EXECUTIVE SUMMARY

Resilience Models and Frameworks

A Literature Survey

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1. Purpose & Scope

This summary distills a literature review prepared for EPRI's Climate READi initiative, a project intended to develop a probabilistic risk assessment (PRA) framework and benefit/cost analysis (BCA) model for utility resilience investment. The review surveys the present landscape of resilience-related tools, models, and utility-developed frameworks, asking which existing approaches already contain elements—metrics, data sources, interfaces, or process structures—that could shape or feed into a Climate READi model.

The review observes that resilience planning is far less mature than reliability planning. Reliability has decades of standardized metrics (SAIFI, CAIDI) and established BCA practice; resilience, particularly for High Impact, Low Probability (HILP) events such as hurricanes, wildfires, and prolonged cold, lacks an equivalent consensus methodology. As a result, no single existing tool or framework fully replicates Climate READi's aims. Instead, the review catalogs partial matches: tools that supply useful variables or interfaces, and utility frameworks that demonstrate workable end-to-end processes.

The literature is organized into three tiers, reviewed here in turn: general-purpose quantitative tools and calculators (Section 2), utility- and agency-developed resilience frameworks that sequence vulnerability assessment through investment decisions (Section 3), and a supporting set of narrower single-purpose models covering health, equity, climate forecasting, microgrids, and emissions (Section 4).

Recurring Themes Across the Literature

Flexibility & Local Data	Qualitative + Quantitative Blending	Equity as a Formal Criterion
Nearly every utility framework substitutes or supplements default climate datasets (NOAA, IPCC RCP scenarios) with utility-specific or regionally commissioned data once available.	Frameworks consistently pair monetized benefit/cost analysis with scoring systems for benefits that resist dollar conversion, such as community impact or environmental co-benefits.	Utilities in regulated jurisdictions, especially New York, build equity and disadvantaged-community screening directly into scoring, even where it does not yet affect final dollar values.

Key Finding

No tool or framework in the literature replicates Climate READi's end-to-end aims, but a consistent two-stage pattern recurs across nearly every utility example: a climate vulnerability study identifies which assets are exposed and sensitive to specific hazards, followed by a resilience or business-case plan that screens, scores, and prioritizes candidate investments. Climate READi's value will depend on whether it can absorb this common two-stage structure while remaining flexible enough to accept the varied data, scoring conventions, and BCA methods that individual utilities and regulators already use.

2. General-Purpose Tools and Calculators

Section One of the review surveys quantitative tools already in use, mostly for reliability work, that could supply variables, interfaces, or sub-models for a resilience PRA. None offers full resilience coverage on its own; each is a candidate component.

Damage and Design Tools

- **LPNORM:** NRECA's Distribution Optimal Resilience Design Tool models damage from extreme events on distribution circuits and recommends hardening, undergrounding, or microgrid designs. It is open source, accepts data from common utility planning tools (Milsoft Windmil, CYMDIST, GridLAB-D), and is one of the few tools that also models the communications network controlling automated switches. Its scope is limited to distribution and to a narrow set of design choices, and its cost-benefit analysis is basic.

- **GRIP:** The Grid Resilience and Intelligence Platform, developed at SLAC, uses resilience metrics and AI to help grid operators anticipate and prepare for extreme weather, suggesting actions such as pole hardening or crew staging. It is threat-agnostic and focused on identifying the grid's most vulnerable points.
- **FEMP Technical Resilience Navigator:** A Federal Energy Management Program tool that helps agencies assess vulnerabilities in critical water and electrical systems and produces a scorecard with a logically staged decision framework.
- **HAZUS:** FEMA's established damage-estimation model covering physical, social, and economic disaster impacts. Because of its breadth and federal pedigree, it functions as a default likelihood-and-damage data source that other resilience models, including LPNORM, already draw upon.

Economic and Cost Tools

- **POET:** The Power Outage Economics Tool, piloted by Lawrence Berkeley National Laboratory (LBNL) with Commonwealth Edison, estimates the direct and indirect regional economic impact of widespread, long-duration outages by combining customer-preparedness surveys with a computable general equilibrium economic model.
- **ICE Calculator:** Also developed by LBNL, the Interruption Cost Estimator draws on Customer Interruption Cost surveys from over 100,000 U.S. customers to generate a Value of Lost Load/Value of Service figure. It is well validated for reliability work but loses accuracy for outages exceeding 24 hours, limiting its use for major resilience events.
- **REPAIR:** An LBNL model developed in partnership with Commonwealth Edison (part of Exelon), under development, that produces a cost-versus-risk view of investment decisions using Value of Lost Load and historical failure data, and applies Conditional Value at Risk to represent the long tail of rare, severe events.
- **CDF Calculator:** NREL's Customer Damage Function tool estimates the baseline cost of an outage at a given location and how that cost varies with duration, using a Value of Resilience metric to justify investment.
- **CLEAR:** An Excel-based toolkit developed for Massachusetts communities that walks users through load modeling, preliminary cost estimation, and feasibility scoring for resilience investments at critical facilities.

3. Utility and Agency Resilience Frameworks

Section Two of the review catalogs end-to-end frameworks that utilities and agencies have already built to move from climate threat identification through to investment decisions. These frameworks are the most directly transferable material in the review because they demonstrate, in practice, how the pieces fit together.

The Common Two-Stage Pattern

Most investor-owned utilities reviewed, particularly those in New York (Central Hudson, National Grid, Consolidated Edison), follow a near-identical sequence: a Climate Change Vulnerability Study (CCVS) scores assets against hazard exposure, sensitivity, and consequence of failure, followed by a Climate Change Resilience Plan (CCRP) or equivalent that screens, scores, and ranks candidate investments. The vulnerability score is typically the product of an exposure rating and a potential-impact rating (itself the product of sensitivity and consequence scores), producing a single relative ranking per asset class.

Vulnerability and Prioritization Approaches by Utility

Utility / Framework	Vulnerability Method	Prioritization / Scoring
Central Hudson	CCVS scores exposure, sensitivity, and consequence for five hazards (heat, cold,	Multi-Criteria Decision Analysis (MCDA) scores each measure 1–10 against

Utility / Framework	Vulnerability Method	Prioritization / Scoring
	flooding, precipitation, wind) using a nearest-neighbor link to weather stations.	weighted criteria, then ranks by a cost-efficiency ratio (benefit score ÷ cost).
Duke Energy	Same exposure/sensitivity/consequence structure across five hazards, rated low/medium/high to a 2050 horizon under IPCC RCP 4.5 and 8.5 scenarios.	Exploring Risk Spend Efficiency (risk reduction ÷ cost) and a co-benefit/adaptation-benefit Multi-Criteria Assessment; BCA used only to choose among similar options.
National Grid (NMPC)	CCVS uses MIT, Columbia, and proprietary precipitation data alongside FEMA flood data for temperature, flooding, wind, and ice.	Business Case Justification (BCJ) combines a System Reliability Score, Criticality Score, and Community Resilience Score (1–5 each) into a percentile ranking; equity tracked for visibility only.
Consolidated Edison	CCVS uses downscaled CMIP5 global climate models, with RCP 8.5 for temperature/precipitation and RCP 5.0 for sea level rise.	Climate Change Implementation Plan classifies investments into resilience-driven, planning/design integration, and new-technology categories; reliability budgets adjusted upward for rising temperatures.
SP Energy (UK)	Risk matrix across three horizons (2030, 2050, 2100) and two RCP scenarios, built on the Energy Network Association's climate adaptation methodology.	Adaptation pathways identify a tipping point per risk, setting a trigger date for action rather than assuming immediate investment; reviewed on an ongoing monitoring cycle.

Frameworks That Depart From the Pattern

- **Sandia Laboratories:** Rather than a vulnerability-first sequence, Sandia's framework isolates the resilience component of a BCA by running the analysis twice: once without resilience measures as a baseline, once with them included. The framework's "Utility Cost Test" is recommended as the default, and it explicitly supports non-monetizable benefits through weighting or proxy scoring.
- **Entergy:** Builds outward from the utility to a regional, multi-stakeholder view of resilience, explicitly favoring "no regrets" investments such as wetland restoration that may not be fully captured by a standard cost-benefit analysis, and accepting ratios up to 2.0 (rather than the conventional 1.0 threshold) to capture measures with strong co-benefits, such as saltmarsh restoration. It validates simulated storm data against historical cyclone behavior and commits to revisiting the analysis every five years as technology evolves.
- **Tennessee Valley Authority:** Narrower in scope, addressing only heat- and drought-driven generation risk for one river basin, but notable for incorporating a population-growth model (LandCast) to project future demand and for explicitly separating the cost of energy shortages from the cost of customer outages.
- **Hunts Point Resiliency Study (New York City):** A community-scale rather than utility-scale case study, pricing the resilience value of microgrids and distributed generation for a food-distribution district using federal BCA guidelines. It produced a detailed monetized benefit case (avoided revenue and inventory loss, sheltering value, emissions reduction) but did not demonstrate how to prioritize across multiple competing projects.
- **Electricity Subsector Transmission Resilience Maturity Model (TRMM):** Modeled on the Department of Energy's Cybersecurity Capability Maturity Model, TRMM assesses an organization's resilience practice maturity across nine domains (program management, risk assessment, event response, workforce management, and others) rather than analyzing specific investments. It benchmarks progress but does not generate costs, benefits, or project comparisons.

- **DOE Climate Change and the Electricity Sector Guides:** A general-purpose, iterative framework moving from decision-context scoping through hazard exposure, vulnerability and cost assessment, to a prioritized portfolio of measures. Its companion sea-level-rise case study demonstrates the framework applied to a single hazard and is offered in the literature as a plausible starting structure for Climate READi given its broad applicability.

Metrics in Play, by Decision Stage

Despite differing terminology, the metrics utilities rely on cluster by where they sit in the vulnerability-to-investment sequence. None of the frameworks reviewed relies on a single metric; each layers a reliability-linked figure, a monetized consequence figure, and a non-monetized score together before ranking projects.

Stage	Representative Metrics	Where It Appears
Hazard & exposure	RCP climate scenarios, recurrence intervals, hazard maps, exposure scores (1–3 or 1–5 scale).	Central Hudson, Duke Energy, SP Energy, National Grid CCVS processes.
Asset vulnerability	Sensitivity and consequence scores, fragility curves, pole/transformer age thresholds.	Central Hudson and Duke Energy's shared exposure × sensitivity × consequence formula.
Outage consequence	VoLL/VOS, Customer Interruption Cost, energy not served, avoided restoration cost.	ICE Calculator, CDF Calculator, POET, Hunts Point benefit-cost case.
Tail risk	Conditional Value at Risk, worst-case scenario stress testing, probability-weighted loss.	REPAIR's CVaR treatment of HILP events; Sandia's acknowledged gap in assigning HILP probabilities.
Prioritization	Benefit-cost ratio, NPV, Risk Spend Efficiency, MCDA score, Business Case Justification percentile.	Sandia's Utility Cost Test, Duke's RSE, Central Hudson's MCDA, National Grid's BCJ.

Common Ground on Equity and Stakeholder Engagement

Every New York-jurisdiction framework reviewed (Central Hudson, National Grid, Consolidated Edison) builds formal equity or disadvantaged-community screening into its process, generally using census-based social vulnerability data, though in most cases equity functions as a visibility flag rather than a scoring input that changes which projects are funded. Entergy and Ausgrid extend this further, treating community resilience as a co-equal goal alongside utility-asset resilience rather than as a secondary screen.

4. Supporting Single-Purpose Models

The review's appendix catalogs narrower models that could supply individual inputs to a broader resilience model rather than serving as frameworks in their own right. These cluster into four domains.

- **Health and Equity:** The CDC/ATSDR Social Vulnerability Index and Climate and Economic Justice Screening Tool supply census-based equity data; the Department of Transportation's value-of-statistical-life guidance and EPA's COBRA tool monetize health and safety benefits; Sandia's ReNCAT tool recommends microgrid portfolios using a Social Burden Metric.
- **Climate Forecasting:** The UConn Outage Prediction Model forecasts storm-driven outages for Northeastern utilities; broader climate and damage data is generally sourced from NOAA and FEMA/HAZUS rather than from a dedicated forecasting tool.
- **Microgrids and Distributed Energy Resources:** NREL's System Advisor Model and REopt, Sandia's Microgrid Design Toolkit, and DER-CAM each evaluate the technical and economic feasibility of renewable and storage assets, including how long a microgrid can sustain critical load during an outage.
- **Environment and Emissions:** EPA's AVERT calculator estimates avoided emissions from changes in generation mix and can feed directly into COBRA for health-benefit valuation.

Additional Cross-Cutting Frameworks

- **PNNL Valuation Framework:** A generic five-step valuation process (define the question, define scope and scenarios, run system analyses, compare metrics against objectives, decide) intended to standardize how utilities value grid services across sustainability, affordability, security, flexibility, reliability, and resilience. It explicitly recommends chaining multiple models so that one model's output becomes another's input.
- **Customer-Focused Resilience Framework:** Argues that the most cost-effective resilience investments are those that speed recovery after an event regardless of cause, rather than those that target a single hazard, since multi-threat measures are generally more cost-effective than single-threat hardening.
- **Ausgrid (Australia):** Explicitly forward-looking because historical outage data is treated as an unreliable guide to future climate-driven risk. Its final portfolio decision weighs net present value alongside risk appetite, strategic alignment, and consistency with community resilience plans, rather than ranking strictly by benefit-cost ratio.

5. Conclusions

Across nearly thirty tools and frameworks, the literature converges on a small number of durable conclusions that bear directly on the design of a Climate READi model.

- **No turnkey solution exists:** No single existing model or framework fully replicates Climate READi's aims; the value of the literature is componentry, not a template to adopt wholesale.
- **The two-stage pattern is the strongest convergence point:** Vulnerability assessment (exposure × sensitivity × consequence) followed by a scored or monetized prioritization stage recurs across nearly every investor-owned utility example and is the most defensible starting structure for a Climate READi framework.
- **Flexibility on data and methodology is non-negotiable:** Utilities and regulators consistently substitute their own climate data, scoring conventions, and BCA methodologies (such as the Utility Cost Test) for any default the model might supply; a Climate READi tool that mandates a single dataset or method risks being unusable across jurisdictions.
- **Resilience benefits resist full monetization:** Nearly every framework pairs a dollar-based BCA with a parallel qualitative or semi-quantitative scoring mechanism (MCDA, BCJ, Risk Spend Efficiency) to capture benefits—community resilience, equity, environmental co-benefits—that a pure BCA cannot price; Climate READi should expect to support both tracks simultaneously.
- **Equity is now a structural requirement, not an afterthought:** Regulatory pressure, especially in New York, has made disadvantaged-community screening a standard component of utility resilience plans, even where it does not yet alter funding decisions directly.
- **HILP events remain the weakest link:** Multiple frameworks, including Sandia's, acknowledge that High Impact, Low Probability events are difficult to assign probabilities to and are often handled by falling back on FEMA-sourced estimates; this is flagged as a likely gap that Climate READi's probabilistic risk assessment is specifically positioned to fill.

Overall Assessment

The literature confirms that resilience planning is following reliability planning's historical path, but several years behind it, with utilities independently converging on similar two-stage processes without a shared standard. Climate READi's opportunity is to formalize this emerging consensus into a flexible, open framework: one that accepts utility-specific climate and asset data, supports multiple BCA conventions side by side, and integrates qualitative scoring for benefits that cannot be priced, rather than displacing the practices utilities have already begun to build.

References

This summary is drawn from EPRI's internal literature review, "Resilience Models and Frameworks: Literature Review" (Draft, April 2024), prepared to inform the Climate READi project. The review itself compiles and cites primary sources for each tool and framework discussed, including reports and technical papers published by NRECA, Lawrence Berkeley National Laboratory, Sandia National Laboratories, NREL, FEMA, the U.S. Department of Energy, and the utilities named throughout (Central Hudson, Duke Energy, National Grid, Consolidated Edison, Entergy, SP Energy, Tennessee Valley Authority, and Ausgrid). Readers seeking primary source documentation, links, and technical detail for any individual tool or framework should consult the full literature review.

- Federal Energy Management Program (hosted by Pacific Northwest National Laboratory), Technical Resilience Navigator — structured site-level workflow for identifying energy and water resilience vulnerabilities and prioritizing solutions.
- FEMA, HAZUS — desktop GIS-based natural hazard loss estimation platform with state-level inventory data for floods and other disasters, drawn upon by several models in this review as a default damage data source.
- Lawrence Berkeley National Laboratory, Interruption Cost Estimate (ICE) Calculator — customer interruption cost survey tool used by utility planners to value reliability and resilience investments.
- National Renewable Energy Laboratory, Customer Damage Function Calculator — facility-level screening tool for baseline outage cost and resilience investment justification.
- Sandia National Laboratories, benefit-cost analysis methodology for resilience investments — framework for isolating and evaluating the resilience component of utility BCAs.
- U.S. Department of Energy, Climate Change and the Electricity Sector: Guide for Climate Change Resilience Planning, and its companion guide for sea level rise and storm surge — stepwise guidance for assessing climate vulnerabilities and developing resilience solutions.
- Utility climate resilience plans and case studies reviewed in the source report, including Central Hudson, Duke Energy, National Grid, Entergy, SP Energy Networks, Consolidated Edison, the Hunts Point Resiliency Study, and the Tennessee Valley Authority case study.