be updated after policy or climate events, compared across business units and incorporated into formal governance cycles (Pasupuleti 2026t, pp. 36–83; Pasupuleti 2026l, pp. 106–133).

1.3 Climate-Aware Location Strategy, Facility Networks and Portfolio Reconfiguration

Within geopolitically fragmented and climate-exposed markets, the central conceptual issue is location advantage under fragmentation, institutional distance, option value, duplication versus relocation and the economics of regionalized production. These elements define the state space in which firms decide whether to continue, diversify, duplicate, hedge or exit particular relationships. The model emphasizes path dependence: earlier sourcing, technology and infrastructure choices can restrict the speed with which a firm responds to a new policy regime. It also separates resilience capacity from realized performance, since a firm may possess alternatives that are never activated or may suffer despite diversification when substitutes share a common bottleneck. Conceptual validity therefore depends on mapping dependencies at the level relevant to the decision being studied. The cited work supplies methodological and strategic anchors for modelling those relationships (Pasupuleti 2026l, pp. 106–133; Pasupuleti 2026r, pp. 78–105). In Climate-Aware Location Strategy, Facility Networks and Portfolio Reconfiguration, this lens is operationalized through multi-criteria decision analysis, robust optimization, cost-risk frontiers and institutional benchmarking. The resulting conceptual target is a location portfolio that balances efficiency with political, energy, digital and logistics resilience.

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Analysis proceeds through multi-criteria decision analysis, robust optimization, cost-risk frontiers and institutional benchmarking, with each technique assigned to a distinct analytical question. The methodological significance lies in combining statistical discipline with operational realism: models must represent the decision horizon, constraints and observability that managers actually face. Data leakage, post-treatment variables and retrospective supplier visibility are treated as threats to inference, while model drift and structural change are treated as threats to prediction. The design also requires a baseline or simpler comparator so that additional model complexity must earn its place through better decision-relevant performance. Limitations are carried forward into governance thresholds, ensuring that uncertainty affects how outputs may be used. This approach draws directly on the methodological breadth of the retained reference set (Pasupuleti 2026q, pp. 1–30; Pasupuleti 2024m, pp. 173–192). For Climate-Aware Location Strategy, Facility Networks and Portfolio Reconfiguration, diagnosis explicitly links location advantage under fragmentation, institutional distance, option value, duplication versus relocation and the economics of regionalized production. The prescribed workflow is to define candidate locations;

normalize cost, policy, skills, energy and infrastructure variables; impose service and compliance constraints; simulate disruptions; compare portfolio solutions. Evaluation reports location frontiers, diversification constraints, transition roadmaps, supplier-development plans and investment-gate criteria before strategic use.

A reproducible implementation can be organized as follows: define candidate locations; normalize cost, policy, skills, energy and infrastructure variables; impose service and compliance constraints; simulate disruptions; compare portfolio solutions. The innovation contribution is a location portfolio that balances efficiency with political, energy, digital and logistics resilience. Reproducibility is treated as a strategic property because managers may need to reconstruct why a sourcing, investment or hedging decision was made after the relevant market regime has changed. The framework is assessed in Indian industrial corridors and ASEAN-adjacent sourcing, European nearshoring, African regional manufacturing nodes and Mexico/United States production integration, where differences in infrastructure, regulation and market depth create useful stress tests of generalizability. Research outputs include location frontiers, diversification constraints, transition roadmaps, supplier-development plans and investment-gate criteria. Their role is to convert abstract resilience concepts into measurable, reviewable and institutionally actionable artefacts (Pasupuleti 2026l, pp. 106–133; Pasupuleti 2024m, pp. 173–192).

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1.4 Uncertainty, Scenario Design and Stress-Testing Research Logic

The research question becomes tractable when attention is directed to deep uncertainty, regime shifts, structural breaks, scenario plausibility and the distinction between probability-weighted forecasting and exploratory stress testing. Rather than treating fragmentation as a single shock, the subsection frames it as a sequence of constraints that can affect access, price, timing, information and governance simultaneously. This perspective supports a layered account of vulnerability in which direct exposure is only the first step; second-order dependence, common infrastructure and institutional response determine whether disruption propagates. The theory also recognizes adaptation as costly and uneven, which means that a nominally available substitute may not be economically or operationally usable. Comparative analysis must therefore preserve the distinction between formal availability and effective substitutability across jurisdictions. The relevant supplied studies reinforce

this multi-layer research logic (Pasupuleti 2021f, pp. 26–50; Pasupuleti 2026q, pp. 1–30). In Uncertainty, Scenario Design and Stress-Testing Research Logic, this lens is operationalized through scenario generation, stochastic modelling, sensitivity analysis, reverse stress testing and decision robustness. The resulting conceptual target is a scenario library linked to management actions rather than a collection of narrative futures.

The methodological architecture combines scenario generation, stochastic modelling, sensitivity analysis, reverse stress testing and decision robustness. The workflow does not assume that richer computation automatically produces stronger evidence; instead, model choice follows the structure of the strategic question and the available counterfactual information. Estimation is paired with diagnostics for overlap, breakpoints, missingness and stability, while simulation is used when historical support is insufficient for the contemplated scenario. For predictive components, out-of-time testing is preferred to random validation because policy and hazard regimes and market conditions evolve. For optimization, feasibility and governance constraints are encoded before objective improvement is assessed. The retained references provide a basis for this integrated but claim-bounded analytical architecture (Pasupuleti 2024m, pp. 173–192; Pasupuleti 2021d, pp. 1–25). For Uncertainty, Scenario Design and Stress-Testing Research Logic, diagnosis explicitly links deep uncertainty, regime shifts, structural breaks, scenario plausibility and the distinction between probability-weighted forecasting and exploratory stress testing. The prescribed workflow is to identify decision-relevant uncertainties; build internally consistent scenarios; parameterize constraints and shocks; evaluate strategies across states; locate failure thresholds; revise contingencies. Evaluation reports scenario trees, trigger thresholds, robustness scores, failure envelopes and contingency playbooks before strategic use.

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The data-to-decision lifecycle should identify decision-relevant uncertainties; build internally consistent scenarios; parameterize constraints and shocks; evaluate strategies across states; locate failure thresholds; revise contingencies. When implemented as a governed system, the result is a scenario library linked to management actions rather than a collection of narrative futures. The process connects operational teams, analysts and decision owners through documented handoffs, which reduces the risk that model outputs become detached from technical feasibility or

policy constraints. Cross-regional relevance is tested through currency and energy stress in South Asia, regulatory divergence in Europe, infrastructure uncertainty in African corridors and trade-policy shifts across the Americas; the intention is not to force uniform thresholds but to preserve a common analytical grammar. The study therefore produces scenario trees, trigger thresholds, robustness scores, failure envelopes and contingency playbooks. These outputs can be embedded in board review, procurement governance, investment approval or public-policy dialogue depending on the use case (Pasupuleti 2021f, pp. 26–50; Pasupuleti 2021d, pp. 1–25).

1.5 Measurement Architecture and Cross-Regional Comparative Research

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For global supply-chain strategy, the relevant theoretical lens combines construct validity, measurement invariance, data comparability and the risk of conflating institutional differences with performance differences. The core proposition is that strategic resilience emerges from configurations of relationships, capabilities and decision rights rather than from any single indicator. This makes boundary selection essential: the analyst must specify which product, market, technology, time horizon and jurisdiction define the system under study. The framework then asks where concentration is created, how shocks can travel, which alternatives remain feasible and what information managers require before acting. Such explicit scoping reduces the risk of overgeneralizing from aggregate country measures to firm-level decisions. It also allows the same constructs to be applied across regions with different industrial and regulatory structures (Pasupuleti 2026i, pp. 142–180; Pasupuleti 2022a, pp. 53–72). In Measurement Architecture and Cross-Regional Comparative Research, this lens is operationalized through indicator design, hierarchical measurement, missing-data diagnostics, normalization and mixed-method validation. The resulting conceptual target is a comparative measurement system that supports global analysis without forcing heterogeneous institutions into identical assumptions.

To operationalize the construct, the research design integrates indicator design, hierarchical measurement, missing-data diagnostics, normalization and mixed-method validation. Each stage is connected to an evidence standard: measurement requires traceable definitions, explanation requires defensible identification, forecasting requires regime-sensitive validation, and action requires constraints plus accountable approval. Cross-jurisdictional analysis adds a further requirement because identical

variables may reflect different institutional processes. The design therefore documents source provenance, local definitions and transformation rules before pooling information. Sensitivity analysis tests whether strategic conclusions survive reasonable changes in assumptions, and human review is concentrated where evidence is sparse or consequences are material. These methodological safeguards align with the analytical concerns represented in the cited corpus (Pasupuleti 2024a; Pasupuleti 2021a, pp. 149–173). For Measurement Architecture and Cross-Regional Comparative Research, diagnosis explicitly links construct validity, measurement invariance, data comparability and the risk of conflating institutional differences with performance differences. The prescribed workflow is to define constructs; map available variables by region; document collection differences; standardize units; test sensitivity to scaling; triangulate quantitative indicators with governance evidence. Evaluation reports data dictionaries, comparability matrices, uncertainty flags, construct-validation notes and evidence-quality scores before strategic use.

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Operationalization requires teams to define constructs; map available variables by region; document collection differences; standardize units; test sensitivity to scaling; triangulate quantitative indicators with governance evidence. The practical research contribution is a comparative measurement system that supports global analysis without forcing heterogeneous institutions into identical assumptions. A critical design principle is that every material recommendation can be traced to a source state, model configuration and set of assumptions, allowing decisions to be challenged or reproduced. The framework is designed for South Asian state-level ecosystems, European regulatory systems, African development corridors and federal/subnational policy environments in the Americas, which permits comparison of strategic mechanisms under different institutional and infrastructure conditions. Core outputs are data dictionaries, comparability matrices, uncertainty flags, construct-validation notes and evidence-quality scores. Used together, they provide a scalable protocol for learning from shocks, revising thresholds and strengthening governance over time (Pasupuleti 2026i, pp. 142–180; Pasupuleti 2021a, pp. 149–173).

Chapter 2. Statistical Explanation and Causal Inference for Trade, Hazard and Supply-Chain Disruption

The second chapter develops the explanatory layer required to learn from observed disruptions. Tariffs, export controls, floods, droughts, energy-price spikes and infrastructure failures can coincide with demand and financial changes, making simple before-and-after comparison unreliable. Econometric and causal methods are therefore organized around explicit treatments, counterfactuals and regime changes, while distributional analysis captures the possibility that average effects conceal severe losses in particular supplier tiers, sectors or regions (Pasupuleti 2023e, pp. 29–40; Pasupuleti 2023d, pp. 76–87; Pasupuleti 2024h, pp. 23–46; Pasupuleti 2024k, pp. 193–210).

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Scenario econometrics extends this evidence when historical analogues are incomplete. Empirical relationships are estimated where support exists, but geopolitical or climate assumptions are recorded separately and propagated through counterfactual paths. The principal outputs are causal diagrams, identification checklists, regime-sensitive estimates, uncertainty intervals, heterogeneous-effect profiles and decision thresholds that state when diversification, adaptation or inventory interventions are supported by evidence and when they remain scenario-dependent (Pasupuleti 2026g, pp. 49–91; Pasupuleti 2026i, pp. 142–180; Pasupuleti 2021e, pp. 316–330).

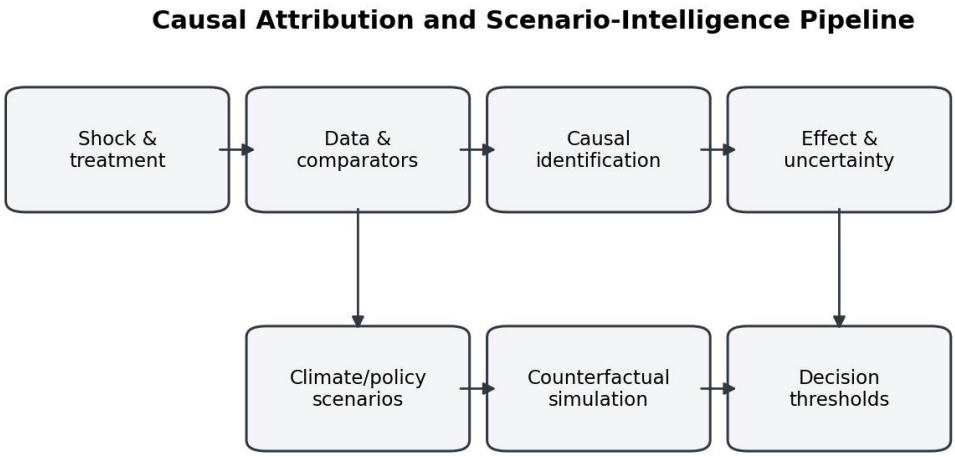


Figure 2.1 Causal Attribution and Scenario-Intelligence Pipeline

Method	Primary question	Key assumption or risk	Decision output
Panel/event study	How trade or operational outcomes change around discrete shocks	Comparator validity and timing	Estimated event effects and persistence
Causal time series	How a hazard or policy shock alters counterfactual dynamic outcomes' process	Credible	Time-varying effect with uncertainty
Double machine learning	Which adaptation interventions work under high-dimensional confounding	Observed confounders and overlap	Average and conditional treatment effects
Regime models	How freight, energy or supply volatility changes across states	Correct regime specification	Stress parameters and transition indicators
Scenario econometrics	What strategies survive structural breaks with limited precedent	Transparent scenario assumptions	Thresholds and robustness envelopes
Distributional analysis	Which supplier tiers, sectors or regions bear the largest losses	Comparable subgroup definitions	Tail effects and targeted resilience investment

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Table 2.1 Statistical and Causal Methods for Supply-Chain Shock Attribution

Theme I. Compound Geopolitical and Climate Risk in Multi-Tier Supply Networks

Supply-chain risk becomes analytically incomplete when geopolitical disruption and climate hazards are treated as separate domains. Trade restrictions, strategic rivalry, energy insecurity, extreme weather, hydrological stress and infrastructure outages can interact through the same production and logistics network, changing both the probability and the consequence of interruption. A useful theoretical model therefore distinguishes hazard, exposure, vulnerability and adaptive capacity while representing policy-sensitive dependencies across suppliers, facilities, ports, grids, communications and finance. The firm is embedded in a wider system whose lower tiers may be only partially observed, so resilience research must examine direct links, shared upstream dependencies and cross-sector infrastructure on which continuity depends. (Pasupuleti 2026b, pp. 59–84; Pasupuleti 2026m, pp. 118–142; Pasupuleti 2026o, pp. 143–165)

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The practical implication is a compound-risk register that links each material product family to jurisdictions, climate zones, critical inputs, transport corridors and enabling infrastructure. Scenario intelligence can then evaluate combinations that conventional risk matrices miss, such as drought coinciding with energy shortages or geopolitical restrictions affecting the same alternative supplier region chosen for climate diversification. The governance output is a tiered escalation protocol in which exposure measures, substitution time, recovery capacity and uncertainty determine when procurement, operations, treasury or public-policy teams intervene. (Pasupuleti 2026q, pp. 1–30; Pasupuleti 2026e, pp. 1–23; Pasupuleti 2026w, pp. 1–28)

Theme II. Graph Analytics for Hidden Concentration, Chokepoints and Cascading Failure

Graph analytics provides the structural language required for multi-tier supply chains because vulnerability depends on relationships rather than on isolated supplier attributes. Nodes can represent firms, facilities, ports, data centres, substations or jurisdictions, while edges encode material flows, logistics dependencies, digital services, financial links or shared infrastructure. Centrality, bridge structure, community detection, path redundancy and node-removal experiments reveal forms of

concentration that are invisible in first-tier supplier counts. Topological and graph-learning methods are especially useful when incomplete observations must be combined with domain constraints and network inference. (Pasupuleti 2026j, pp. 29–59; Pasupuleti 2026d, pp. 114–141; Pasupuleti 2026l, pp. 106–133)

A graph-based resilience programme should move from entity resolution to multiplex network construction, structural diagnostics, perturbation tests and candidate substitution discovery. Criticality scores are most useful when interpreted with operational data such as capacity, qualification status, lead time and climate exposure; structural importance alone does not imply that a node is practically irreplaceable. Research outputs include multi-layer dependency graphs, chokepoint rankings, cascade paths, shared-risk communities and route or supplier alternatives that can be passed directly into digital-twin experiments. (Pasupuleti 2026s, pp. 134–160; Pasupuleti 2026r, pp. 78–105; Pasupuleti 2026u, pp. 142–165)

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Theme III. Climate Intelligence, Geospatial Exposure and Nonstationary Hazard Modelling

Climate risk changes supply-chain analysis because historical frequency is not always a stable guide to future disruption. Heat, flood, drought, wildfire, storm and sea-level hazards interact with local infrastructure, water availability, energy systems and transport accessibility, creating spatially heterogeneous exposure. Earth-system foundation models, remote sensing, hydrological nowcasting and geospatial causal methods offer complementary ways to represent this uncertainty. The methodological task is to connect hazard information at appropriate spatial and temporal scales to facility, supplier and corridor decisions without treating model output as deterministic truth. (Pasupuleti 2026a, pp. 166–198; Pasupuleti 2026t, pp. 36–83; Pasupuleti 2026h, pp. 1–21)

Operational climate intelligence combines geocoded assets, supplier locations, route geometry, hazard layers and infrastructure dependencies within a time-aware data model. Scenario design should include chronic shifts as well as acute extremes, and should distinguish physical damage, capacity loss, access constraints and recovery delay. The resulting artefacts include climate-adjusted supplier scores, corridor hazard maps, time-to-recovery distributions, adaptation option registers and

thresholds for inventory, routing or location review. (Pasupuleti 2026v, pp. 49–71; Pasupuleti 2024i, pp. 131–151; Pasupuleti 2024b, pp. 47–67)

Theme IV. Digital Twins for Supply-Chain Stress Testing and Adaptive Reconfiguration

A supply-chain digital twin is valuable not because it visually replicates the network but because it maintains a computational state of entities, flows, capacities, constraints and decision rules that can be perturbed before operational commitments are made. The twin can integrate graph structure with event streams, climate hazards, policy scenarios, production constraints and logistics capacities. This makes it possible to test cascading disruption, compare reconfiguration strategies and identify which interventions remain robust across multiple plausible futures. (Pasupuleti 2026c, pp. 87–113; Pasupuleti 2026n, pp. 85–105; Pasupuleti 2024f)

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A disciplined twin workflow specifies system boundaries, calibrates baseline flows, encodes substitution and capacity constraints, introduces scenario shocks, records intervention logic and compares recovery trajectories. Validation should focus on whether the twin reproduces decision-relevant behaviours rather than superficial visual similarity. Research outputs include scenario replay libraries, bottleneck utilization measures, recovery curves, rerouting experiments, inventory policies and assumption registers that make strategic learning reproducible. (Pasupuleti 2024o; Pasupuleti 2024e; Pasupuleti 2024d)

Theme V. Scenario Intelligence for Geopolitical, Climate and Energy Shock Portfolios

Scenario intelligence addresses futures that cannot be estimated reliably from a single historical distribution. Supply chains may face combinations of tariffs, sanctions, conflict, commodity scarcity, energy-price shocks, carbon constraints and climate extremes whose joint occurrence has limited precedent. Scenario methods therefore complement econometrics by making structural assumptions explicit, exploring failure boundaries and testing the robustness of decisions rather than claiming precise probabilities for unprecedented events. (Pasupuleti 2026g, pp. 49–91; Pasupuleti 2026p, pp. 181–233; Pasupuleti 2026f, pp. 166–185)

A mature scenario architecture distinguishes exploratory scenarios, stress scenarios, reverse stress tests and decision-trigger scenarios. Each scenario should specify initiating events, transmission channels, duration, geographic scope, operational constraints and recovery assumptions. Outputs are not merely narratives: they include parameterized scenario sets, break-even thresholds, resilience envelopes and pre-authorized response options that can be replayed in digital twins and updated as new evidence arrives. (Pasupuleti 2026i, pp. 142–180; Pasupuleti 2026k, pp. 234–284; Pasupuleti 2024r)

Theme VI. Causal Inference and Regime-Aware Forecasting for Supply-Chain Decisions

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Prediction can signal emerging disruption, but strategic learning also requires evidence about mechanism. Causal time-series models, double machine learning, feature-dependence analysis and streaming policy evaluation can estimate how tariffs, climate events, supplier interventions or infrastructure changes affect lead times, prices, capacity and continuity under explicit assumptions. Forecasting adds a different function: estimating future demand, logistics states or hazard-sensitive variables while recognizing nonstationarity and structural breaks. (Pasupuleti 2023a, pp. 114–126; Pasupuleti 2023c, pp. 126–142; Pasupuleti 2024g, pp. 90–111)

The research design should therefore separate attribution from prediction. Causal models document treatment definitions, comparators, confounders and sensitivity; predictive models use out-of-time validation, calibration checks and drift detection. The combined workflow creates counterfactual estimates, regime-specific forecast intervals and evidence-based thresholds for diversification, inventory, supplier development or rerouting decisions. Where support is weak, outputs are downgraded from recommendations to scenario inputs rather than presented with false precision. (Pasupuleti 2024m, pp. 173–192; Pasupuleti 2024j; Pasupuleti 2024p)

Theme VII. Optimization of Sourcing, Inventory, Routing and Infrastructure Resilience

Resilience decisions are inherently multi-objective. Lower cost can increase concentration, additional inventory can raise working-capital exposure, alternative routes can increase emissions, and geographic diversification may move production

into regions with different climate or policy risks. Robust optimization and reinforcement-learning approaches provide structured ways to search these trade-offs, provided hard technical, regulatory, financial and continuity constraints are represented before an objective is optimized. (Pasupuleti 2023b, pp. 114–125; Pasupuleti 2023g, pp. 41–52; Pasupuleti 2023h, pp. 53–63)

Decision models can compare supplier portfolios, production allocation, inventory buffers, transport routing, energy sourcing and facility investment under scenario ensembles. The most useful output is not a single optimum but a frontier showing how cost, service, recovery time, emissions and risk change across feasible configurations. Governance requires that optimization recommendations remain interpretable, stress-tested and subject to qualification rules so that mathematically attractive alternatives are not mistaken for operationally deployable ones. (Pasupuleti 2022a, pp. 53–72; Pasupuleti 2022b, pp. 29–52; Pasupuleti 2024q, pp. 152–172)

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Theme VIII. Scalable Data Engineering, Edge Intelligence and Evidence Lineage

Graph analytics and digital twins are only as reliable as the data architecture that connects supplier masters, enterprise systems, trade records, telemetry, geospatial layers, hazard feeds and policy documents. Cross-border operations add latency, data-residency and connectivity constraints, while lower-tier supplier information may be incomplete or inconsistent. Big-data pipelines, streaming systems and edge analytics therefore form part of the resilience architecture rather than a neutral technical backend. (Pasupuleti 2023e, pp. 29–40; Pasupuleti 2023d, pp. 76–87; Pasupuleti 2024h, pp. 23–46)

A scalable evidence lifecycle requires canonical entity identifiers, event-time preservation, source provenance, versioned transformations, regional access controls and reproducible feature definitions. Edge and multi-region execution can preserve essential monitoring when connectivity is degraded or data cannot leave a jurisdiction. Outputs include lineage graphs, data-quality rules, regional processing patterns, service-dependency maps and auditable datasets that allow digital-twin and graph-model decisions to be reconstructed after a disruption. (Pasupuleti 2024k, pp. 193–210; Pasupuleti 2021b, pp. 356–367; Pasupuleti 2021e, pp. 316–330)

Theme IX. Trustworthy AI, Cyber-Physical Assurance and Model Governance

Supply-chain intelligence can influence supplier exclusion, inventory allocation, facility investment and emergency routing, so technical accuracy alone is not sufficient. Trustworthy AI requires robustness to distribution shift, transparent evidence chains, cyber resilience, access control, human contestability and defined decision rights. The assurance problem becomes more demanding when the same system operates across jurisdictions with different regulatory expectations and when climate or geopolitical shocks move the data distribution outside normal operating ranges. (Pasupuleti 2024l; Pasupuleti 2024n; Pasupuleti 2024a)

A layered governance model combines model inventories, approval tiers, validation records, policy-as-code, secure computation, monitoring thresholds and independent challenge. High-impact recommendations should retain human authorization and preserve the scenario assumptions that produced them. The resulting governance artefacts include model cards, audit trails, exception logs, recovery procedures and cross-functional escalation rules that allow firms to scale advanced analytics without surrendering accountability. (Pasupuleti 2023f, pp. 195–210; Pasupuleti 2021d, pp. 1–25; Pasupuleti 2021f, pp. 26–50)

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Theme X. Sectoral Resilience, Public-Private Coordination and Climate-Aware Governance

Manufacturing, agriculture, energy, logistics, telecommunications and finance experience compound supply-chain risk differently, yet they share dependencies on infrastructure, data, standards and public institutions. Climate adaptation and geopolitical resilience therefore require coordination beyond the boundary of a single firm. Ports, grids, customs systems, digital networks and emergency response mechanisms are partly collective assets, while private companies hold operational information needed to understand bottlenecks and recovery possibilities. (Pasupuleti 2024c; Pasupuleti 2022c, pp. 92–110; Pasupuleti 2021g, pp. 246–258)

A sectoral governance framework should define shared metrics, confidentiality boundaries, joint stress-test protocols and mechanisms for policy learning. Public institutions can use system-level indicators without requiring disclosure of commercially sensitive detail, while firms can align contingency planning with infrastructure and regulatory realities. The research agenda therefore evaluates resilience through continuity, adaptability, climate exposure, network redundancy,

governance quality and distributional effects across South Asia, Europe, Africa and the Americas. (Pasupuleti 2021a, pp. 149–173; Pasupuleti 2021c, pp. 99–123; Pasupuleti 2025a, pp. 198–222)

2.1 Trade Policy, Market Access and Competitiveness Measurement

The analytical starting point is trade diversion, preference utilization, tariff and non-tariff barriers, industrial competitiveness and rules-of-origin exposure. In this subsection, those concepts are treated as connected mechanisms rather than as independent risk labels. The supply-chain significance lies in how they alter feasible relationships among firms, jurisdictions and infrastructure providers, thereby changing both the cost and the reversibility of strategic commitments. A useful model separates observable exposure from deeper vulnerability and asks whether alternatives are technically substitutable, legally available and operationally reachable within the disruption horizon. That distinction prevents a high supplier count from being mistaken for genuine resilience. The conceptual boundary also matters for comparative research because the same nominal exposure can create different consequences when institutions, logistics capacity or financing conditions differ across regions. The supplied corpus provides relevant foundations for this systems-oriented interpretation (Pasupuleti 2026b, pp. 59–84; Pasupuleti 2021f, pp. 26–50). In Trade Policy, Market Access and Competitiveness Measurement, this lens is operationalized through panel econometrics, gravity-style controls, event studies, difference-in-differences logic and competitiveness decomposition. The resulting conceptual target is a trade-policy evidence layer that distinguishes observed reallocation from causal policy effects.

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Methodologically, the subsection uses panel econometrics, gravity-style controls, event studies, difference-in-differences logic and competitiveness decomposition. These methods are selected because the research problem mixes observable outcomes with policy- and climate-sensitive uncertainty, so no single predictive score can establish mechanism and decision quality at the same time. The design therefore states identification assumptions before estimation, separates training from evaluation where machine learning is used, and subjects optimization outputs to hard operational

and governance constraints. Particular attention is paid to missing relationships, endogenous policy responses, structural breaks and uneven data quality across jurisdictions. Robustness is evaluated through alternative specifications, sensitivity tests and explicit failure conditions rather than through fit statistics alone. This disciplined separation of explanation, prediction and action is consistent with the methodological resources in the supplied corpus (Pasupuleti 2023a, pp. 114–126; Pasupuleti 2026i, pp. 142–180). For Trade Policy, Market Access and Competitiveness Measurement, diagnosis explicitly links trade diversion, preference utilization, tariff and non-tariff barriers, industrial competitiveness and rules-of-origin exposure. The prescribed workflow is to specify policy treatment; establish pre-policy baselines; construct affected and comparison groups; estimate effects; test pre-trends and alternative windows; convert estimates into market-access scenarios. Evaluation reports treatment definitions, effect estimates, robustness checks, preference-utilization metrics and market-entry decision notes before strategic use.

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The operational workflow is sequential: specify policy treatment; establish pre-policy baselines; construct affected and comparison groups; estimate effects; test pre-trends and alternative windows; convert estimates into market-access scenarios. The principal capability created is a trade-policy evidence layer that distinguishes observed reallocation from causal policy effects. By retaining data versions, assumptions, model states and approval records, the pipeline leaves an auditable path from evidence to strategic action and makes later review possible after conditions change. Global applicability is examined through regional trade agreements in South Asia and Africa, single-market and external trade changes in Europe, and North/South American trade-corridor adjustments. The comparison uses common constructs but allows local thresholds, data availability and governance overlays to vary, avoiding the assumption that institutional diversity is measurement noise. Research outputs comprise treatment definitions, effect estimates, robustness checks, preference-utilization metrics and market-entry decision notes. Together, these artefacts support repeated stress testing, executive decision review and cumulative research across cases (Pasupuleti 2026b, pp. 59–84; Pasupuleti 2026i, pp. 142–180).

2.2 Econometric Identification of Geopolitical, Energy and Macro-Financial Shocks

A rigorous treatment of the topic begins with shock transmission through prices, exchange rates, input costs, demand, financing conditions and investment expectations. Theoretical reasoning focuses on the mechanism by which an external constraint is transmitted into firm behaviour, rather than assuming that country-level risk automatically predicts operational outcomes. This requires attention to contractual structure, supplier relationships, digital dependencies and the option value of alternative configurations. The analysis therefore distinguishes structural dependence, strategic choice and residual uncertainty, making it possible to ask which vulnerabilities can be redesigned and which must instead be buffered. The framework is intentionally relational: a location or supplier becomes critical because of its place in a broader network, not because of an isolated attribute. Such framing supports cross-border comparison while preserving institutional differences that affect adaptation costs (Pasupuleti 2026m, pp. 118–142; Pasupuleti 2024e). In Econometric Identification of Geopolitical, Energy and Macro-Financial Shocks, this lens is operationalized through time-series models, local projections, structural-break tests, volatility models and regime-aware forecasting. The resulting conceptual target is a transmission model that translates geopolitical and energy disturbances into operating and financial risk channels.

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The explanatory and decision logic is built from time-series models, local projections, structural-break tests, volatility models and regime-aware forecasting. Implementation begins by specifying what each method is allowed to claim: descriptive models organize exposure, causal designs test mechanisms, predictive models estimate future states, and optimization models search within a constrained action space. Assumptions about comparators, stationarity, data completeness and institutional stability are documented because fragmentation can invalidate relationships learned in quieter periods. Validation is therefore regime-aware and includes checks on calibration, subgroup performance and sensitivity to omitted or uncertain links. Where evidence is weak, the output is downgraded from recommendation to scenario input. The cited sources support this emphasis on methodological fit, uncertainty and controlled use of advanced analytics (Pasupuleti 2024h, pp. 23–46; Pasupuleti 2026q, pp. 1–30). For Econometric Identification of Geopolitical, Energy and Macro-Financial Shocks, diagnosis explicitly links shock transmission through prices, exchange rates, input costs, demand, financing

conditions and investment expectations. The prescribed workflow is to align event timing with market and operating data; test stationarity and breaks; estimate transmission dynamics; compare model classes; quantify uncertainty; connect macro paths to firm exposures. Evaluation reports impulse paths, regime indicators, inflation pass-through measures, forecast intervals and management stress assumptions before strategic use.

In practice, the research pipeline should align event timing with market and operating data; test stationarity and breaks; estimate transmission dynamics; compare model classes; quantify uncertainty; connect macro paths to firm exposures. This design produces a transmission model that translates geopolitical and energy disturbances into operating and financial risk channels, linking analytical output to a defined management process rather than leaving results as stand-alone reports. The implementation records when information was known, who validated material assumptions and which constraints shaped the final option set. Application across energy-importing South Asian economies, European industrial systems, commodity-exporting African economies and diversified American markets provides a test of portability: models are expected to preserve conceptual meaning while adapting to regional data and institutional conditions. The resulting deliverables include impulse paths, regime indicators, inflation pass-through measures, forecast intervals and management stress assumptions. These can be updated after policy or climate events, compared across business units and incorporated into formal governance cycles (Pasupuleti 2026m, pp. 118–142; Pasupuleti 2026q, pp. 1–30).

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2.3 Causal Effects of Sourcing, Diversification and Supplier Interventions

Within geopolitically fragmented and climate-exposed markets, the central conceptual issue is treatment-effect heterogeneity, selection into diversification, supplier development and the endogeneity of resilience investment. These elements define the state space in which firms decide whether to continue, diversify, duplicate, hedge or exit particular relationships. The model emphasizes path dependence: earlier sourcing, technology and infrastructure choices can restrict the speed with which a firm responds to a new policy regime. It also separates resilience capacity from realized performance, since a firm may possess alternatives that are never activated or may suffer despite diversification when substitutes share a common bottleneck.

Conceptual validity therefore depends on mapping dependencies at the level relevant to the decision being studied. The cited work supplies methodological and strategic anchors for modelling those relationships (Pasupuleti 2023h, pp. 53–63; Pasupuleti 2021b, pp. 356–367). In Causal Effects of Sourcing, Diversification and Supplier Interventions, this lens is operationalized through double machine learning, propensity methods, panel matching, causal forests and targeted robustness analysis. The resulting conceptual target is a causal decision framework that estimates where diversification or supplier-support interventions are likely to create the greatest resilience benefit.

Analysis proceeds through double machine learning, propensity methods, panel matching, causal forests and targeted robustness analysis, with each technique assigned to a distinct analytical question. The methodological significance lies in combining statistical discipline with operational realism: models must represent the decision horizon, constraints and observability that managers actually face. Data leakage, post-treatment variables and retrospective supplier visibility are treated as threats to inference, while model drift and structural change are treated as threats to prediction. The design also requires a baseline or simpler comparator so that additional model complexity must earn its place through better decision-relevant performance. Limitations are carried forward into governance thresholds, ensuring that uncertainty affects how outputs may be used. This approach draws directly on the methodological breadth of the retained reference set (Pasupuleti 2023d, pp. 76–87; Pasupuleti 2023e, pp. 29–40). For Causal Effects of Sourcing, Diversification and Supplier Interventions, diagnosis explicitly links treatment-effect heterogeneity, selection into diversification, supplier development and the endogeneity of resilience investment. The prescribed workflow is to define intervention and outcome; identify confounders; separate training from estimation samples; estimate conditional effects; test overlap; examine sensitivity to unobserved confounding. Evaluation reports conditional treatment effects, overlap diagnostics, policy targeting rules, sensitivity analyses and intervention-monitoring protocols before strategic use.

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A reproducible implementation can be organized as follows: define intervention and outcome; identify confounders; separate training from estimation samples; estimate conditional effects; test overlap; examine sensitivity to unobserved confounding. The innovation contribution is a causal decision framework that

estimates where diversification or supplier-support interventions are likely to create the greatest resilience benefit. Reproducibility is treated as a strategic property because managers may need to reconstruct why a sourcing, investment or hedging decision was made after the relevant market regime has changed. The framework is assessed in supplier upgrading in South Asia, dual sourcing in Europe, local-content programmes in Africa and reshoring incentives in the Americas, where differences in infrastructure, regulation and market depth create useful stress tests of generalizability. Research outputs include conditional treatment effects, overlap diagnostics, policy targeting rules, sensitivity analyses and intervention-monitoring protocols. Their role is to convert abstract resilience concepts into measurable, reviewable and institutionally actionable artefacts (Pasupuleti 2025h, pp. 53–63; Pasupuleti 2023e, pp. 29–40).

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2.4 Distributional Exposure across Sectors, Regions and Supplier Tiers

The research question becomes tractable when attention is directed to heterogeneous exposure by sector, firm size, workforce, region and position within value chains. Rather than treating fragmentation as a single shock, the subsection frames it as a sequence of constraints that can affect access, price, timing, information and governance simultaneously. This perspective supports a layered account of vulnerability in which direct exposure is only the first step; second-order dependence, common infrastructure and institutional response determine whether disruption propagates. The theory also recognizes adaptation as costly and uneven, which means that a nominally available substitute may not be economically or operationally usable. Comparative analysis must therefore preserve the distinction between formal availability and effective substitutability across jurisdictions. The relevant supplied studies reinforce this multi-layer research logic (Pasupuleti 2026c, pp. 87–113; Pasupuleti 2024f). In Distributional Exposure across Sectors, Regions and Supplier Tiers, this lens is operationalized through quantile analysis, distributional treatment effects, multilevel models and subgroup-stability testing. The resulting conceptual target is an inclusion-aware resilience assessment that prevents aggregate gains from hiding concentrated adjustment costs.

The methodological architecture combines quantile analysis, distributional treatment effects, multilevel models and subgroup-stability testing. The workflow

does not assume that richer computation automatically produces stronger evidence; instead, model choice follows the structure of the strategic question and the available counterfactual information. Estimation is paired with diagnostics for overlap, breakpoints, missingness and stability, while simulation is used when historical support is insufficient for the contemplated scenario. For predictive components, out-of-time testing is preferred to random validation because policy and hazard regimes and market conditions evolve. For optimization, feasibility and governance constraints are encoded before objective improvement is assessed. The retained references provide a basis for this integrated but claim-bounded analytical architecture (Pasupuleti 2026n, pp. 85–105; Pasupuleti 2024o). For Distributional Exposure across Sectors, Regions and Supplier Tiers, diagnosis explicitly links heterogeneous exposure by sector, firm size, workforce, region and position within value chains. The prescribed workflow is to partition outcomes by economically meaningful strata; estimate average and tail effects; compare structural sensitivity; test whether subgroup results survive alternative specifications; connect findings to transition support. Evaluation reports distributional profiles, vulnerability clusters, transition indicators, policy-compensation options and workforce-resilience metrics before strategic use.

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The data-to-decision lifecycle should partition outcomes by economically meaningful strata; estimate average and tail effects; compare structural sensitivity; test whether subgroup results survive alternative specifications; connect findings to transition support. When implemented as a governed system, the result is an inclusion-aware resilience assessment that prevents aggregate gains from hiding concentrated adjustment costs. The process connects operational teams, analysts and decision owners through documented handoffs, which reduces the risk that model outputs become detached from technical feasibility or policy constraints. Cross-regional relevance is tested through labour-intensive South Asian manufacturing, European transition regions, African logistics and resource zones, and American manufacturing communities; the intention is not to force uniform thresholds but to preserve a common analytical grammar. The study therefore produces distributional profiles, vulnerability clusters, transition indicators, policy-compensation options and workforce-resilience metrics. These outputs can be embedded in board review, procurement governance, investment approval or public-policy dialogue depending on the use case (Pasupuleti 2026c, pp. 87–113; Pasupuleti 2024o).

2.5 Scenario Econometrics, Counterfactual Adaptation and Decision Thresholds

For global supply-chain strategy, the relevant theoretical lens combines counterfactual reasoning under structural uncertainty, policy discontinuity and limited historical analogues. The core proposition is that strategic resilience emerges from configurations of relationships, capabilities and decision rights rather than from any single indicator. This makes boundary selection essential: the analyst must specify which product, market, technology, time horizon and jurisdiction define the system under study. The framework then asks where concentration is created, how shocks can travel, which alternatives remain feasible and what information managers require before acting. Such explicit scoping reduces the risk of overgeneralizing from aggregate country measures to firm-level decisions. It also allows the same constructs to be applied across regions with different industrial and regulatory structures (Pasupuleti 2021e, pp. 316–330; Pasupuleti 2021f, pp. 26–50). In Scenario Econometrics, Counterfactual Adaptation and Decision Thresholds, this lens is operationalized through hybrid econometric-scenario models, Bayesian or simulation-based uncertainty propagation, reverse stress tests and threshold analysis. The resulting conceptual target is a decision-threshold framework that joins statistical evidence with transparent strategic assumptions.

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To operationalize the construct, the research design integrates hybrid econometric-scenario models, Bayesian or simulation-based uncertainty propagation, reverse stress tests and threshold analysis. Each stage is connected to an evidence standard: measurement requires traceable definitions, explanation requires defensible identification, forecasting requires regime-sensitive validation, and action requires constraints plus accountable approval. Cross-jurisdictional analysis adds a further requirement because identical variables may reflect different institutional processes. The design therefore documents source provenance, local definitions and transformation rules before pooling information. Sensitivity analysis tests whether strategic conclusions survive reasonable changes in assumptions, and human review is concentrated where evidence is sparse or consequences are material. These methodological safeguards align with the analytical concerns represented in the cited corpus (Pasupuleti 2024g, pp. 90–111; Pasupuleti 2026l, pp. 106–133). For Scenario Econometrics, Counterfactual Adaptation and Decision Thresholds, diagnosis explicitly links counterfactual reasoning under structural uncertainty, policy

discontinuity and limited historical analogues. The prescribed workflow is to estimate empirical relationships where support exists; encode policy or geopolitical assumptions explicitly; simulate counterfactual paths; identify strategy failure points; document which outputs are evidence-driven versus scenario-driven. Evaluation reports counterfactual paths, break-even thresholds, scenario-attribution tables, robustness envelopes and executive decision gates before strategic use.

Operationalization requires teams to estimate empirical relationships where support exists; encode policy or geopolitical assumptions explicitly; simulate counterfactual paths; identify strategy failure points; document which outputs are evidence-driven versus scenario-driven. The practical research contribution is a decision-threshold framework that joins statistical evidence with transparent strategic assumptions. A critical design principle is that every material recommendation can be traced to a source state, model configuration and set of assumptions, allowing decisions to be challenged or reproduced. The framework is designed for trade-policy volatility in South Asia, sanctions and industrial-policy scenarios in Europe, infrastructure finance scenarios in Africa and tariff/currency scenarios in the Americas, which permits comparison of strategic mechanisms under different institutional and infrastructure conditions. Core outputs are counterfactual paths, break-even thresholds, scenario-attribution tables, robustness envelopes and executive decision gates. Used together, they provide a scalable protocol for learning from shocks, revising thresholds and strengthening governance over time (Pasupuleti 2021e, pp. 316–330; Pasupuleti 2026l, pp. 106–133).

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Chapter 3. Graph AI, Forecasting and Optimization for Resilient Supply-Chain Decisions

The third chapter turns network structure and external signals into predictive and prescriptive intelligence. Graph machine learning is used to rank supplier criticality, infer hidden relationships and discover substitution candidates; time-series and multimodal models forecast demand, lead times, hazards and policy-sensitive variables; optimization methods then test sourcing, inventory, routing and capacity decisions under explicit constraints. The methodological principle is separation of tasks so that predictive accuracy is not confused with causal evidence or operational feasibility (Pasupuleti 2026a, pp. 166–198; Pasupuleti 2026t, pp. 36–83; Pasupuleti 2026h, pp. 1–21; Pasupuleti 2026w, pp. 49–71).

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Trustworthiness is integrated into performance. A resilient model must communicate uncertainty, remain calibrated under regime change, preserve evidence provenance and degrade safely when data or services fail. Evaluation therefore includes out-of-time validation, missing-edge sensitivity, scenario robustness, constraint violations and reproducibility of the final recommendation. Research outputs include graph risk scores, hazard-aware forecasts, substitution rankings, Pareto resilience frontiers and human-review gates for high-impact decisions (Pasupuleti 2023b, pp. 114–125; Pasupuleti 2023g, pp. 41–52; Pasupuleti 2021g, pp. 246–258).

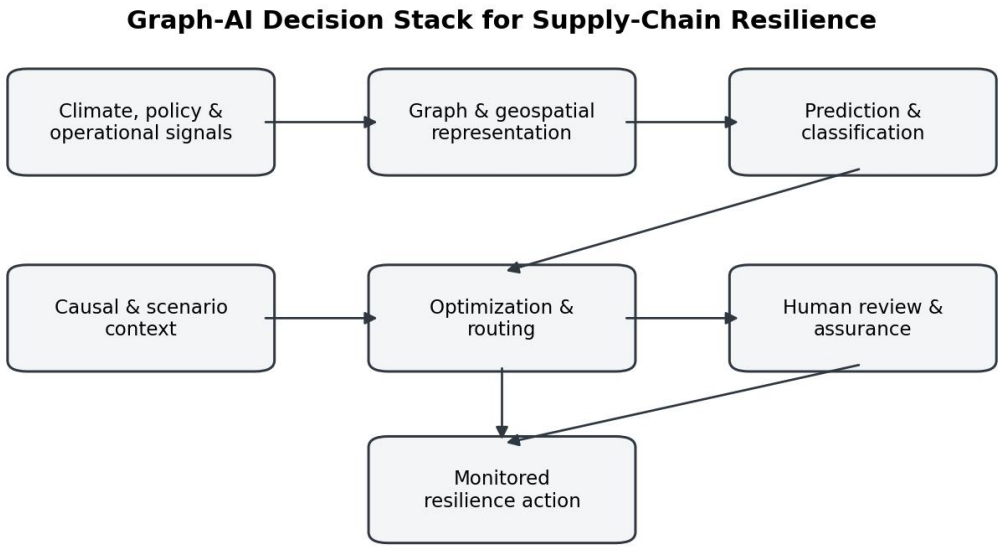


Figure 3.1 Graph-AI Decision Stack for Supply-Chain Resilience

AI task	Model family	Evaluation focus	Required guardrail
Supplier criticality	Graph neural networks and structural measures	Calibration; ranking stability; missing-edge sensitivity	Procurement verification and evidence traceability
Climate/hazard forecasting	Earth-system, geospatial and time-series models	Out-of-time error; interval coverage;	Hazard-source provenance and fallback baseline
Disruption classification	Multimodal and retrieval-augmented models	Precision; recall; evidence agreement	Human validation of high-impact alerts
Sourcing/routing optimization	Robust optimization and reinforcement learning	Constraint violations; recovery-cost frontier	Hard technical, legal and continuity constraints
Scenario synthesis	Generative and simulation-based models	Coverage of plausible states; internal consistency	Assumption registry and expert challenge
Executive decision support	Explainable models and scenario dashboards	Reproducibility; contestability; latency	Decision logs and approval tiers

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Table 3.1 Graph-AI Tasks, Evaluation Metrics and Governance Controls

3.1 Multimodal Early Warning from Climate, Policy, Trade and Operational Signals

The analytical starting point is weak signals, heterogeneous information sources, temporal alignment and the difference between relevance retrieval and causal evidence. In this subsection, those concepts are treated as connected mechanisms

rather than as independent risk labels. The supply-chain significance lies in how they alter feasible relationships among firms, jurisdictions and infrastructure providers, thereby changing both the cost and the reversibility of strategic commitments. A useful model separates observable exposure from deeper vulnerability and asks whether alternatives are technically substitutable, legally available and operationally reachable within the disruption horizon. That distinction prevents a high supplier count from being mistaken for genuine resilience. The conceptual boundary also matters for comparative research because the same nominal exposure can create different consequences when institutions, logistics capacity or financing conditions differ across regions. The supplied corpus provides relevant foundations for this systems-oriented interpretation (Pasupuleti 2023a, pp. 114–126; Pasupuleti 2026j, pp. 29–59). In Multimodal Early Warning from Climate, Policy, Trade and Operational Signals, this lens is operationalized through foundation models, retrieval-augmented analysis, embedding-based classification, anomaly detection and calibrated forecasting. The resulting conceptual target is an early-warning layer that converts fragmented information into ranked, traceable hypotheses for human assessment.

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Methodologically, the subsection uses foundation models, retrieval-augmented analysis, embedding-based classification, anomaly detection and calibrated forecasting. These methods are selected because the research problem mixes observable outcomes with policy- and climate-sensitive uncertainty, so no single predictive score can establish mechanism and decision quality at the same time. The design therefore states identification assumptions before estimation, separates training from evaluation where machine learning is used, and subjects optimization outputs to hard operational and governance constraints. Particular attention is paid to missing relationships, endogenous policy responses, structural breaks and uneven data quality across jurisdictions. Robustness is evaluated through alternative specifications, sensitivity tests and explicit failure conditions rather than through fit statistics alone. This disciplined separation of explanation, prediction and action is consistent with the methodological resources in the supplied corpus (Pasupuleti 2026i, pp. 142–180; Pasupuleti 2021g, pp. 246–258). For Multimodal Early Warning from Climate, Policy, Trade and Operational Signals, diagnosis explicitly links weak signals, heterogeneous information sources, temporal alignment and the difference between relevance retrieval and causal evidence. The prescribed workflow is to collect policy, trade,

market and operational signals; timestamp and deduplicate events; retrieve source context; classify materiality; aggregate signals; validate alerts against later operational outcomes. Evaluation reports alert precision, lead-time metrics, evidence packets, source-provenance logs and analyst escalation rules before strategic use.

The operational workflow is sequential: collect policy, trade, market and operational signals; timestamp and deduplicate events; retrieve source context; classify materiality; aggregate signals; validate alerts against later operational outcomes. The principal capability created is an early-warning layer that converts fragmented information into ranked, traceable hypotheses for human assessment. By retaining data versions, assumptions, model states and approval records, the pipeline leaves an auditable path from evidence to strategic action and makes later review possible after conditions change. Global applicability is examined through multilingual policy environments in South Asia and Africa, dense regulatory documentation in Europe, and high-frequency market and policy signals in the Americas. The comparison uses common constructs but allows local thresholds, data availability and governance overlays to vary, avoiding the assumption that institutional diversity is measurement noise. Research outputs comprise alert precision, lead-time metrics, evidence packets, source-provenance logs and analyst escalation rules. Together, these artefacts support repeated stress testing, executive decision review and cumulative research across cases (Pasupuleti 2023a, pp. 114–126; Pasupuleti 2021g, pp. 246–258).

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3.2 Graph AI for Supplier Networks, Corridor Risk and Substitution Discovery

A rigorous treatment of the topic begins with relational learning, structural dependence, hidden supplier communities and the interpretation of graph signals under incomplete network observation. Theoretical reasoning focuses on the mechanism by which an external constraint is transmitted into firm behaviour, rather than assuming that country-level risk automatically predicts operational outcomes. This requires attention to contractual structure, supplier relationships, digital dependencies and the option value of alternative configurations. The analysis therefore distinguishes structural dependence, strategic choice and residual uncertainty, making it possible to ask which vulnerabilities can be redesigned and which must instead be buffered. The framework is intentionally relational: a location

or supplier becomes critical because of its place in a broader network, not because of an isolated attribute. Such framing supports cross-border comparison while preserving institutional differences that affect adaptation costs (Pasupuleti 2026t, pp. 36–83; Pasupuleti 2026a, pp. 166–198). In Graph AI for Supplier Networks, Corridor Risk and Substitution Discovery, this lens is operationalized through graph neural networks, topological features, link prediction, centrality-aware learning and constrained candidate ranking. The resulting conceptual target is a graph-based supplier intelligence capability that identifies both vulnerability and feasible reconfiguration pathways.

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The explanatory and decision logic is built from graph neural networks, topological features, link prediction, centrality-aware learning and constrained candidate ranking. Implementation begins by specifying what each method is allowed to claim: descriptive models organize exposure, causal designs test mechanisms, predictive models estimate future states, and optimization models search within a constrained action space. Assumptions about comparators, stationarity, data completeness and institutional stability are documented because fragmentation can invalidate relationships learned in quieter periods. Validation is therefore regime-aware and includes checks on calibration, subgroup performance and sensitivity to omitted or uncertain links. Where evidence is weak, the output is downgraded from recommendation to scenario input. The cited sources support this emphasis on methodological fit, uncertainty and controlled use of advanced analytics (Pasupuleti 2021a, pp. 149–173; Pasupuleti 2024b, pp. 47–67). For Graph AI for Supplier Networks, Corridor Risk and Substitution Discovery, diagnosis explicitly links relational learning, structural dependence, hidden supplier communities and the interpretation of graph signals under incomplete network observation. The prescribed workflow is to construct the supplier graph; encode firm, product and jurisdiction attributes; train relational models; test robustness to missing edges; rank substitution candidates; validate with procurement and technical qualification data. Evaluation reports node-risk scores, missing-link estimates, candidate-supplier rankings, cascade simulations and qualification queues before strategic use.

In practice, the research pipeline should construct the supplier graph; encode firm, product and jurisdiction attributes; train relational models; test robustness to missing edges; rank substitution candidates; validate with procurement and technical

qualification data. This design produces a graph-based supplier intelligence capability that identifies both vulnerability and feasible reconfiguration pathways, linking analytical output to a defined management process rather than leaving results as stand-alone reports. The implementation records when information was known, who validated material assumptions and which constraints shaped the final option set. Application across electronics and automotive networks in Asia, cross-border manufacturing in Europe, mineral-processing chains in Africa and regionalized production in North America provides a test of portability: models are expected to preserve conceptual meaning while adapting to regional data and institutional conditions. The resulting deliverables include node-risk scores, missing-link estimates, candidate-supplier rankings, cascade simulations and qualification queues. These can be updated after policy or climate events, compared across business units and incorporated into formal governance cycles (Pasupuleti 2026t, pp. 36–83; Pasupuleti 2024b, pp. 47–67).

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3.3 Forecasting Demand, Inputs, Lead Times and Hazards under Nonstationarity

Within geopolitically fragmented and climate-exposed markets, the central conceptual issue is nonstationarity, model drift, sparse shocks and the danger of extrapolating stable-period relationships into fragmented regimes. These elements define the state space in which firms decide whether to continue, diversify, duplicate, hedge or exit particular relationships. The model emphasizes path dependence: earlier sourcing, technology and infrastructure choices can restrict the speed with which a firm responds to a new policy regime. It also separates resilience capacity from realized performance, since a firm may possess alternatives that are never activated or may suffer despite diversification when substitutes share a common bottleneck. Conceptual validity therefore depends on mapping dependencies at the level relevant to the decision being studied. The cited work supplies methodological and strategic anchors for modelling those relationships (Pasupuleti 2024h, pp. 23–46; Pasupuleti 2024e). In Forecasting Demand, Inputs, Lead Times and Hazards under Nonstationarity, this lens is operationalized through ensemble forecasting, time-series/deep-learning comparison, conformal risk control, change-point detection and

rolling backtests. The resulting conceptual target is a forecast service that explicitly communicates when models are outside their reliable operating range.

Analysis proceeds through ensemble forecasting, time-series/deep-learning comparison, conformal risk control, change-point detection and rolling backtests, with each technique assigned to a distinct analytical question. The methodological significance lies in combining statistical discipline with operational realism: models must represent the decision horizon, constraints and observability that managers actually face. Data leakage, post-treatment variables and retrospective supplier visibility are treated as threats to inference, while model drift and structural change are treated as threats to prediction. The design also requires a baseline or simpler comparator so that additional model complexity must earn its place through better decision-relevant performance. Limitations are carried forward into governance thresholds, ensuring that uncertainty affects how outputs may be used. This approach draws directly on the methodological breadth of the retained reference set (Pasupuleti 2026e, pp. 1–23; Pasupuleti 2026n, pp. 85–105). For Forecasting Demand, Inputs, Lead Times and Hazards under Nonstationarity, diagnosis explicitly links nonstationarity, model drift, sparse shocks and the danger of extrapolating stable-period relationships into fragmented regimes. The prescribed workflow is to establish naive baselines; create regime-aware train/test splits; compare classical and deep models; monitor calibration; detect drift; downgrade automation when error or uncertainty exceeds thresholds. Evaluation reports forecast error, calibration, interval coverage, regime-specific performance, drift alarms and fallback forecasting rules before strategic use.

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A reproducible implementation can be organized as follows: establish naive baselines; create regime-aware train/test splits; compare classical and deep models; monitor calibration; detect drift; downgrade automation when error or uncertainty exceeds thresholds. The innovation contribution is a forecast service that explicitly communicates when models are outside their reliable operating range. Reproducibility is treated as a strategic property because managers may need to reconstruct why a sourcing, investment or hedging decision was made after the relevant market regime has changed. The framework is assessed in import-demand forecasting in South Asia, industrial input demand in Europe, corridor volumes in Africa and cross-border e-commerce or manufacturing flows in the Americas, where differences in

infrastructure, regulation and market depth create useful stress tests of generalizability. Research outputs include forecast error, calibration, interval coverage, regime-specific performance, drift alarms and fallback forecasting rules. Their role is to convert abstract resilience concepts into measurable, reviewable and institutionally actionable artefacts (Pasupuleti 2024h, pp. 23–46; Pasupuleti 2026n, pp. 85–105).

3.4 Optimization of Sourcing, Inventory, Routing and Climate Resilience

The research question becomes tractable when attention is directed to multi-objective optimization under competing cost, service, geopolitical, carbon, liquidity and recovery constraints. Rather than treating fragmentation as a single shock, the subsection frames it as a sequence of constraints that can affect access, price, timing, information and governance simultaneously. This perspective supports a layered account of vulnerability in which direct exposure is only the first step; second-order dependence, common infrastructure and institutional response determine whether disruption propagates. The theory also recognizes adaptation as costly and uneven, which means that a nominally available substitute may not be economically or operationally usable. Comparative analysis must therefore preserve the distinction between formal availability and effective substitutability across jurisdictions. The relevant supplied studies reinforce this multi-layer research logic (Pasupuleti 2026l, pp. 106–133; Pasupuleti 2024g, pp. 90–111). In Optimization of Sourcing, Inventory, Routing and Climate Resilience, this lens is operationalized through robust optimization, reinforcement learning, scenario-constrained portfolio models and multi-criteria search. The resulting conceptual target is a coordinated operations-finance optimizer that makes resilience trade-offs explicit rather than embedding them in opaque heuristics.

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The methodological architecture combines robust optimization, reinforcement learning, scenario-constrained portfolio models and multi-criteria search. The workflow does not assume that richer computation automatically produces stronger evidence; instead, model choice follows the structure of the strategic question and the available counterfactual information. Estimation is paired with diagnostics for overlap, breakpoints, missingness and stability, while simulation is used when historical support is insufficient for the contemplated scenario. For predictive components, out-of-time testing is preferred to random validation because policy and hazard regimes

and market conditions evolve. For optimization, feasibility and governance constraints are encoded before objective improvement is assessed. The retained references provide a basis for this integrated but claim-bounded analytical architecture (Pasupuleti 2026g, pp. 49–91; Pasupuleti 2026q, pp. 1–30). For Optimization of Sourcing, Inventory, Routing and Climate Resilience, diagnosis explicitly links multi-objective optimization under competing cost, service, geopolitical, carbon, liquidity and recovery constraints. The prescribed workflow is to define decision variables and hard constraints; generate scenarios; optimize candidate policies; simulate performance; penalize brittle solutions; subject preferred policies to human and compliance review. Evaluation reports Pareto frontiers, expected shortfall, recovery-time objectives, constraint-violation rates and approved policy libraries before strategic use.

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The data-to-decision lifecycle should define decision variables and hard constraints; generate scenarios; optimize candidate policies; simulate performance; penalize brittle solutions; subject preferred policies to human and compliance review. When implemented as a governed system, the result is a coordinated operations-finance optimizer that makes resilience trade-offs explicit rather than embedding them in opaque heuristics. The process connects operational teams, analysts and decision owners through documented handoffs, which reduces the risk that model outputs become detached from technical feasibility or policy constraints. Cross-regional relevance is tested through regional sourcing portfolios in South Asia, capacity allocation in Europe, infrastructure-constrained African operations and inventory/hedging integration in the Americas; the intention is not to force uniform thresholds but to preserve a common analytical grammar. The study therefore produces Pareto frontiers, expected shortfall, recovery-time objectives, constraint-violation rates and approved policy libraries. These outputs can be embedded in board review, procurement governance, investment approval or public-policy dialogue depending on the use case (Pasupuleti 2026l, pp. 106–133; Pasupuleti 2026q, pp. 1–30).

3.5 Trustworthy AI, Human Oversight and Supply-Chain Model Governance

For global supply-chain strategy, the relevant theoretical lens combines model risk, transparency, contestability, accountability and the difference between technical

performance and legitimate strategic use. The core proposition is that strategic resilience emerges from configurations of relationships, capabilities and decision rights rather than from any single indicator. This makes boundary selection essential: the analyst must specify which product, market, technology, time horizon and jurisdiction define the system under study. The framework then asks where concentration is created, how shocks can travel, which alternatives remain feasible and what information managers require before acting. Such explicit scoping reduces the risk of overgeneralizing from aggregate country measures to firm-level decisions. It also allows the same constructs to be applied across regions with different industrial and regulatory structures (Pasupuleti 2022a, pp. 53–72; Pasupuleti 2022b, pp. 29–52). In Trustworthy AI, Human Oversight and Supply-Chain Model Governance, this lens is operationalized through model cards, explainability, robustness testing, secure deployment, policy-as-code and independent validation. The resulting conceptual target is an assurance system that lets firms scale AI internationally while preserving accountability across jurisdictions.

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To operationalize the construct, the research design integrates model cards, explainability, robustness testing, secure deployment, policy-as-code and independent validation. Each stage is connected to an evidence standard: measurement requires traceable definitions, explanation requires defensible identification, forecasting requires regime-sensitive validation, and action requires constraints plus accountable approval. Cross-jurisdictional analysis adds a further requirement because identical variables may reflect different institutional processes. The design therefore documents source provenance, local definitions and transformation rules before pooling information. Sensitivity analysis tests whether strategic conclusions survive reasonable changes in assumptions, and human review is concentrated where evidence is sparse or consequences are material. These methodological safeguards align with the analytical concerns represented in the cited corpus (Pasupuleti 2021g, pp. 246–258; Pasupuleti 2024a). For Trustworthy AI, Human Oversight and Supply-Chain Model Governance, diagnosis explicitly links model risk, transparency, contestability, accountability and the difference between technical performance and legitimate strategic use. The prescribed workflow is to classify decision impact; define approved data and model scope; validate across regimes; document limitations; monitor drift and access; require human authorization for high-impact exceptions.

Evaluation reports model inventories, approval tiers, audit trails, exception logs, monitoring thresholds and independent challenge records before strategic use.

Operationalization requires teams to classify decision impact; define approved data and model scope; validate across regimes; document limitations; monitor drift and access; require human authorization for high-impact exceptions. The practical research contribution is an assurance system that lets firms scale AI internationally while preserving accountability across jurisdictions. A critical design principle is that every material recommendation can be traced to a source state, model configuration and set of assumptions, allowing decisions to be challenged or reproduced. The framework is designed for data-protection and administrative-law constraints in Europe, digital-sovereignty concerns in India and other South Asian markets, capacity variation across African jurisdictions and sector-specific obligations in the Americas, which permits comparison of strategic mechanisms under different institutional and infrastructure conditions. Core outputs are model inventories, approval tiers, audit trails, exception logs, monitoring thresholds and independent challenge records. Used together, they provide a scalable protocol for learning from shocks, revising thresholds and strengthening governance over time (Pasupuleti 2022a, pp. 53–72; Pasupuleti 2024a).

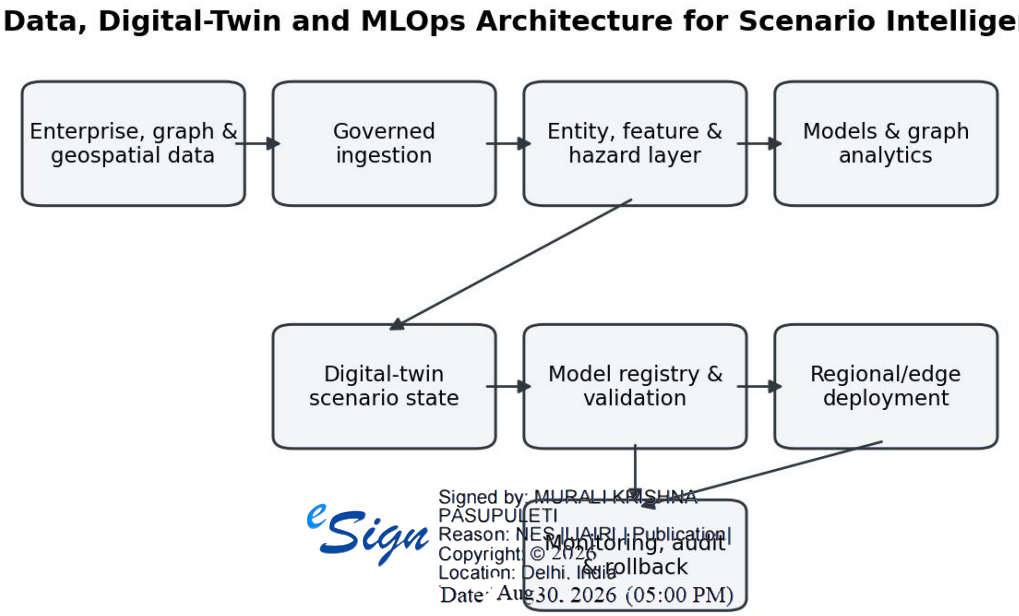
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Chapter 4. Big-Data Engineering, Digital Twins and Reproducible Scenario Intelligence

The fourth chapter provides the data and computational architecture that makes continuous supply-chain intelligence possible. Enterprise records, supplier data, logistics events, telemetry, geospatial layers, climate feeds and policy documents arrive with different identifiers, timestamps and jurisdictional constraints. A governed data architecture therefore requires entity resolution, lineage, streaming and batch integration, regional access controls and reproducible feature construction. These capabilities are prerequisites for reliable graph analytics and digital twins rather than implementation details that can be added later (Pasupuleti 2023b, pp. 114–125; Pasupuleti 2023g, pp. 41–52; Pasupuleti 2023h, pp. 53–63; Pasupuleti 2022a, pp. 53–72; Pasupuleti 2022b, pp. 29–52).

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Digital twins form the experimentation layer of the architecture. They maintain system state, network topology, capacities, hazards and decision rules so that shocks can be replayed and response options compared before live implementation. MLOps then versions data, models, scenarios and approvals, while edge and multi-region processing support continuity under connectivity or sovereignty constraints. Outputs include an event-driven supply-chain schema, digital-twin validation protocol, scenario registry, model-risk controls and cyber-physical recovery procedures (Pasupuleti 2026h, pp. 1–21; Pasupuleti 2023h, pp. 53–63; Pasupuleti 2024l; Pasupuleti 2023f, pp. 195–210).



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Figure 4.1 Data, Digital-Twin and MLOps Architecture for Scenario Intelligence

Lifecycle layer	Core function	Control requirement	Resilience contribution
Ingestion	Collect supplier, logistics, trade, telemetry, climate and policy events	Source identity, event time and schema validation	Reduces blind spots and stale evidence
Entity/graph layer	Reconcile firms, facilities, products, routes and shared infrastructure	Canonical IDs, edge provenance and versioning	Enables multi-tier dependency analysis
Hazard/feature layer	Align geospatial exposure, operating state and model features	Spatial resolution, lineage and transformation records	Connects physical risk to operational decisions
Twin/model layer	Estimate, predict and simulate scenario responses	Experiment tracking and assumption registry	Supports repeatable stress testing
Deployment/monitoring	Serve analytics across regions and edge locations	Policy gates, access control, drift and incident ownership	Preserves continuity under disruption
Audit/recovery	Reconstruct decisions and restore trusted states	Immutable logs, rollback and backup procedures	Accelerates recovery and accountability

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Table 4.1 Scalable Lifecycle for Graph, Digital-Twin and Scenario Intelligence

4.1 Supply-Chain Data Architecture, Geospatial Lineage and Entity Resolution

The analytical starting point is data as a strategic asset whose meaning, jurisdiction and lineage must be preserved across operational, external and model-generated sources. In this subsection, those concepts are treated as connected mechanisms rather than as independent risk labels. The supply-chain significance lies in how they alter feasible relationships among firms, jurisdictions and infrastructure providers, thereby changing both the cost and the reversibility of strategic commitments. A useful model separates observable exposure from deeper vulnerability and asks whether alternatives are technically substitutable, legally available and operationally reachable within the disruption horizon. That distinction prevents a high supplier count from being mistaken for genuine resilience. The conceptual boundary also matters for comparative research because the same nominal exposure can create different consequences when institutions, logistics capacity or financing conditions differ across regions. The supplied corpus provides relevant foundations for this systems-oriented interpretation (Pasupuleti 2026l, pp. 106–133; Pasupuleti 2024g, pp. 90–111). In Supply-Chain Data Architecture, Geospatial Lineage and Entity Resolution, this lens is operationalized through lakehouse-style integration, entity resolution, metadata management, lineage tracking and schema governance. The resulting conceptual target is a governed analytical substrate that allows trade, supplier, climate, market and infrastructure evidence to be combined reproducibly.

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Methodologically, the subsection uses lakehouse-style integration, entity resolution, metadata management, lineage tracking and schema governance. These methods are selected because the research problem mixes observable outcomes with policy- and climate-sensitive uncertainty, so no single predictive score can establish mechanism and decision quality at the same time. The design therefore states identification assumptions before estimation, separates training from evaluation where machine learning is used, and subjects optimization outputs to hard operational and governance constraints. Particular attention is paid to missing relationships, endogenous policy responses, structural breaks and uneven data quality across jurisdictions. Robustness is evaluated through alternative specifications, sensitivity tests and explicit failure conditions rather than through fit statistics alone. This disciplined separation of explanation, prediction and action is consistent with the

methodological resources in the supplied corpus (Pasupuleti 2026q, pp. 1–30; Pasupuleti 2026i, pp. 142–180). For Supply-Chain Data Architecture, Geospatial Lineage and Entity Resolution, diagnosis explicitly links data as a strategic asset whose meaning, jurisdiction and lineage must be preserved across operational, external and model-generated sources. The prescribed workflow is to catalogue sources; define canonical entities; reconcile identifiers; retain event time and source time; version transformations; expose lineage to analysts and model pipelines. Evaluation reports canonical schemas, lineage graphs, data-quality rules, retention policies and reproducible feature definitions before strategic use.

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The operational workflow is sequential: catalogue sources; define canonical entities; reconcile identifiers; retain event time and source time; version transformations; expose lineage to analysts and model pipelines. The principal capability created is a governed analytical substrate that allows trade, supplier, climate, market and infrastructure evidence to be combined reproducibly. By retaining data versions, assumptions, model states and approval records, the pipeline leaves an auditable path from evidence to strategic action and makes later review possible after conditions change. Global applicability is examined through distributed data estates of multinational firms operating across South Asia, Europe, Africa and the Americas. The comparison uses common constructs but allows local thresholds, data availability and governance overlays to vary, avoiding the assumption that institutional diversity is measurement noise. Research outputs comprise canonical schemas, lineage graphs, data-quality rules, retention policies and reproducible feature definitions. Together, these artefacts support repeated stress testing, executive decision review and cumulative research across cases (Pasupuleti 2026l, pp. 106–133; Pasupuleti 2026i, pp. 142–180).

4.2 Streaming and Edge Analytics for Climate-Sensitive Cross-Border Operations

A rigorous treatment of the topic begins with latency, connectivity, regional execution and the tension between centralized analytics and local data or continuity requirements. Theoretical reasoning focuses on the mechanism by which an external constraint is transmitted into firm behaviour, rather than assuming that country-level risk automatically predicts operational outcomes. This requires attention to

contractual structure, supplier relationships, digital dependencies and the option value of alternative configurations. The analysis therefore distinguishes structural dependence, strategic choice and residual uncertainty, making it possible to ask which vulnerabilities can be redesigned and which must instead be buffered. The framework is intentionally relational: a location or supplier becomes critical because of its place in a broader network, not because of an isolated attribute. Such framing supports cross-border comparison while preserving institutional differences that affect adaptation costs (Pasupuleti 2026i, pp. 142–180; Pasupuleti 2023a, pp. 114–126). In Streaming and Edge Analytics for Climate-Sensitive Cross-Border Operations, this lens is operationalized through stream processing, edge inference, federated patterns, messaging systems and region-aware service orchestration. The resulting conceptual target is a modular analytics operating model that maintains functionality during connectivity restrictions or regional policy divergence.

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The explanatory and decision logic is built from stream processing, edge inference, federated patterns, messaging systems and region-aware service orchestration. Implementation begins by specifying what each method is allowed to claim: descriptive models organize exposure, causal designs test mechanisms, predictive models estimate future states, and optimization models search within a constrained action space. Assumptions about comparators, stationarity, data completeness and institutional stability are documented because fragmentation can invalidate relationships learned in quieter periods. Validation is therefore regime-aware and includes checks on calibration, subgroup performance and sensitivity to omitted or uncertain links. Where evidence is weak, the output is downgraded from recommendation to scenario input. The cited sources support this emphasis on methodological fit, uncertainty and controlled use of advanced analytics (Pasupuleti 2024c; Pasupuleti 2026d, pp. 114–141). For Streaming and Edge Analytics for Climate-Sensitive Cross-Border Operations, diagnosis explicitly links latency, connectivity, regional execution and the tension between centralized analytics and local data or continuity requirements. The prescribed workflow is to classify workloads by latency and jurisdiction; place processing near data where required; synchronize approved features rather than raw records; design degraded modes; test failover between regions. Evaluation reports latency objectives, regional availability, data-egress controls, failover tests and service-dependency maps before strategic use.

In practice, the research pipeline should classify workloads by latency and jurisdiction; place processing near data where required; synchronize approved features rather than raw records; design degraded modes; test failover between regions. This design produces a modular analytics operating model that retains functionality during connectivity restrictions or regional policy divergence, linking analytical output to a defined management process rather than leaving results as stand-alone reports. The implementation records when information was known, who validated material assumptions and which constraints shaped the final option set. Application across manufacturing and logistics sites in South Asia, data-residency constrained European operations, connectivity-variable African environments and multi-cloud American deployments provides a test of portability: models are expected to preserve conceptual meaning while adapting to regional data and institutional conditions. The resulting deliverables include latency objectives, regional availability, data-egress controls, failover tests and service-dependency maps. These can be updated after policy or climate events, compared across business units and incorporated into formal governance cycles (Pasupuleti 2026i, pp. 142–180; Pasupuleti 2026d, pp. 114–141).

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4.3 Digital Twins for Multi-Hazard Supply-Chain Stress Testing and Experimentation

Within geopolitically fragmented and climate-exposed markets, the central conceptual issue is digital representation of state, constraints and interventions across facilities, suppliers, logistics and markets. These elements define the state space in which firms decide whether to continue, diversify, duplicate, hedge or exit particular relationships. The model emphasizes path dependence: earlier sourcing, technology and infrastructure choices can restrict the speed with which a firm responds to a new policy regime. It also separates resilience capacity from realized performance, since a firm may possess alternatives that are never activated or may suffer despite diversification when substitutes share a common bottleneck. Conceptual validity therefore depends on mapping dependencies at the level relevant to the decision being studied. The cited work supplies methodological and strategic anchors for modelling those relationships (Pasupuleti 2026h, pp. 1–21; Pasupuleti 2026l, pp. 106–133). In Digital Twins for Multi-Hazard Supply-Chain Stress Testing and Experimentation,

this lens is operationalized through event-driven simulation, agent-based or system-dynamics components, scenario replay and policy comparison. The resulting conceptual target is a controlled environment for testing reconfiguration before committing capital or disrupting live operations.

Analysis proceeds through event-driven simulation, agent-based or system-dynamics components, scenario replay and policy comparison, with each technique assigned to a distinct analytical question. The methodological significance lies in combining statistical discipline with operational realism: models must represent the decision horizon, constraints and observability that managers actually face. Data leakage, post-treatment variables and retrospective supplier visibility are treated as threats to inference, while model drift and structural change are treated as threats to prediction. The design also requires a baseline or simpler comparator so that additional model complexity must earn its place through better decision-relevant performance. Limitations are carried forward into governance thresholds, ensuring that uncertainty affects how outputs may be used. This approach draws directly on the methodological breadth of the retained reference set (Pasupuleti 2021d, pp. 1–25; Pasupuleti 2024m, pp. 173–192). For Digital Twins for Multi-Hazard Supply-Chain Stress Testing and Experimentation, diagnosis explicitly links digital representation of state, constraints and interventions across facilities, suppliers, logistics and markets. The prescribed workflow is to define system boundaries; calibrate baseline flows; encode capacity and policy constraints; inject shocks; compare interventions; record assumptions and validation gaps; update the twin with observed events. Evaluation reports scenario replay results, bottleneck utilization, recovery trajectories, intervention comparisons and assumption registers before strategic use.

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A reproducible implementation can be organized as follows: define system boundaries; calibrate baseline flows; encode capacity and policy constraints; inject shocks; compare interventions; record assumptions and validation gaps; update the twin with observed events. The innovation contribution is a controlled environment for testing reconfiguration before committing capital or disrupting live operations. Reproducibility is treated as a strategic property because managers may need to reconstruct why a sourcing, investment or hedging decision was made after the relevant market regime has changed. The framework is assessed in port and corridor stress in South Asia, industrial-energy scenarios in Europe, infrastructure bottlenecks

in Africa and regional supply-network redesign in the Americas, where differences in infrastructure, regulation and market depth create useful stress tests of generalizability. Research outputs include scenario replay results, bottleneck utilization, recovery trajectories, intervention comparisons and assumption registers. Their role is to convert abstract resilience concepts into measurable, reviewable and institutionally actionable artefacts (Pasupuleti 2026h, pp. 1–21; Pasupuleti 2024m, pp. 173–192).

4.4 MLOps, Reproducibility and Model Risk under Geopolitical-Climate Drift

The research question becomes tractable when attention is directed to reproducibility, version control, validation independence, regional model variants and controlled change management. Rather than treating fragmentation as a single shock, the subsection frames it as a sequence of constraints that can affect access, price, timing, information and governance simultaneously. This perspective supports a layered account of vulnerability in which direct exposure is only the first step; second-order dependence, common infrastructure and institutional response determine whether disruption propagates. The theory also recognizes adaptation as costly and uneven, which means that a nominally available substitute may not be economically or operationally usable. Comparative analysis must therefore preserve the distinction between formal availability and effective substitutability across jurisdictions. The relevant supplied studies reinforce this multi-layer research logic (Pasupuleti 2026i, pp. 142–180; Pasupuleti 2026q, pp. 1–30). In MLOps, Reproducibility and Model Risk under Geopolitical-Climate Drift, this lens is operationalized through model registries, feature stores, CI/CD with policy gates, champion-challenger testing and reproducible experiment tracking. The resulting conceptual target is a strategic MLOps framework that makes international AI systems auditable and resilient to staff, vendor or model turnover.

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The methodological architecture combines model registries, feature stores, CI/CD with policy gates, champion-challenger testing and reproducible experiment tracking. The workflow does not assume that richer computation automatically produces stronger evidence; instead, model choice follows the structure of the strategic question and the available counterfactual information. Estimation is paired with diagnostics for overlap, breakpoints, missingness and stability, while simulation is used when historical support is insufficient for the contemplated scenario. For predictive

components, out-of-time testing is preferred to random validation because policy and hazard regimes and market conditions evolve. For optimization, feasibility and governance constraints are encoded before objective improvement is assessed. The retained references provide a basis for this integrated but claim-bounded analytical architecture (Pasupuleti 2023a, pp. 114–126; Pasupuleti 2024c). For MLOps, Reproducibility and Model Risk under Geopolitical-Climate Drift, diagnosis explicitly links reproducibility, version control, validation independence, regional model variants and controlled change management. The prescribed workflow is to version datasets and code; register models; bind approvals to jurisdiction and use case; backtest before release; monitor live performance; archive decisions; roll back when controls fail. Evaluation reports reproducibility checks, deployment manifests, validation sign-offs, drift metrics, rollback procedures and model-retirement records before strategic use.

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The data-to-decision lifecycle should version datasets and code; register models; bind approvals to jurisdiction and use case; backtest before release; monitor live performance; archive decisions; roll back when controls fail. When implemented as a governed system, the result is a strategic MLOps framework that makes international AI systems auditable and resilient to staff, vendor or model turnover. The process connects operational teams, analysts and decision owners through documented handoffs, which reduces the risk that model outputs become detached from technical feasibility or policy constraints. Cross-regional relevance is tested through global organizations with regional subsidiaries, joint ventures and outsourced technology partners across all four regions; the intention is not to force uniform thresholds but to preserve a common analytical grammar. The study therefore produces reproducibility checks, deployment manifests, validation sign-offs, drift metrics, rollback procedures and model-retirement records. These outputs can be embedded in board review, procurement governance, investment approval or public-policy dialogue depending on the use case (Pasupuleti 2026i, pp. 142–180; Pasupuleti 2024c).

4.5 Cyber-Physical Resilience, Data Sovereignty and Secure Scenario Infrastructure

For global supply-chain strategy, the relevant theoretical lens combines cyber-physical dependence, vendor concentration, secure computation, access control and

data-sovereignty constraints. The core proposition is that strategic resilience emerges from configurations of relationships, capabilities and decision rights rather than from any single indicator. This makes boundary selection essential: the analyst must specify which product, market, technology, time horizon and jurisdiction define the system under study. The framework then asks where concentration is created, how shocks can travel, which alternatives remain feasible and what information managers require before acting. Such explicit scoping reduces the risk of overgeneralizing from aggregate country measures to firm-level decisions. It also allows the same constructs to be applied across regions with different industrial and regulatory structures (Pasupuleti 2026l, pp. 106–133; Pasupuleti 2026h, pp. 1–21). In Cyber-Physical Resilience, Data Sovereignty and Secure Scenario Infrastructure, this lens is operationalized through zero-trust architecture, encryption, confidential processing, policy-as-code and resilience testing of digital dependencies. The resulting conceptual target is a secure analytics architecture that protects strategic models and preserves decision continuity during cyber or geopolitical disruption.

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To operationalize the construct, the research design integrates zero-trust architecture, encryption, confidential processing, policy-as-code and resilience testing of digital dependencies. Each stage is connected to an evidence standard: measurement requires traceable definitions, explanation requires defensible identification, forecasting requires regime-sensitive validation, and action requires constraints plus accountable approval. Cross-jurisdictional analysis adds a further requirement because identical variables may reflect different institutional processes. The design therefore documents source provenance, local definitions and transformation rules before pooling information. Sensitivity analysis tests whether strategic conclusions survive reasonable changes in assumptions, and human review is concentrated where evidence is sparse or consequences are material. These methodological safeguards align with the analytical concerns represented in the cited corpus (Pasupuleti 2021f, pp. 26–50; Pasupuleti 2021e, pp. 316–330). For Cyber-Physical Resilience, Data Sovereignty and Secure Scenario Infrastructure, diagnosis explicitly links cyber-physical dependence, vendor concentration, secure computation, access control and data-sovereignty constraints. The prescribed workflow is to map critical services; classify sensitive data; define trust boundaries; enforce least privilege; test vendor or region failure; retain secure offline or degraded procedures for essential

decisions. Evaluation reports trust-boundary maps, vendor concentration metrics, recovery objectives, access-control evidence and secure-computation policies before strategic use.

Operationalization requires teams to map critical services; classify sensitive data; define trust boundaries; enforce least privilege; test vendor or region failure; retain secure offline or degraded procedures for essential decisions. The practical research contribution is a secure analytics architecture that protects strategic models and preserves decision continuity during cyber or geopolitical disruption. A critical design principle is that every material recommendation can be traced to a source state, model configuration and set of assumptions, allowing decisions to be challenged or reproduced. The framework is designed for telecommunications and cloud dependencies in South Asia, sovereignty requirements in Europe, critical connectivity in Africa and financial/digital infrastructure in the Americas, which permits comparison of strategic mechanisms under different institutional and infrastructure conditions. Core outputs are trust-boundary maps, vendor concentration metrics, recovery objectives, access-control evidence and secure-computation policies. Used together, they provide a scalable protocol for learning from shocks, revising thresholds and strengthening governance over time (Pasupuleti 2026l, pp. 106–133; Pasupuleti 2021e, pp. 316–330).

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Chapter 5. Sectoral Resilience, Climate Adaptation and Governance of Critical Supply Networks

The final chapter applies the integrated framework to manufacturing, agriculture, energy, finance, transport, telecommunications and shared infrastructure. Sectoral analysis preserves common resilience constructs while allowing different physical and institutional constraints: manufacturing emphasizes supplier and capacity topology; agriculture adds climate and water exposure; energy adds grid and fuel security; logistics adds corridor and port capacity; finance adds liquidity and insurance; digital services add sovereignty and cyber dependence. This comparative framing supports both firm strategy and policy analysis (Pasupuleti 2026c, pp. 87–113; Pasupuleti 2024e; Pasupuleti 2023a, pp. 1–4; Pasupuleti 2024c).

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Governance is treated as a network capability because major disruptions cross organizational boundaries. Firms, infrastructure operators and public institutions need compatible scenario languages, shared system-level metrics and clear confidentiality rules. The culminating outputs are a sectoral resilience matrix, public-private stress-test protocol, climate-aware investment framework, trustworthy-AI governance model and multi-year research agenda for comparing adaptation pathways across South Asia, Europe, Africa and the Americas (Pasupuleti 2026w, pp. 1–28; Pasupuleti 2024j; Pasupuleti 2021c, pp. 99–123; Pasupuleti 2025a, pp. 198–222).

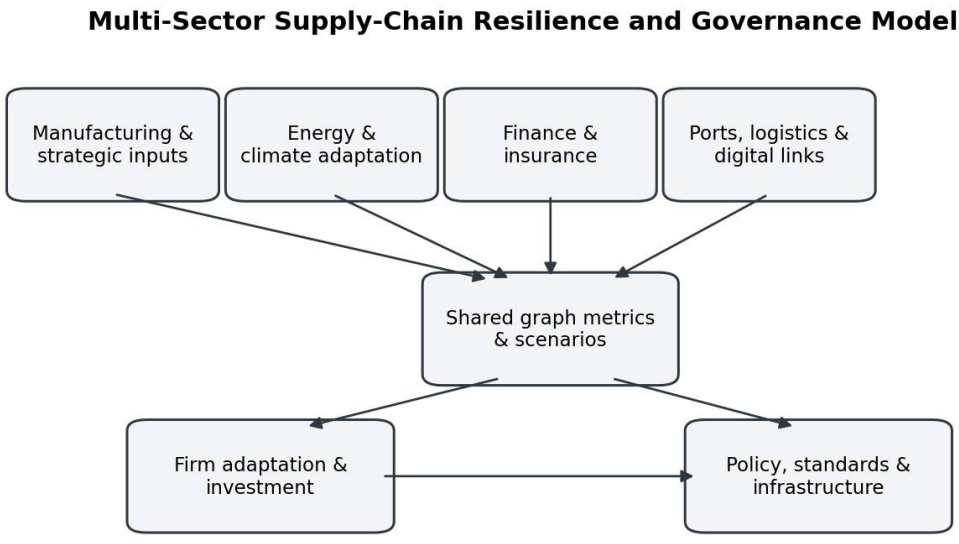


Figure 5.1 Multi-Sector Supply-Chain Resilience and Governance Model

Sector/domain	Compound exposure	AI-enabled response	Governance priority
Manufacturing	Input concentration, climate-sensitive facilities and technology controls	Supplier graphs, digital-twin capacity tests, predictive operations	Supplier development and strategic-input policy
Agriculture/food	Drought, flood, heat and variability	Geospatial hazard and logistics models, climate-smart sourcing scenarios	Food security, traceability and adaptation support
Energy/critical inputs	Fuel, grid and mineral concentration with transition risk	Demand forecasting, network stress tests, location optimization	Infrastructure investment and transition security
Transport/logistics	Port closure, border friction, extreme weather and capacity scarcity	Graph routing, rerouting optimization, twin replay	Corridor redundancy and shared disruption information
Finance/insurance	Liquidity, currency, counterparty and physical-risk transmission	Scenario stress tests, hedging and resilience-finance allocation	Risk disclosure, capital and insurance governance
Digital/telecom	Vendor concentration, data residency and service disruption	Multi-region orchestration, edge analytics, policy-as-code	Cybersecurity, sovereignty and interoperability

Table 5.1 Sectoral Supply-Chain Resilience Priorities and Coordinated Responses

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5.1 Manufacturing, Strategic Inputs and Climate-Resilient Production Ecosystems

The analytical starting point is industrial capability, supplier depth, skills, technology access and the resilience value of regional production ecosystems. In this subsection, those concepts are treated as connected mechanisms rather than as independent risk labels. The supply-chain significance lies in how they alter feasible relationships among firms, jurisdictions and infrastructure providers, thereby changing both the cost and the reversibility of strategic commitments. A useful model separates observable exposure from deeper vulnerability and asks whether alternatives are technically substitutable, legally available and operationally reachable within the disruption horizon. That distinction prevents a high supplier count from being mistaken for genuine resilience. The conceptual boundary also matters for comparative research because the same nominal exposure can create different consequences when institutions, logistics capacity or financing conditions differ across regions. The supplied corpus provides relevant foundations for this systems-oriented interpretation (Pasupuleti 2024b, pp. 47–67; Pasupuleti 2026e, pp. 1–23). In Manufacturing, Strategic Inputs and Climate-Resilient Production Ecosystems, this lens is operationalized through cluster benchmarking, network analysis, production optimization and capability-gap assessment. The resulting conceptual target is a manufacturing-resilience roadmap that links strategic technology priorities to operational capability and workforce development.

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Methodologically, the subsection uses cluster benchmarking, network analysis, production optimization and capability-gap assessment. These methods are selected because the research problem mixes observable outcomes with policy- and climate-sensitive uncertainty, so no single predictive score can establish mechanism and decision quality at the same time. The design therefore states identification assumptions before estimation, separates training from evaluation where machine learning is used, and subjects optimization outputs to hard operational and governance constraints. Particular attention is paid to missing relationships, endogenous policy responses, structural breaks and uneven data quality across jurisdictions. Robustness is evaluated through alternative specifications, sensitivity tests and explicit failure conditions rather than through fit statistics alone. This disciplined separation of explanation, prediction and action is consistent with the methodological resources in

the supplied corpus (Pasupuleti 2026l, pp. 106–133; Pasupuleti 2024o). For Manufacturing, Strategic Inputs and Climate-Resilient Production Ecosystems, diagnosis explicitly links industrial capability, supplier depth, skills, technology access and the resilience value of regional production ecosystems. The prescribed workflow is to map critical inputs and process capabilities; assess supplier and workforce depth; model capacity substitution; test regional shocks; design supplier-development and investment sequences. Evaluation reports capability matrices, supplier-depth indicators, skills gaps, capacity options and regional investment portfolios before strategic use.

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The operational workflow is sequential: map critical inputs and process capabilities; assess supplier and workforce depth; model capacity substitution; test regional shocks; design supplier-development and investment sequences. The principal capability created is a manufacturing-resilience roadmap that links strategic technology priorities to operational capability and workforce development. By retaining data versions, assumptions, model states and approval records, the pipeline leaves an auditable path from evidence to strategic action and makes later review possible after conditions change. Global applicability is examined through Indian and broader South Asian manufacturing belts, European industrial clusters, African industrialization corridors and North American strategic manufacturing initiatives. The comparison uses common constructs but allows local thresholds, data availability and governance overlays to vary, avoiding the assumption that institutional diversity is measurement noise. Research outputs comprise capability matrices, supplier-depth indicators, skills gaps, capacity options and regional investment portfolios. Together, these artefacts support repeated stress testing, executive decision review and cumulative research across cases (Pasupuleti 2024b, pp. 47–67; Pasupuleti 2024o).

5.2 Energy, Climate Adaptation and Critical-Input Continuity

A rigorous treatment of the topic begins with energy and climate security, transition risk, input dependency, carbon constraints and the interaction between geoeconomic and sustainability strategy. Theoretical reasoning focuses on the mechanism by which an external constraint is transmitted into firm behaviour, rather than assuming that country-level risk automatically predicts operational outcomes. This requires attention to contractual structure, supplier relationships, digital

dependencies and the option value of alternative configurations. The analysis therefore distinguishes structural dependence, strategic choice and residual uncertainty, making it possible to ask which vulnerabilities can be redesigned and which must instead be buffered. The framework is intentionally relational: a location or supplier becomes critical because of its place in a broader network, not because of an isolated attribute. Such framing supports cross-border comparison while preserving institutional differences that affect adaptation costs (Pasupuleti 2026q, pp. 1–30; Pasupuleti 2026l, pp. 106–133). In Energy, Climate Adaptation and Critical-Input Continuity, this lens is operationalized through energy-demand forecasting, scenario analysis, location optimization and transition-risk evaluation. The resulting conceptual target is an energy-and-input resilience strategy that reduces exposure without treating decarbonization and security as separate programs.

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The explanatory and decision logic is built from energy-demand forecasting, scenario analysis, location optimization and transition-risk evaluation. Implementation begins by specifying what each method is allowed to claim: descriptive models organize exposure, causal designs test mechanisms, predictive models estimate future states, and optimization models search within a constrained action space. Assumptions about comparators, stationarity, data completeness and institutional stability are documented because fragmentation can invalidate relationships learned in quieter periods. Validation is therefore regime-aware and includes checks on calibration, subgroup performance and sensitivity to omitted or uncertain links. Where evidence is weak, the output is downgraded from recommendation to scenario input. The cited sources support this emphasis on methodological fit, uncertainty and controlled use of advanced analytics (Pasupuleti 2026r, pp. 78–105; Pasupuleti 2024g, pp. 90–111). For Energy, Climate Adaptation and Critical-Input Continuity, diagnosis explicitly links energy and climate security, transition risk, input dependency, carbon constraints and the interaction between geoeconomic and sustainability strategy. The prescribed workflow is to quantify energy and input intensity; map sources and infrastructure; stress prices and availability; evaluate substitution and efficiency; sequence capital investment with policy and financing constraints. Evaluation reports energy-security metrics, critical-input concentration, transition pathways, capital plans and resilience-adjusted sustainability indicators before strategic use.

In practice, the research pipeline should quantify energy and input intensity; map sources and infrastructure; stress prices and availability; evaluate substitution and efficiency; sequence capital investment with policy and financing constraints. This design produces an energy-and-input resilience strategy that reduces exposure without treating decarbonization and security as separate programmes, linking analytical output to a defined management process rather than leaving results as stand-alone reports. The implementation records when information was known, who validated material assumptions and which constraints shaped the final option set. Application across renewable integration in South Asia, industrial decarbonization in Europe, mineral and power-system development in Africa and energy-transition investments across the Americas provides a test of portability. Models are expected to preserve conceptual meaning while adapting to regional data and institutional conditions. The resulting deliverables include energy-security metrics, critical-input concentration, transition pathways, capital plans and resilience-adjusted sustainability indicators. These can be updated after policy or climate events, compared across business units and incorporated into formal governance cycles (Pasupuleti 2026q, pp. 1–30; Pasupuleti 2024g, pp. 90–111).

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5.3 Trade Finance, Insurance and Climate-Geopolitical Financial Resilience

Within geopolitically fragmented and climate-exposed markets, the central conceptual issue is financial contagion, liquidity, payment infrastructure, digital services, regulatory fragmentation and the financing of resilience investment. These elements define the state space in which firms decide whether to continue, diversify, duplicate, hedge or exit particular relationships. The model emphasizes path dependence: earlier sourcing, technology and infrastructure choices can restrict the speed with which a firm responds to a new policy regime. It also separates resilience capacity from realized performance, since a firm may possess alternatives that are never activated or may suffer despite diversification when substitutes share a common bottleneck. Conceptual validity therefore depends on mapping dependencies at the level relevant to the decision being studied. The cited work supplies methodological and strategic anchors for modelling those relationships (Pasupuleti 2026l, pp. 106–133; Pasupuleti 2026g, pp. 49–91). In Trade Finance, Insurance and Climate-Geopolitical Financial Resilience, this lens is operationalized through portfolio stress

testing, systemic-risk constraints, fintech benchmarking and scenario-linked capital allocation. The resulting conceptual target is a capital-resilience framework that synchronizes treasury, investment and supply-chain reconfiguration.

Analysis proceeds through portfolio stress testing, systemic-risk constraints, fintech benchmarking and scenario-linked capital allocation, with each technique assigned to a distinct analytical question. The methodological significance lies in combining statistical discipline with operational realism: models must represent the decision horizon, constraints and observability that managers actually face. Data leakage, post-treatment variables and retrospective supplier visibility are treated as threats to inference, while model drift and structural change are treated as threats to prediction. The design also requires a baseline or simpler comparator so that additional model complexity must earn its place through better decision-relevant performance. Limitations are carried forward into governance thresholds, ensuring that uncertainty affects how outputs may be used. This approach draws directly on the methodological breadth of the retained reference set (Pasupuleti 2026q, pp. 1–30; Pasupuleti 2024g, pp. 90–111). For Trade Finance, Insurance and Climate-Geopolitical Financial Resilience, diagnosis explicitly links financial contagion, liquidity, payment infrastructure, digital services, regulatory fragmentation and the financing of resilience investment. The prescribed workflow is to connect operating scenarios to cash flow and funding needs; stress currencies and asset prices; test payment or counterparty disruptions; compare financing structures; set liquidity and hedge triggers. Evaluation reports liquidity buffers, hedge effectiveness, counterparty concentration, financing headroom and capital-allocation gates before strategic use.

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A reproducible implementation can be organized as follows: connect operating scenarios to cash flow and funding needs; stress currencies and asset prices; test payment or counterparty disruptions; compare financing structures; set liquidity and hedge triggers. The innovation contribution is a capital-resilience framework that synchronizes treasury, investment and supply-chain reconfiguration. Reproducibility is treated as a strategic property because managers may need to reconstruct why a sourcing, investment or hedging decision was made after the relevant market regime has changed. The framework is assessed in fintech-intensive South Asian markets, European capital and regulatory systems, African trade-finance needs and deep financial markets in the Americas, where differences in infrastructure, regulation and

market depth create useful stress tests of generalizability. Research outputs include liquidity buffers, hedge effectiveness, counterparty concentration, financing headroom and capital-allocation gates. Their role is to convert abstract resilience concepts into measurable, reviewable and institutionally actionable artefacts (Pasupuleti 2026l, pp. 106–133; Pasupuleti 2024g, pp. 90–111).

5.4 Ports, Transport, Logistics Corridors and Multimodal Rerouting

The research question becomes tractable when attention is directed to corridor dependence, port and border capacity, last-mile constraints, telecommunications reliability and vendor concentration. Rather than treating fragmentation as a single shock, the subsection frames it as a sequence of constraints that can affect access, price, timing, information and governance simultaneously. This perspective supports a layered account of vulnerability in which direct exposure is only the first step; second-order dependence, common infrastructure and institutional response determine whether disruption propagates. The theory also recognizes adaptation as costly and uneven, which means that a nominally available substitute may not be economically or operationally usable. Comparative analysis must therefore preserve the distinction between formal availability and effective substitutability across jurisdictions. The relevant supplied studies reinforce this multi-layer research logic (Pasupuleti 2024m, pp. 173–192; Pasupuleti 2021d, pp. 1–25). In Ports, Transport, Logistics Corridors and Multimodal Rerouting, this lens is operationalized through network flow analysis, route optimization, capacity simulation and infrastructure stress testing. The resulting conceptual target is a corridor-resilience system that connects physical and digital routes rather than managing them separately.

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The methodological architecture combines network flow analysis, route optimization, capacity simulation and infrastructure stress testing. The workflow does not assume that richer computation automatically produces stronger evidence; instead, model choice follows the structure of the strategic question and the available counterfactual information. Estimation is paired with diagnostics for overlap, breakpoints, missingness and stability, while simulation is used when historical support is insufficient for the contemplated scenario. For predictive components, out-of-time testing is preferred to random validation because policy and hazard regimes and market conditions evolve. For optimization, feasibility and governance

constraints are encoded before objective improvement is assessed. The retained references provide a basis for this integrated but claim-bounded analytical architecture (Pasupuleti 2026h, pp. 1–21; Pasupuleti 2026l, pp. 106–133). For Ports, Transport, Logistics Corridors and Multimodal Rerouting, diagnosis explicitly links corridor dependence, port and border capacity, last-mile constraints, telecommunications reliability and vendor concentration. The prescribed workflow is to map product-to-corridor dependencies; measure alternative route capacity; model border and transport delays; test telecom or cloud outages; prequalify contingency logistics and communications arrangements. Evaluation reports route criticality, rerouting time, capacity headroom, service-continuity objectives and corridor contingency agreements before strategic use.

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The data-to-decision lifecycle should map product-to-corridor dependencies; measure alternative route capacity; model border and transport delays; test telecom or cloud outages; prequalify contingency logistics and communications arrangements. When implemented as a governed system, the result is a corridor-resilience system that connects physical and digital routes rather than managing them separately. The process connects operational teams, analysts and decision owners through documented handoffs, which reduces the risk that model outputs become detached from technical feasibility or policy constraints. Cross-regional relevance is tested through South Asian port-industrial corridors, European multimodal networks, African trade corridors and North American cross-border transport systems; the intention is not to force uniform thresholds but to preserve a common analytical grammar. The study therefore produces route criticality, rerouting time, capacity headroom, service-continuity objectives and corridor contingency agreements. These outputs can be embedded in board review, procurement governance, investment approval or public-policy dialogue depending on the use case (Pasupuleti 2024m, pp. 173–192; Pasupuleti 2026l, pp. 106–133).

5.5 Public-Private Governance, Climate Resilience and Future Research Horizons

For global supply-chain strategy, the relevant theoretical lens combines institutional coordination, responsible AI, industrial policy, public-private information asymmetry and the governance of resilience externalities. The core proposition is that

strategic resilience emerges from configurations of relationships, capabilities and decision rights rather than from any single indicator. This makes boundary selection essential: the analyst must specify which product, market, technology, time horizon and jurisdiction define the system under study. The framework then asks where concentration is created, how shocks can travel, which alternatives remain feasible and what information managers require before acting. Such explicit scoping reduces the risk of overgeneralizing from aggregate country measures to firm-level decisions. It also allows the same constructs to be applied across regions with different industrial and regulatory structures (Pasupuleti 2026l, pp. 106–133; Pasupuleti 2026i, pp. 142–180). In Public-Private Governance, Climate Resilience and Future Research Horizons, this lens is operationalized through comparative governance analysis, policy evaluation, responsible-AI assurance and multi-stakeholder stress testing. The resulting conceptual target is a governance ecosystem in which firms and public institutions can coordinate on systemic risks without collapsing distinct mandates.

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To operationalize the construct, the research design integrates comparative governance analysis, policy evaluation, responsible-AI assurance and multi-stakeholder stress testing. Each stage is connected to an evidence standard: measurement requires traceable definitions, explanation requires defensible identification, forecasting requires regime-sensitive validation, and action requires constraints plus accountable approval. Cross-jurisdictional analysis adds a further requirement because identical variables may reflect different institutional processes. The design therefore documents source provenance, local definitions and transformation rules before pooling information. Sensitivity analysis tests whether strategic conclusions survive reasonable changes in assumptions, and human review is concentrated where evidence is sparse or consequences are material. These methodological safeguards align with the analytical concerns represented in the cited corpus (Pasupuleti 2024g, pp. 90–111; Pasupuleti 2026q, pp. 1–30). For Public-Private Governance, Climate Resilience and Future Research Horizons, diagnosis explicitly links institutional coordination, responsible AI, industrial policy, public-private information asymmetry and the governance of resilience externalities. The prescribed workflow is to define shared risk vocabulary; identify information that can be exchanged; run joint scenarios; separate commercial confidentiality from system-level indicators; evaluate interventions; revise standards and incentives. Evaluation

reports public-private stress-test protocols, governance scorecards, AI assurance standards, policy-learning loops and a comparative future-research agenda before strategic use.

Operationalization requires teams to define shared risk vocabulary; identify information that can be exchanged; run joint scenarios; separate commercial confidentiality from system-level indicators; evaluate interventions; revise standards and incentives. The practical research contribution is a governance ecosystem in which firms and public institutions can coordinate on systemic risks without collapsing distinct mandates. A critical design principle is that every material recommendation can be traced to a source state, model configuration and set of assumptions, allowing decisions to be challenged or reproduced. The framework is designed for regional cooperation in South Asia, regulatory coordination in Europe, infrastructure and development partnerships in Africa and federal/private coordination in the Americas, which permits comparison of strategic mechanisms under different institutional and infrastructure conditions. Core outputs are public-private stress-test protocols, governance scorecards, AI assurance standards, policy-learning loops and a comparative future-research agenda. Used together, they provide a scalable protocol for learning from shocks, revising thresholds and strengthening governance over time (Pasupuleti 2026l, pp. 106–133; Pasupuleti 2026q, pp. 1–30).

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Glossary

Adaptive capacity — The ability of a firm or system to modify resources, relationships and decision rules when external conditions change.

Causal inference — A set of methods used to estimate the effect of an intervention or shock relative to a credible counterfactual.

Chokepoint — A node, route, supplier, technology or service whose disruption can constrain a disproportionate share of supply-chain activity.

Data sovereignty — The principle that data collection, storage, processing and access may be governed by the laws and policy requirements of particular jurisdictions.

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Digital twin — A computational representation of system state, constraints and interventions used to simulate and compare operational scenarios.

Compound supply-chain risk — Interaction of geopolitical, climate, infrastructure and market hazards that can propagate through connected supply networks.

Graph analytics — Methods that analyse entities and their relationships as networks, allowing structural dependence, centrality and cascade pathways to be measured.

Global value chain (GVC) — The cross-border configuration of activities, firms, assets and services that collectively create and deliver a product or service.

MLOps — Operational practices for versioning, validating, deploying, monitoring and governing machine-learning systems reproducibly.

Policy-as-code — Translation of governance or compliance rules into machine-enforceable controls within digital systems.

Regime shift — A change in the statistical, institutional or policy environment that alters previously stable relationships.

Resilience — The capacity to anticipate, absorb, adapt to and recover from disruption while maintaining acceptable strategic and operational performance.

Robust optimization — Optimization that seeks decisions performing acceptably across a specified set of uncertain conditions rather than only under a single forecast.

Scenario analysis — Structured exploration of alternative future states used to test decisions under uncertainty that may not be well represented by historical probabilities.

Strategic interdependence — A condition in which economic relationships create reciprocal advantages but also potential leverage, vulnerability or constraint.

Substitutability — The practical ability to replace a supplier, input, location, route, technology or service within required technical, legal, cost and time limits.

Trustworthy AI — AI designed and operated with appropriate reliability, transparency, robustness, security, accountability and human oversight for its decision context.

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References

Pasupuleti, MK 2021a, 'A Comparative Computational Study of OR, Stochastic Programming, and Deep RL for Sustainable Cloud and Network Operations', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 01, no. 12, National Education Services, pp. 149–173.

Pasupuleti, MK 2021b, 'A Unified Framework for Feature Dependence: Theory, Algorithms, and Causal Inference', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 01, no. 01, National Education Services, pp. 356–367.

Pasupuleti, MK 2021c, 'Hierarchical OR + RL Control for Cloud and Network Operations Under Policy-as-Code Constraints', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 01, no. 12, National Education Services, pp. 99–123.

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Pasupuleti, MK 2021d, 'Operations Research Challenges in Energy-Efficient Cloud and Network Infrastructure: An Integrated AI–Simulation Perspective', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 01, no. 12, National Education Services, pp. 1–25.

Pasupuleti, MK 2021e, 'Quantifying AI's Socio-Economic Futures: An Uncertainty-Aware Scenario Generation Framework', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 01, no. 01, National Education Services, pp. 316–330.

Pasupuleti, MK 2021f, 'Stochastic Modelling and Scenario Generation for Cloud Workload and Network Traffic in OR Models', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 01, no. 12, National Education Services, pp. 26–50.

Pasupuleti, MK 2021g, 'Towards Socially Beneficial AI: Alignment Frameworks, Causal Impact Metrics, and Governance Pathways', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 01, no. 01, National Education Services, pp. 246–258.

Pasupuleti, MK 2022a, 'Building a Data-Driven Operations Backbone: Governance and Performance of Big-Data Pipelines with Hadoop and Apache Spark in Cloud Firms', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 02, no. 12, National Education Services, pp. 53–72.

Pasupuleti, MK 2022b, 'Policy-as-Code in Cloud Governance: Impacts of Cloud Custodian on Cost, Compliance, and Managerial Control', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 02, no. 12, National Education Services, pp. 29–52.

Pasupuleti, MK 2022c, 'Strategic Siting of Data Centres: A GIS-Based Multi-Criteria Decision Framework for Cost, Risk, and Sustainability', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 02, no. 12, National Education Services, pp. 92–110.

Pasupuleti, MK 2023a, 'AI Climate Risk in ArcGIS: Foundation-Model Remote Sensing and Spatio-Temporal Causality', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 03, no. 12, National Education Services, pp. 114–126.

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Pasupuleti, MK 2023b, 'AI Digital Twins in Simulink: Safe RL for Hardware-in-the-Loop Control', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 03, no. 06, National Education Services, pp. 114–125.

Pasupuleti, MK 2023c, 'AI Hydrologic Nowcasting in HEC-HMS: Graph Neural Nets under Nonstationarity', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 03, no. 06, National Education Services, pp. 126–142.

Pasupuleti, MK 2023d, 'AI-Augmented Causal Inference in R: Double-ML with Bayesian Calibration', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 03, no. 06, National Education Services, pp. 76–87.

Pasupuleti, MK 2023e, 'Causal Time-Series with statsmodels: Conformal Risk Control under Regime Shifts', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 03, no. 03, National Education Services, pp. 29–40.

Pasupuleti, MK 2023f, 'Edge AI with Mosquitto: Secure, QoS-Aware Federated Anomaly Detection', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 03, no. 06, National Education Services, pp. 195–210.

Pasupuleti, MK 2023g, 'GenAI-Assisted ETL on Hadoop: Petascale Batch Causal A/B Pipelines', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 03, no. 03, National Education Services, pp. 41–52.

Pasupuleti, MK 2023h, 'Real-Time Causal Inference on Spark: Structured Streaming for Policy Lift', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 03, no. 03, National Education Services, pp. 53–63.

Pasupuleti, MK 2024a, 6G Security and Vendor Governance: Indian States versus G20 and BRICS Risk Controls, National Education Services.

Pasupuleti, MK 2024b, 'A Unified Big-Data Pipeline for Cloud and Network Telemetry: Design, Implementation, and Benchmarking with Hadoop and Apache Spark', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 04, no. 12, National Education Services, pp. 47–67.

Pasupuleti, MK 2024c, Agri-AI for Climate-Smart Farming: Indian State Readiness with G20 And BRICS Comparative Lessons, National Education Services.

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Pasupuleti, MK 2024d, AI Mobility, EV Scaling And Road Safety: Indian State Comparison with G20 And BRICS Policiess, National Education Services.

Pasupuleti, MK 2024e, AI-Driven Smart Grids And Renewables Forecasting: Indian State Readiness vs G20 And BRICS Blueprints, National Education Services.

Pasupuleti, MK 2024f, Circular And Low-Carbon Manufacturing: Indian State ESG Competitiveness with G20 And BRICS Benchmarks, National Education Services.

Pasupuleti, MK 2024g, 'Climate and Flood-Aware Data Centre Siting: A GIS and Hydrologic Simulation-Based Framework for Risk-Aware Cloud Infrastructure', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 04, no. 12, National Education Services, pp. 90–111.

Pasupuleti, MK 2024h, 'Comparing Classical Time Series and Deep Learning Approaches for Cloud Workload Forecasting: A Data Pipeline Perspective', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 04, no. 12, National Education Services, pp. 23–46.

Pasupuleti, MK 2024i, 'Cross-Layer Optimisation of Network and Cloud Resources: A Joint NS-3 and CloudSim Simulation Study', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 04, no. 12, National Education Services, pp. 131–151.

Pasupuleti, MK 2024j, Cyber Integrity of Climate MRV And Satellite Pipelines: Indian States vs G20 And BRICS, National Education Services.

Pasupuleti, MK 2024k, 'Econometric Modelling of Cloud and Network Demand: A Comparative Study Using R, Stata, SPSS, and EViews', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 04, no. 12, National Education Services, pp. 193–210.

Pasupuleti, MK 2024l, Edge AI And Data Center Expansion: Indian State Digital Capacity vs G20 And BRICS, National Education Services.

Pasupuleti, MK 2024m, 'Geo-Visual Analytics for Energy-Efficient Cloud and Network Infrastructure Using ArcGIS and Simulation Data', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 04, no. 12, National Education Services, pp. 173–192.

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Pasupuleti, MK 2024n, Green Data Centers And Digital Inclusion: State-Level ESG Benchmark with G20 And BRICS, National Education Services.

Pasupuleti, MK 2024o, Industrial AI And Reskilling: Indian State Manufacturing Belts Compared with G20 And BRICS Leaders, National Education Services.

Pasupuleti, MK 2024p, Just Transition And Affordable Clean Energy: Indian State ESG Roadmaps with G20 And BRICS Learning, National Education Services.

Pasupuleti, MK 2024q, 'Policy-Aware Cloud Control Loops: Integrating MQTT Telemetry with Cloud Custodian for Safe RL-Based Resource Management', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 04, no. 12, National Education Services, pp. 152–172.

Pasupuleti, MK 2024r, Quantum Finance Readiness: India's State Innovation Clusters Benchmarked to G20 And BRICS, National Education Services.

Pasupuleti, MK 2025a, 'Secure Computation After Quantum: PQC, Confidential Clouds, and Policy-Grade Auditability', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 05, no. 12, National Education Services, pp. 198–222.

Pasupuleti, MK 2026a, 'A Unified Topological and Tensor Framework for Interpretable AI in Networks, Fraud, and Power Systems', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 04, pp. 166–198.

Pasupuleti, MK 2026b, 'AI-Driven Trade Analytics for Evaluating Free Trade Agreement Outcomes and Industrial Competitiveness', International Journal of

Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 01, National Education Services, pp. 59–84.

Pasupuleti, MK 2026c, 'Artificial Intelligence for Autonomous Manufacturing, Predictive Maintenance and Real-Time Quality Assurance', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 03, National Education Services, pp. 87–113.

Pasupuleti, MK 2026d, 'Artificial Intelligence for Climate Risk, Emissions Intelligence and Planetary-Scale Environmental Decision-Making', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 03, National Education Services, pp. 114–141.

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Pasupuleti, MK 2026e, 'Cross-Sector Cascade Resilience in the Post-Quantum Transition: Coupled-Network Theorems and Stress-Testing Algorithms for Finance–Telecom–Industrial Control Systems (ICS)', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 01, National Education Services, pp. 1–23.

Pasupuleti, MK 2026f, 'Crypto–Traditional Portfolio Contagion: Modeling Volatility Clustering and Tail-Risk Spillovers', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 02, National Education Services, pp. 166–185.

Pasupuleti, MK 2026g, "Deep Hedging with Generative Market Models for Climate-Aware Portfolio Risk and Financial Resilience," (ed.), International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 07, pp. 49–91.

Pasupuleti, MK 2026h, 'Disaster Digital Twins: AI World Models for Predicting Cascading Infrastructure Failures', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 02, National Education Services, pp. 1–21.

Pasupuleti, MK 2026i, "Distributional Policy Evaluation for Heterogeneous Treatment Effects, Social Equity and Climate-Transition Governance," (ed.), International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 07, pp. 142–180.

Pasupuleti, MK 2026j, 'Earth System Foundation Models for Predicting Extreme Climate Events Through Integrated Satellite, Oceanic, and Land-Surface Intelligence', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 03, National Education Services, pp. 29–59.

Pasupuleti, MK 2026k, "Functional and Object-Oriented Data Analysis for Complex Biomedical, Environmental and Socioeconomic Systems," (ed.), International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 07, pp. 234–284.

Pasupuleti, MK 2026l, "Geospatial Quantum–AI Climate–Finance Digital Twins: Carbon Integrity, Infrastructure Resilience, Systemic Risk and Inclusive Development," (ed.), International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 08, pp. 106–133.

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Pasupuleti, MK 2026m, 'Global Energy Crises, Geopolitical Conflict, and Economic Vulnerability: Econometric Evidence on Inflation Transmission, Growth Effects, and Renewable Transition Resilience', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 04, pp. 118–142.

Pasupuleti, MK 2026n, 'Hybrid Quantum–AI Optimization Models for Energy-Efficient and High-Yield Industrial Manufacturing Systems', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 01, National Education Services, pp. 85–105.

Pasupuleti, MK 2026o, 'India's Foreign Policy, Geostrategic Trade, and National Power in an AI-Driven World', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 04, pp. 143–165.

Pasupuleti, MK 2026p, "Physics-Informed Reinforcement Learning for Financial Markets, Deep Hedging and Systemic-Risk-Constrained Portfolio Optimization," (ed.), International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 07, pp. 181–233.

Pasupuleti, MK 2026q, "Quantum Topological Autonomous Decision Ecosystems for Geoeconomic Risk, Climate, Energy Markets, Smart Cities and Resilient Global Infrastructure," (ed.), International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 08, pp. 1–30.

Pasupuleti, MK 2026r, "Quantum Topological Neural Operators and Digital Twin Intelligence for Multiscale Climate, Energy, Hydrological, Urban, Industrial and Health Systems," (ed.), International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 08, pp. 78–105.

Pasupuleti, MK 2026s, "Quantum–AI Earth-System Intelligence for Climate-Risk Discovery, Natural-Capital Valuation and Planetary Investment Decision Systems," (ed.), International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 08, pp. 134–160.

Pasupuleti, MK 2026t, "Quantum–AI for High-Dimensional Learning: Graph Neural Networks, Topological Data Analysis, Tensor Networks, and Sparse Predictive Modelling," (ed.), International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 06, pp. 36–83.

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Pasupuleti, MK 2026u, 'Satellite-Based Carbon MRV: Remote Sensing and Atmospheric Inference for Verifiable Carbon Removal', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 02, National Education Services, pp. 142–165.

Pasupuleti, MK 2026v, 'Self-Healing Smart Infrastructure: Programmable Materials for Autonomous Repair and Sensing', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 02, National Education Services, pp. 49–71.

Pasupuleti, MK 2026w, 'Toward Trustworthy Artificial Intelligence in Law and Public Administration: Transparency, Accountability and Decision Support', International Journal of Academic and Industrial Research Innovations(IJAIRI), vol. 06, no. 03, National Education Services, pp. 1–28.

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