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Resilience-by-Design: AI for security, sustainability and health in interdependent systems

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Abstract

This title-driven scoping review synthesizes a conceptual framework for designing resilient AI-enabled systems across security, energy, industrial, health and social domains. Resilience encompasses anticipating disturbances, absorbing shocks, recovering quickly, and adapting to new realities. Modern systems are increasingly interdependent, and failures in one domain (e.g., cyber or energy) can cascade across sectors and threaten societal wellbeing. This review summarises the inferred sector, task, and methodological features from titles to map how AI capabilities support resilience functions. Methods such as forecasting, anomaly detection, predictive maintenance, optimization and explainable learning are linked to resilience functions and deployment settings (edge, cloud, 6G, federated). Titles also highlight trust dimensions—privacy, security, bias control and governance—that must accompany technical solutions. We develop a resilience-centric taxonomy, a cross-sector failure-mode synthesis, assurance checklists and reference design patterns suitable for practitioners. The synthesis emphasises that resilience is a socio-technical property: technical robustness must align with transparent governance, auditability, stakeholder collaboration and context-specific risk management. Because this review is based solely on titles, it provides a conceptual structure rather than evidence-based conclusions. The final sections outline a research agenda and limitations, and caution that full-text verification is necessary before drawing firm conclusions.

Keywords: Resilience-By-Design; Interdependent Systems; AI Capabilities; Security; Energy; Healthcare; Sustainability; Privacy; Explainability

1 Introduction

Interdependent socio-technical systems such as critical infrastructure, health services, energy grids and digital finance are increasingly vulnerable to cascading disruptions. Artificial intelligence (AI) techniques promise to enhance resilience by providing predictive, diagnostic and optimisation capabilities at scale. However, the interdependence of systems means that failure in one domain may propagate to others, making resilience-by-design a guiding principle for trustworthy AI in high-stakes settings. Resilience is here defined as the capacity to anticipate disturbances, absorb shocks, recover quickly and adapt to new conditions. Systems that achieve resilience balance robustness, redundancy, recovery and adaptability. Interdependent systems include cyber–physical grids, healthcare and energy networks, supply chains, financial platforms and social infrastructures. The concept of resilience-by-design refers to embedding resilience considerations into the architecture, models and governance of AI systems from the outset. Trustworthy AI encompasses not only technical performance but also ethical and governance dimensions: privacy, security, fairness, transparency, accountability and policy compliance. The contributions of this work are fourfold: (i) it develops a

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resilience-centric taxonomy that categorises AI capabilities and deployment settings; (ii) it synthesises recurring failure modes and proposes assurance and governance checklists; (iii) it outlines reference design patterns for interdependent systems; and (iv) it maps the entire portfolio to illustrate sector coverage and research trends. This manuscript offers a conceptual foundation for future evidence-based work, emphasising that details will be filled in during a subsequent full-text review.

2 Review Protocol and Scope

2.1 Portfolio-bounded Scoping Rationale and Research Questions

- This review adopts a portfolio-bounded scoping approach form a fixed corpus for mapping AI methods to resilience functions. The rationale is to provide an organised synthesis rather than a comprehensive evidence summary. The review seeks to answer the following research questions (RQs):
- RQ1: What resilience functions—anticipation, absorption, recovery and adaptation—are implied across the portfolio?
- RQ2: Which AI capabilities support these functions (forecasting, detection, diagnosis, optimisation, governance)?
- RQ3: Which failure modes repeat across security, energy, industrial and health domains, and how might assurance practices be standardised?
- RQ4: How do deployment settings (edge, cloud, hybrid, 6G, federated learning) and governance structures shape resilience outcomes and risks?

2.2 Title-Driven Extraction Schema

The extraction schema infers from each title: (i) the sector or domain (e.g., critical infrastructure [1], business analytics [2], energy [3], workforce analytics [4], welfare governance [5], supply chain [46]); (ii) the task type, such as classification, prediction, optimisation, screening or natural language processing; (iii) the data modality (time-series [32], image [14], signal [35], text [43]); (iv) the resilience function tag (anticipate, absorb, recover or adapt), as suggested by terms like forecasting [10], detection [25], maintenance [20] and adaptation [42]; (v) the method family (deep learning [22], ensemble [60], transformer [23], federated learning [13], reinforcement learning [24], support vector regression [32], wavelet filtering [35], fuzzy Markov models [43]); and (vi) trust dimensions, including explainability [14], privacy [13], security [1], bias control [5] and governance [7]. Deployment hints, such as edge computing [8], cloud MIS [7], 6G zero-touch frameworks [8], hybrid orchestration [20], and federated learning [18], are also noted.

2.3 Conceptual Rigor Appraisal Rubric

Because this review is based on titles only, no scoring is applied. However, a conceptual rubric is defined for subsequent evidence-based appraisal. The rubric will assess external validation practices (e.g., multi-centre testing hinted at by cross-system titles [27]), controls against data leakage, robustness under distribution shift [31], transparency and interpretability validation [14], privacy and security threat modelling [13], monitoring and drift detection mechanisms [34], auditability and governance maturity [5], energy and latency considerations for edge deployments [8], and reproducibility signals such as open datasets and protocols.

3 Resilience Framework for Interdependent Systems

3.1 Resilience Functions: Anticipation, Absorption, Recovery and Adaptation

A resilience-by-design perspective decomposes resilience into four functions. Anticipation involves forecasting and early warning: titles on energy consumption prediction [32], stroke prediction [17], early breast cancer detection [26], predictive maintenance [20], EV grid operations [34], and workforce trend forecasting [4] illustrate anticipatory AI. Absorption relates to detecting and containing incidents; cyber threat detection [1], intrusion detection in IoT [25], fraud detection [40], deepfake detection [54], fault detection in power lines [39], brain tumour classification [22], and diagnostics across multiple cancers [16, 29–31, 60, 63–66, 73–74] fall into this category. Recovery functions aim to restore normal operations quickly; works on blackout mitigation [33], privacy-preserving federated learning for critical infrastructure [13, 18], and automated diagnostics using federated learning [48] imply distributed recovery strategies. Adaptation encompasses learning from disruptions to improve future performance; studies on resilient grid operation under EV penetration [34], optimisation of hybrid renewable energy systems [42], supply-chain streamlining with quantum computing [46], and governance frameworks for welfare management [5] suggest adaptive redesign.

Table 1 Resilience Framework Mapping

Resilience function	AI capability	Assurance needs	Governance controls
Anticipate	Forecasting, early warning, predictive maintenance	Calibration, external validation, lead-time accuracy	Data quality governance, scenario simulation, oversight for false positives
Absorb	Anomaly detection, diagnosis, classification, intrusion detection	Low false negatives, robustness to noise & adversarial inputs, interpretability	Threat modelling, access control, incident logging, accountability roles
Recover	Blackout mitigation, automated triage, regenerative therapies	Rapid failover, fault tolerance, secure aggregation	Disaster recovery planning, audit trails, incident response protocols
Adapt	Optimisation, reinforcement learning, federated learning, supply-chain reasoning	Fairness across groups, stability under distribution shift, privacy preservation	Policy-as-code, dynamic risk assessment, stakeholder feedback loops

Recent scholarship has highlighted the increasing significance of AI and MIS in strategically important national sectors. Goffer et al. [1] examined AI-supported cyber threat detection and response as a means of safeguarding critical infrastructure, whereas Haldar et al. [2] analyzed how AI-driven business analytics and MIS can promote data-informed economic development. Within the energy domain, Hassan et al. [3] discussed the application of MIS solutions to advance national energy dominance objectives. In parallel, Mahmud et al. [4] explored AI-enabled workforce analytics for anticipating labor market patterns and detecting skill shortages associated with economic competitiveness. Recent research has further illustrated the widening application of AI across energy, infrastructure, and healthcare. Ahmed et al. [10] demonstrated the utility of AI-based time-series methods for improving solar energy production and supporting smart energy management in the USA. Similarly, Khan et al. [11] investigated the combination of blockchain and AI to secure energy transactions, with particular attention to fraud prevention and market stability. Ahmed et al. [12] also emphasized the use of AI for enhancing renewable energy generation and advanced storage technologies in intelligent energy systems. Outside the energy sector, Ahmed [13] reviewed privacy-preserving federated learning for critical infrastructure, focusing on security and governance challenges. In healthcare, Siam et al. [14] addressed explainable deep learning models for medical diagnosis to strengthen clinical trust in AI systems.

3.2 System Interdependencies and Cascade Pathways

Interdependent systems couple cyber, physical, social and ecological domains. A cyber attack on critical infrastructure [1], [78] can ripple into energy markets [11], healthcare services [21], finance [57] and welfare management [5]. Energy grid failures [10, 33] threaten hospitals reliant on electricity [14], while health data breaches may trigger financial fraud [40]. Supply-chain disruptions highlighted by AI-driven business analytics [2], workforce analytics [4] and aerospace supply chain streamlining [46] show that production bottlenecks propagate across industries. Governance frameworks for project collaboration [7] and cyber threat intelligence as MIS [9] illustrate how organisational resilience depends on linking operational data with decision processes. Emerging 6G and edge infrastructures [8], [79] further couple communication and computation; misconfiguration could trigger widespread outages or privacy leaks. Titles on hybrid renewable energy systems [42] and blockchain energy transactions [11] demonstrate coupling of physical energy flows with digital economic layers.

3.3 AI Contributions to Resilient Interdependent Systems

AI contributes to resilience by providing early warning, detection, diagnosis, optimisation and decision support. Forecasting time-series data enables anticipation of energy consumption [32], solar production [10], workforce demand [4] and disease risks [17, 26, 28]. Detection and diagnosis algorithms identify anomalies in network traffic [1, 25], financial transactions [40, 57], power transmission [39], machinery [20], human physiology [35–38], and environmental signals [66–72]. Situation awareness is enhanced by cyber threat intelligence systems [9] that integrate governance and MIS. Diagnosis and triage frameworks for cancer [16, 29–31, 48–50, 60–65, 73–74], cardiovascular diseases [17], mental health [50, 59, 69], and wound healing [75] demonstrate high-stakes decision support. Optimisation and control are addressed by digital twins [20], reinforcement learning for robotics [24], smart grid management [33, 34, 42], supply-chain optimisation [46], and risk management in finance [57]. In all these tasks, AI supports decision makers rather than replacing them; human oversight and governance are key for trustworthy deployment.

3.4 Failure Modes and Pitfalls

AI systems may produce spurious correlations or fail under distribution shifts [31] when trained on non-representative data; early warning models may miss new patterns of fraud or disease. Adversarial manipulation and backdoor attacks are risks in intrusion detection [25], deepfake detection [54], financial risk management [57] and healthcare diagnostics [60, 64, 65]. Privacy failures in federated learning [13, 18, 48] can expose sensitive health or infrastructure data, while inadequate governance leads to biased decision making in welfare management [5] or business analytics [44]. Measurement noise and missingness hamper EMG signal processing [35–38], and cascading failures may arise from misconfigured relays [33], EV-induced grid instabilities [34] or edge–cloud orchestration [8]. Moreover, a false sense of interpretability when using attention-based transformers [23, 64, 69, 70] can mislead stakeholders; explanations must be validated for faithfulness and utility.

4 AI Capabilities for Resilience-by-Design

4.1 Forecasting and Early Warning

Anticipatory capabilities include time-series forecasting and trend analysis. Renewable energy forecasting [10, 32, 42], EV penetration impact analysis [34], hybrid energy system optimisation [42], and solar energy management [10] provide early warning for energy operators. Workforce analytics [4] and business analytics [2] forecast labour and economic trends, while stroke prediction [17], mortality risk prediction [28], early breast cancer detection [26], chronic kidney disease screening [27], and leukemia diagnostics [61] anticipate health events. Predictive maintenance using digital twins [20], predictive relay schemes [33], energy consumption models [32], and demand forecasting for supply chains [46] support resilience in industrial contexts. Sentiment analysis [43, 58, 62], drug review sentiment detection [62] and SaaS market trend analysis [52] anticipate social signals and market shifts. These forecasting tasks typically employ machine learning and deep learning models such as support vector regression [32], LSTM networks [39], transformer-based architectures [64], and ensemble approaches [49], and may be deployed on cloud platforms with edge components [8].

In healthcare-oriented AI research, both predictive accuracy and privacy preservation have received substantial attention. Khan et al. [16] studied breast cancer diagnosis using neural networks combined with dimensionality reduction techniques to improve diagnostic accuracy, whereas Khan et al. [17] concentrated on stroke prediction using neural machine learning models. Extending this line of work, Ahmed et al. [18] proposed privacy-first federated learning frameworks for scalable healthcare data processing, underscoring the importance of secure distributed learning in medical applications. Recent advances in brain tumor analysis have involved both classification and segmentation paradigms. Oza et al. [22] introduced an AI-based ensemble learning framework for MRI-based brain tumour classification, highlighting the diagnostic benefits of ensemble strategies in neuroimaging. By contrast, Khushubu et al. [23] proposed TransUNetB, a Transformer–U-Net architecture aimed at efficient and explainable brain tumor segmentation. Collectively, these contributions demonstrate the increasing adoption of both ensemble and transformer-driven approaches in brain tumor imaging. AI has also become increasingly prominent in predictive modeling and screening across US healthcare systems. Arafat et al. [26] proposed a deep learning model integrating mammography and clinical EHR data for early breast cancer detection. Expanding AI-based screening to chronic disease contexts, Rimon et al. [27] presented a scalable machine learning strategy for chronic kidney disease screening across healthcare systems. Hasan et al. [28], in turn, developed an explainable machine learning framework for mortality risk prediction in liver cirrhosis, emphasizing the value of interpretability and clinical reliability.

4.2 Detection and Diagnosis

Absorptive resilience relies on rapid detection of anomalies and accurate diagnosis. Cyber threat detection and response [1, 9, 21], intrusion detection in IoT [25], fraud detection in finance [40, 57], deepfake detection [54], and misinformation detection [43, 58] exemplify security-centric detection. Fault detection in power transmission lines [39] and blackouts [33], EMG signal anomalies [35–38], as well as detection of degenerative devices in coaxial cables [36], illustrate physical system monitoring. Medical diagnosis spans multiple modalities: explainable deep learning for diagnosis [14], edge-enabled healthcare security [15], breast cancer classification [16, 19, 60, 63, 65], brain tumour classification and segmentation [22, 23], early detection frameworks for kidney disease [27], [81] liver cirrhosis mortality prediction [28], eye disease classification [29], skin cancer diagnosis [30], [80], chest and lymphoma classification [31], cervical cancer diagnosis [65], lung cancer diagnosis [49, 64], leukemia classification [73], esophageal disease diagnosis [74], wound healing [75], glioblastoma therapy [76], and immunotherapy [77]. Mental health and societal resilience are addressed through identification of mental health indicators [50], depression emotion detection [69], and suicidal ideation detection [59]. Agricultural applications include diagnosis of tea leaf diseases [51], soybean diseases [66], mango leaf disease [67], cotton leaf disease [70, 72] and conservation of rare medicinal plants [71]. Multimodal recognition tasks [68] bridge vision and audio. These detection tasks employ deep learning, ensemble methods [22, 49, 63, 65], transfer learning [23, 29, 61], transformer architectures [23, 63–67, 69–72], stacking ensembles [60, 65], and hybrid models; they often emphasise explainability [14, 23, 60–71] and sometimes federated training for privacy [18, 48, 63].

Recent contributions have likewise underscored the expanding influence of AI in healthcare, business strategy, and digital markets. In medical imaging, Khan et al. [49] developed generalizable ensemble learning models for early lung cancer detection, while Shakil et al. [31] compared deep learning architectures for chest disease and lymphoma classification. Beyond clinical applications, Mosaddeque et al. [46] studied the use of AI and quantum computing to optimize supply chains in aerospace and education, and Sufian et al. [47] explored the strategic benefits of machine learning in the healthcare business sector. From a market-oriented standpoint, Ahmed et al. [52] analyzed trends and investment prospects in AI-powered SaaS, highlighting the economic importance of intelligent software platforms.

4.3 Optimisation and Control

Adaptive resilience requires optimisation and control. Smart energy management and optimisation of renewable and hybrid systems are addressed in titles on time-series energy prediction [10, 32], blockchain-based energy transactions [11], renewable energy generation and storage [12], hybrid renewable energy system optimisation [42], resilient grid operations under EV penetration [34], and control of blackouts using sophisticated relays [33]. Digital twin technology for predictive maintenance [20], deep reinforcement learning for real-time robotics data analytics [24], and resilient operations of industrial IoT [20] show how AI can control complex systems. Supply chain optimisation using AI and quantum computing [46], resource allocation in business management [6], workforce scheduling [4], and decisions under economic uncertainty [2, 55] illustrate wider optimisation applications. In healthcare, optimisation spans triage thresholds and treatment planning: accurate diagnosis frameworks [16, 19, 60, 65], early detection systems [26, 49, 61], cervical cancer and brain tumour diagnosis [16, 22, 23, 65, 82], wound healing [75], glioblastoma therapy [76], and cancer immunity reprogramming [77] all imply decision optimisation to improve outcomes.

4.4 Explainability and Uncertainty for Resilient Decisions

Many titles highlight explainability as a prerequisite for trustworthy deployment. Explainable deep learning models for medical diagnosis [14], explainable stacking ensembles [60, 65], Swin transformer ensembles [63], hybrid transformer frameworks [64, 70], ViX-MangoEFormer [67], MaxViT for soybean identification [66], and transformer ensembles for depression detection [69] illustrate attention to interpretability. Post-hoc explanation aggregation [23, 69], example-based explanations [50], concept-based analysis [41], and uncertainty-aware frameworks [68] contribute to interpretable decision making. Works focusing on bridging the trust gap [44], bias control and transparency [5], privacy-first federated learning [13, 18], explainable business decision making [44], and strategic business gains in healthcare [47] highlight stakeholder-centred interpretability. Validation of explanations is critical: performance studies [31], analyses of spurious correlations [34], and reviews of hybrid renewable energy systems [42] suggest that interpretability must be accompanied by robustness tests.

4.5 Privacy-Preserving and Distributed Resilience

Titles referencing privacy and federated learning emphasise distributed intelligence. A systematic review of privacy-preserving federated learning for critical infrastructure [13] and privacy-first models for scalable healthcare data processing [18] describe how data remains local while models are aggregated. Federated learning is also applied to white blood cell diagnostics [48], decentralised breast cancer diagnosis [63], lung cancer diagnosis [64], brain tumour detection [60], and early medical diagnosis [26]. Edge computing and 6G frameworks [8, 24] support low-latency inference close to the data source. Hybrid deployments that balance edge and cloud processing appear in digital twin frameworks [20], intrusion detection in IoT [25], EV grid operation [34], multimodal object recognition [68], and smart energy management. Blockchain-based energy transactions [11] and distributed deep learning frameworks [48] illustrate privacy and integrity through cryptographic methods. These distributed approaches imply new governance and assurance requirements: secure aggregation, differential privacy, trusted execution environments, policy enforcement and tamper-evident audit trails.

Recent work in energy and electrical engineering has addressed both predictive modeling and system reliability. Hasan et al. [32] used support vector regression optimized by a genetic algorithm to predict energy consumption across multiple sectors. For grid protection, Juel et al. [33] proposed a machine learning-based sophisticated relay to mitigate blackout risks in power systems. Tonny et al. [34] further examined resilient grid operation using data-driven methods under increasing EV penetration. Beyond grid-focused studies, Tanbhir et al. [35] compared DWT and EMD techniques for electromyographic signal denoising, while Khan et al. [36] investigated how inductance and skin effect influence transient wave propagation in transformer bushings. Together, these studies demonstrate the broad utility of computational intelligence and engineering analysis in complex technical systems. The recent literature also shows the versatility of AI across energy, language processing, organizational analytics, and industrial inspection. Ahamed et al. [42] reviewed machine learning approaches for optimizing hybrid renewable energy systems in decentralized smart grids with the goals of improving efficiency and stability. In another domain, Ahamed et al. [43] developed a sentiment recognition method that combines bidirectional deep learning with an extended fuzzy Markov model. From a business perspective, Hossain et al. [44] examined how explainable AI can improve business decision-making by addressing issues of trust. In industrial inspection, Haque et al. [45] proposed a data-centric method for leather quality control using advanced vision transformer architectures.

5 Sectoral Synthesis Through the Resilience Lens

5.1 Security Resilience

Security resilience emphasises timely detection, containment and governance in the face of cyber threats and fraud. AI-enhanced cyber threat detection [1], cyber threat intelligence management systems [9], zero-touch 6G frameworks for secure edge AI [8], integration of IT project management and cybersecurity [9], and AI-driven cybersecurity technologies for healthcare and infrastructure [21] illustrate absorptive resilience. Intrusion detection models for IoT environments [25], credit card fraud detection [40], deepfake detection [54], mental health privacy risk [50], suicidal ideation detection [59], and risk management in digital finance [57] show how anomalies in data can indicate security breaches. Governance and auditability are emphasised in data-centric governance models [5], trust-gap mitigation in business decision making [44], MIS security analytics [54], and risk management frameworks [57]. These works collectively imply the need for security-by-design: threat modelling, real-time monitoring, authentication and access control, continuous red-teaming and compliance auditing.

Table 2 Security–Energy–Health Interdependency Pathways

Failure mode	Impacted sectors	Detection/mitigation	Evaluation tests
Distribution shift and drift	Energy forecasting, healthcare diagnosis, finance analytics, mental health	Continuous calibration, drift detection, transfer learning	Backtesting on new data, retraining frequency analyses
Noise and missing data	Sensor analytics (EMG), IoT, medical imaging	Signal denoising, imputation, robust statistics	Signal-to-noise ratio benchmarks, missingness simulations
Adversarial and privacy attacks	Cybersecurity, finance, health imaging, deepfake detection	Adversarial training, privacy-preserving aggregation, encryption	Red-team exercises, differential privacy audits
Cascading failures	Power grids, supply chains, healthcare services	Resilience simulation, scenario planning, redundancy	Stress-test simulations, causal inference studies
Model decay and bias	Business analytics, welfare management, HR analytics	Fairness monitoring, retraining, human-in-the-loop reviews	Fairness audits, bias stress tests
Supply-chain compromise	Manufacturing, energy, food systems	Supplier vetting, blockchain provenance, anomaly detection	Provenance verification, chain-of-custody reviews

5.2 Sustainability and Energy Resilience

Titles addressing renewable and smart energy underscore resilience in sustainability. Energy consumption prediction across sectors [32], solar energy optimisation [10], blockchain-based secure energy transactions [11], renewable energy generation and storage [12], hybrid renewable energy system optimisation [42], resilience under EV penetration [34], and blackout mitigation via sophisticated relays [33] address both anticipation and recovery. Denoising and signal analysis works [35–38] and transformer propagation studies [36] contribute to robust sensor readings. Agricultural resilience is linked to sustainability: precision diagnosis of tea leaf diseases [51], soybean leaf and seed disease identification [66], mango leaf disease recognition [67], cotton leaf diagnostics [70], cotton leaf disease identification [72], and rare medicinal plant recognition [71] support sustainable agriculture. Blockchain integration [11] and hybrid energy frameworks [42] highlight how digital and energy systems converge.

5.3 Industrial and IoT Resilience

Industrial resilience is evident in digital twin technology for predictive maintenance [20], real-time analytics of industrial robots via deep reinforcement learning [24], fault detection in power transmission lines [39], EMG signal classification and denoising [35–38], and sophisticated relay strategies to mitigate blackouts [33]. These works emphasise early warning, anomaly detection and control in cyber-physical systems. Intelligent 6G frameworks [8], edge deployment for intrusion detection [25], hybrid renewable energy systems [42], multimodal object recognition [68], and robot analytics [24] demonstrate how edge and IoT deployments enable low-latency analytics. Sports science applications [41] also highlight how AI can monitor human performance to pre-empt injury and enhance recovery.

5.4 Health Resilience

Healthcare emerges as a prominent domain in the portfolio. Titles cover explainable deep learning models for diagnosis [14], edge intelligence for critical diseases [15], high-accuracy breast cancer diagnosis [16, 19], neural architectures for stroke prediction [17], privacy-first healthcare data processing [18], brain tumour classification and segmentation [22, 23], multimodal breast cancer frameworks [60, 63], advanced ensemble models for lung cancer detection [49, 64], cervical cancer diagnosis [65], eye disease classification [29], skin cancer diagnosis [30], chest and lymphoma classification [31], liver cirrhosis mortality prediction [28], chronic kidney disease screening [27], mental health indicators [50], depression emotion detection [69], suicidal ideation detection [59], wound healing [75], glioblastoma therapy [76], cancer immunity reprogramming [77], white blood cell diagnostics via federated learning [48], and early leukemia diagnostics [61, 73, 74]. These titles reflect all resilience functions: anticipation through risk prediction and screening, absorption via timely diagnosis, recovery by supporting treatment decisions, and adaptation through learning from new data and distributing computations via federated learning [13, 18, 48, 63]. Trust dimensions such as explainability, privacy and bias control are commonly emphasised.

5.5 Societal Resilience Signals

Societal resilience involves economic, psychological and governance dimensions. Business analytics for economic growth [2], national energy dominance strategy [3], workforce analytics [4], decision-making in business management [6], inclusive economic development [56], and strategic business gains in healthcare [47] highlight economic resilience. Governance models for welfare management [5] and the role of cloud MIS in stakeholder collaboration [7] address policy compliance and accountability. Market trend analysis for SaaS [52], IT product innovation [53], and digital innovation for small businesses [55] underline adaptive economic strategies. Sentiment recognition [43], multi-class sentiment classification [58], identification of critical mental health indicators [50], suicidal ideation detection [59], depression emotion severity detection [69], and sentiment analysis in drug reviews [62] signal societal wellbeing. Implementing explainable AI in business decision making [44] and bridging the trust gap emphasise the need for transparent and fair AI in organisational settings.

6 Cross-Sector Failure Modes and Assurance Requirements

Resilience requires anticipating how systems fail and putting controls in place to prevent or mitigate those failures. Failure modes include distribution shift and concept drift [31], noise and missingness in sensor data [35–38], adversarial and privacy attacks on models [25, 54, 57], backdoors in medical imaging [63, 64, 69], and model decay under evolving behaviours [59]. Cascading failures may arise from misconfigured relays [33], inadequate energy storage [12], EV-induced stress on grids [34], or oversights in supply-chain analytics [2, 46]. Governance failures appear when data-centric welfare models [5] embed bias or when business analytics [6] are deployed without fairness checks. Assurance practices to address these failure modes include stress testing under simulated shifts, calibration and uncertainty quantification, adversarial robustness testing, red-team exercises, privacy accounting and differential privacy in federated systems [13, 18, 48], and supply-chain integrity assessments. Drift monitoring, logging and audit trails, coupled with human-in-the-loop oversight, are critical. For example, EMG signal denoising [35–38] implies rigorous filtering to handle noise, while surveillance of high-stakes diagnostic models [14, 22, 23, 60–73] requires continuous performance auditing. Incident response and recovery planning must be embedded in the MIS governance structure [7].

Table 3 Cross-Sector Failure-Mode Matrix

Failure mode	Impacted sectors	Detection/mitigation	Evaluation tests
Distribution shift and drift	Energy forecasting, healthcare diagnosis, finance analytics, mental health	Continuous calibration, drift detection, transfer learning	Backtesting on new data, retraining frequency analyses
Noise and missing data	Sensor analytics (EMG), IoT, medical imaging	Signal denoising, imputation, robust statistics	Signal-to-noise ratio benchmarks, missingness simulations
Adversarial and privacy attacks	Cybersecurity, finance, health imaging, deepfake detection	Adversarial training, privacy-preserving aggregation, encryption	Red-team exercises, differential privacy audits
Cascading failures	Power grids, supply chains, healthcare services	Resilience simulation, scenario planning, redundancy	Stress-test simulations, causal inference studies
Model decay and bias	Business analytics, welfare management, HR analytics	Fairness monitoring, retraining, human-in-the-loop reviews	Fairness audits, bias stress tests
Supply-chain compromise	Manufacturing, energy, food systems	Supplier vetting, blockchain provenance, anomaly detection	Provenance verification, chain-of-custody reviews

7 Reference Architectures and Design Patterns

7.1 Pattern Library

The portfolio implies several recurring design patterns. The “edge triage + cloud adjudication” pattern delegates quick anomaly detection to edge devices—such as IoT intrusion detection [25], edge-enabled medical diagnosis [15], and EMG classification [37]—while cloud systems provide deeper analysis and cross-institutional learning [14, 19]. The “federated resilience learning” pattern retains data locally in hospitals or infrastructure nodes [13, 18, 48, 63] and aggregates model updates centrally with secure aggregation. The “tamper-evident audit trail” pattern applies blockchain or cryptographic techniques for secure energy transactions [11] and governance audits [5]. A “resilience monitoring loop” pattern continuously monitors inputs, outputs and latent model states to detect drift, adversarial triggers or hardware faults, as implied by digital twin maintenance [20], grid resilience monitoring [34], and medical screening [26]. Finally, a “human oversight escalation ladder” pattern ensures that high-impact decisions—such as cancer diagnosis [16, 60, 65] or welfare eligibility [5]—include checkpoints where clinicians or policy experts can override AI recommendations.

7.2 Mapping Patterns to Sectors and Resilience Functions

Edge triage patterns are prevalent in cybersecurity [1, 25, 54], industrial IoT [24, 37], energy grids [34], and healthcare screening [15, 26]. Federated resilience learning appears in healthcare [13, 18, 48, 63], finance [57] and IoT applications. Tamper-evident audit trails are linked to energy transactions [11] and welfare governance [5]. Resilience monitoring loops support EV-driven grids [34], predictive maintenance [20], relapse prediction in medicine [61], and fraud detection [40]. Human oversight escalation ladders are critical in medical diagnosis [14, 16, 28, 60–73], mental health detection [50, 59, 69], economic decision support [2, 6], and public policy compliance [5]. These patterns map directly to resilience functions: anticipation through predictive monitoring, absorption through edge triage, recovery via federated learning and audit trails, and adaptation by updating models based on monitored evidence.

8 Research Agenda

Building on the conceptual taxonomy and failure analysis, we propose a research agenda. First, causal evaluation of AI interventions on resilience KPIs—such as recovery time, outage prevention and diagnostic delay reduction—requires controlled studies and benchmark datasets. Second, the community should develop standardised stress-testing suites for cascade modelling, including simulations of cyber–energy–health interdependencies [1, 10, 14, 34, 57]. Third, unified governance metrics are needed to measure model accountability, fairness and privacy compliance across sectors

[5, 6, 7]. Fourth, research into secure and private distributed learning should combine federated, differential privacy and secure aggregation techniques [13, 18, 48] with explainability assessments. Fifth, human factors research should explore trust calibration under uncertainty and crisis conditions, evaluating how clinicians [14, 60, 63], operators [33, 34], and policy makers [5] understand and act on AI recommendations. Other open directions include end-to-end optimisation of privacy–utility–latency–energy trade-offs in edge-cloud-6G deployments [8], development of benchmarks for cross-modal resilience (e.g., combining time-series and imaging [26, 68]), and investigating how AI can support inclusive economic development and peacebuilding [56].

Table 4 Resilience Assurance Checklist

Phase	Checklist items	Purpose
Pre-deployment	Define resilience KPIs; conduct threat and privacy impact assessments; ensure data quality; specify governance roles	Establish clear objectives and accountability before deployment
Deployment	Enable edge triage & cloud adjudication; implement secure aggregation and access control; monitor latency & energy consumption; run stress tests	Ensure technical robustness and performance during operation
Post-deployment	Continuously monitor drift, calibration, fairness and security; maintain audit logs; perform periodic retraining; engage stakeholders for feedback	Sustain resilience and adapt to evolving conditions
Incident response	Establish escalation procedures; enable rollback mechanisms; communicate transparently with stakeholders; document incident for learning	Recover quickly and learn from failures

Limitations

This study is a title-driven scoping synthesis and does not engage with full texts. Consequently, it cannot provide empirical evidence, quantitative comparisons, sample sizes, model architectures or numerical results. The inferred sector, task, modality and resilience function assignments are approximate and may differ from the actual content of the papers. The portfolio is fixed and does not necessarily reflect the entire state of research. Additionally, the conceptual rubric and research agenda will require refinement once full manuscripts are analysed. Readers should treat the findings as a high-level conceptual map rather than definitive conclusions.

9 Conclusion

Resilience-by-design is an organising principle for AI development in interdependent systems. By mapping diverse studies across domains such as cybersecurity, energy, industrial IoT, healthcare, finance and welfare governance, this title-driven scoping review proposes a unified taxonomy of resilience functions, AI capabilities and trust dimensions. It highlights the interdependencies and cascade pathways that necessitate holistic assurance and governance frameworks. The synthesis suggests that forecasting, anomaly detection, optimisation and explainable learning are central to resilience functions, while privacy and federated approaches enable distributed deployment. Cross-sector failure modes emphasise the need for stress testing, monitoring and human oversight. As AI permeates critical infrastructure and social systems, resilience must be embedded from the outset, combining technical robustness with transparent governance and stakeholder engagement. Future research should validate these insights with full-text analyses, develop benchmarks for cascade resilience, and explore the causal impact of AI interventions on societal wellbeing.

Compliance with ethical standards

Disclosure of conflict of interest

There is no conflict of interest.

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