Sandia's Integrated Methodology for Energy Resilience Analysis

In light of growing threats to our nation's energy systems, the U.S. government has prioritized enhanced energy resilience. Presidential Policy Directive-21 (PPD-21) defines resilience as "the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions" and notes that resilience "includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents."[1]

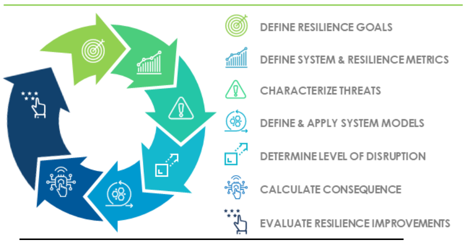
Sandia National Laboratories' Resilient Energy Systems (RES) Strategic Initiative (SI) is establishing a strategic vision for U.S. energy systems' resilience through threat-informed research and development, enabling energy systems to successfully adapt in an environment of accelerating change. A key challenge in promoting energy systems resilience lies in developing rigorous resilience analysis methodologies to quantify system performance. Resilience analysis methodologies should enable us to evaluate the consequences of various disruptions and the relative effectiveness of potential means to mitigate disruptions. To address this challenge, the RES SI has synthesized the common components of Sandia's resilience frameworks into an integrated methodology for energy resilience analysis.

Sandia's Resilience Analysis Expertise

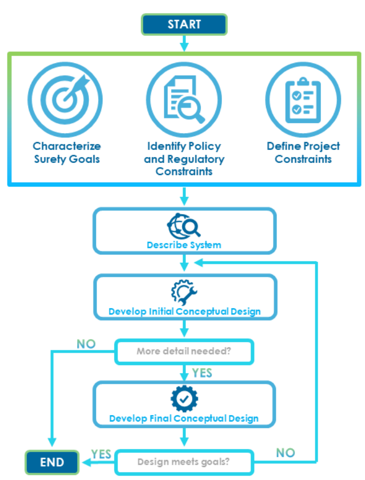
Over the last two decades, Sandia has developed multiple frameworks to analyze resilience and applied them to inform designs, investments, and decisions in various energy and interdependent systems. Depicted in chronological order below, these approaches demonstrate both the breadth and depth of Sandia's resilience analysis expertise. The Infrastructure Resilience Analysis Methodology (IRAM) focuses on recovery costs for critical infrastructures.[2] The Resilience Analysis Process (RAP) is a consequence-based framework developed for the Quadrennial Energy Review.[3] The Energy Surety Design Methodology (ESDM) is a detailed design methodology for electric grid planning that accounts for resilience as well as other energy surety goals (e.g., safety, security).[4] The Integrated Cyber Physical Impact Analysis (ICPIA) focuses on resilience to cyber-physical attacks.[5] The Designing Resilient Communities (DRC) Framework enables cities and utilities to align their investment planning for a more resilient electrical grid. [6]

Resilient Community Design Framework (DRC)

Resilient Analysis Process (RAP)

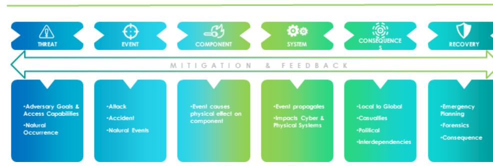


Energy Surety Design Methodology (ESDM)



Infrastructure Resilience Analysis Methodology (IRAM)

Integrated Cyber Physical Impact Analysis (ICPIA)

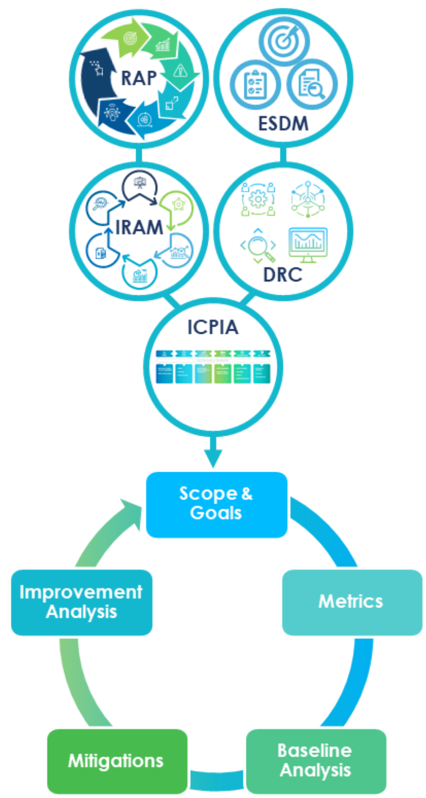


[1] PPD-21, Presidential Policy Directive 21: Critical Infrastructure Security and Resilience, Washington, D.C.: Executive Office of the President, 2013.
[2] B. Biringer, E. Vugrin and D. Warren, Critical Infrastructure System Security and Resiliency, Boca Raton: CRC Press, 2013.
[3] J.P. Watson, R. Guttromson, C. Silva-Monroy, R. Jeffers, K. Jones, J. Ellison, C. Rath, J. Gearhart, D. Jones, T. Corbet, C. Hanley and L. T. Walker, "Conceptual Framework for Developing Resilience Metrics for the Electricity, Oil, and Gas Sectors in the United States," Sandia National Laboratories (SAND2014-18019), Albuquerque, 2014.
[4] R. Broderick, M. A. Cook, M. B. DeMenno, M. El Khatib, R. Guttromson, M. M. Hightower, K. A. Jones, A. S. Nanco, B. L. Schenkman, D. A. Schoenwald and C. A. Silva Monroy, "Energy Surety Design Methodology," Sandia National Laboratories (SAND2019-11463), Albuquerque, 2015.
[5] L. A. Dawson and M. A. Cook, "Integrated Cyber/Physical Impact Analysis to Secure US Critical Infrastructure," Sandia National Laboratories (SAND2016-8046 C), Albuquerque, 2016.
[6] R. F. Jeffers, R. J. Broderick, K. A. Jones and M. B. DeMenno, "Designing Resilient Communities Project Stakeholder Advisory Group Meeting 3 Summary Report," Sandia National Laboratories (SAND2019-12173 O), Albuquerque, 2109.

Sandia's Integrated Methodology for Resilience Analysis

While each of these frameworks delivers a unique value for a particular resilience issue, they rely on a common set of resilience analysis principles. Synthesizing the common components of Sandia's existing frameworks provides an integrated methodology for resilience analysis consisting of the following steps:

1. **Scope and Goals**
   - 1.1. Define the system (e.g., geographic/jurisdictional boundaries, sectors/infrastructures, temporal scale)
   - 1.2. Define threats (e.g., natural, intentional, accidental, structural) or select threat-agnostic approach
     - ➢ Focus on acute threats that create high consequence disruptions, include chronic threats as variables
   - 1.3. Define resilience goals
     - ➢ Consult all relevant stakeholders (e.g., infrastructure owners and operators; local, state, and national policymakers; and interest groups such as consumer, citizen, trade, or professional groups)
     - ➢ Use PPD-21 resilience definition
2. **Metrics**
   - 2.1. Define consequence categories (e.g., economic, social, national security, or service/performance) and associated metrics (e.g., recovery costs, access to community lifeline services, mission assurance, or load not served)
   - 2.2. Select corresponding resilience metrics for individual infrastructures and multi-infrastructure analysis; prioritize performance-based metrics
3. **Baseline Analysis**
   - 3.1. Model threats/disruptions, component impacts, and system impacts using historical data and/or simulations
   - 3.2. Estimate consequences and calculate metrics (without mitigations)
4. **Mitigations**
   - 4.1. Specify alternative resilience mitigations (i.e., planning, operational, and/or policy actions that enhance a system's ability to prepare, withstand, respond, and/or recover)
     - ➢ Consider any system constraints (e.g., project, technology, policy, market)
   - 4.2. Evaluate/prioritize resilience mitigations by estimating consequences and calculating metrics with mitigations
   - 4.3. Implement selected resilience mitigations
5. **Improvement Analysis**
   - 5.1. Evaluate the real-world effectiveness of resilience mitigations
   - 5.2. Restart cycle as needed



The Value of an Integrated Methodology

Sandia's integrated methodology highlights the unique contributions of our approach to resilience analysis. First, the method is explicitly threat-informed, drawing on Sandia's extensive expertise in both intentional and natural hazards. Second, it is consequence-focused, considering a range of technical, social, economic, and national security impacts. Third, it is performance-based, using modeling and simulation to evaluate system level impacts of disruptions and potential mitigations. Finally, it is attentive to infrastructure dependencies and interdependencies, leveraging our experience across critical infrastructure sectors.

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