# Towards Metrics for Resilience Characterization and Challenges in Valuing Distribution System Resilience Improvements

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**GMLC 1.1 METRICS ANALYSIS**
**GMLC1.5.7: LAB VALUATION ANALYSIS TEAM**

April 7, 2021

Resilience Workshop

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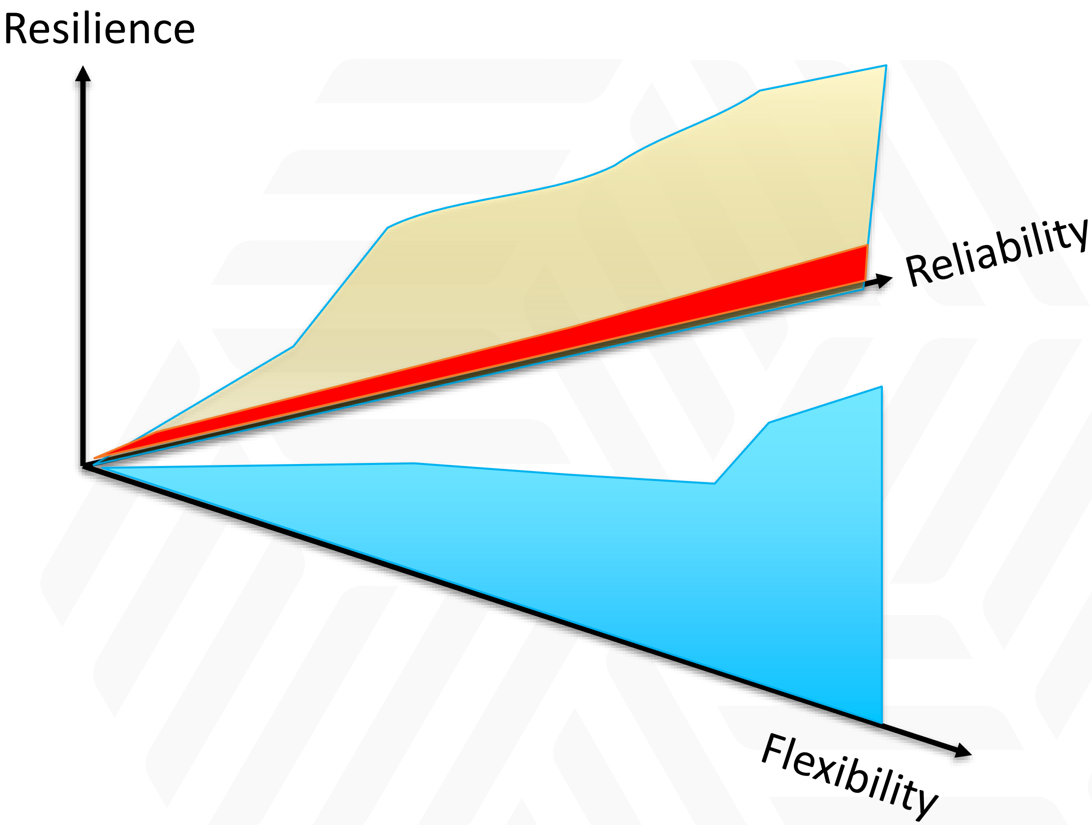
# Overview of Presentation

- ► Landscape of metrics and processes specific to resilience characterization
- ► Delineation between ***reliability*** and ***resilience***
- ► 2 approaches toward Resilience Characterization
  - Attribute-based
  - Performance-based

- ► Example of R&D to improve resilience of grid infrastructure and how to value it.

# Landscape of Characteristics and Dependencies




- When reliability ↑ then (usually - NOT always) resilience ↑
- When flexibility ↑ then resilience ↑

# Landscape of Existing and Proposed Metrics – Example: **Reliability** (GMLC 1.1)

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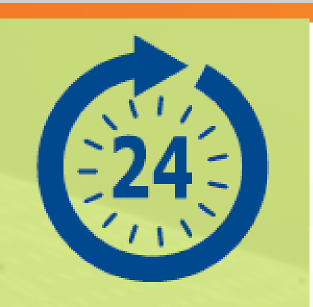


# Mature

## Distribution Reliability

| Existing metrics | Existing (data needed) |
|---|---|
| SAIFI | Total customers served |
| SAIDI | |
| CAIDI | Customer interruption duration |
| CAIFI | |
| CTAIDI | |
| ASAI | Customer hours service availability |
| | Customer service hours demanded |
| MAIFI | Total customer momentary interruptions |
| | |
| CEMI | Total customers experiencing more than n sustained outages |
| CEMSMI | Total customers experiencing more than n momentary interruptions |
| CI | Customers interrupted |
| CMI | Customer minutes interrupted |
| ASIFI | Total connected kVA of load interrupted |
| ASIDI | Total connected kVA served |
| CELID | total number of customers that have experienced more than eight interruptions in a single reporting year |
| SARI | Circuit outage number and duration |
| COR | number of correct operations |
| | total number of operations commanded |
| DELI | total distribution equipment experiencing long outages |
| DEMI | length of interruption (by equipment type) |
| ACOD | Transmission circuit outage and duration |
| ACSI | |
| TACS | total amount of equipment that have more than N # of interruptions in a single year |
| FOHMY | Outages per hundred miles per year |

| Proposed Metrics | Proposed Data Needed |
|---|---|
| Interruption Cost | Customers interrupted (by type of customer) |
| | Characteristics of interruptions by customer type (e.g., duration, start time) |

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# Landscape of Existing and Proposed Metrics – Example: **Resilience** (GMLC 1.1)

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## Resilience

| Existing (metrics) | Existing (data needed) |
|---|---|
| Cost of recovery | |
| Utility revenue lost | outage cost for utility ($) |
| Cost of grid damage | total cost of equipment repair |
| Cost per outage | |

| Proposed Metrics | Proposed (data needed) |
|---|---|
| Cumulative customer-hours of outages | customer interruption duration (hours) |
| Cumulative customer energy demand not served | total kVA of load interrupted |
| Avg (or %) customers experiencing an outage during a specified time period | total kVA of load served |
| Cumulative critical customer-hours of outages | critical customer interruption duration |
| Critical customer energy demand not served | total kVA of load interrupted for critical customers |
| Avg (or %) of critical loads that experience an outage | total kVA of load severed to critical customers |
| Time to recovery | |
| Cost of recovery | |
| Loss of utility revenue | outage cost for utility ($) |
| Cost of grid damages (e.g., repair or replace lines, transformers) | total cost of equipment repair |
| Avoided outage cost | total kVA of interrupted load avoided |
| | $ / kVA |
| **Critical services without power** | number of critical services without power |
| | total number of critical services |
| **Critical services without power after backup fails** | total number of critical services with backup power |
| | duration of backup power for critical services |
| Loss of assets and perishables | |
| Business interruption costs | avg business losses per day (other than utility) |
| **Impact on GMP or GRP** | |
| Key production facilities w/o power | total number of key production facilities w/o power (how is this different from total kVA interrupted for critical customers?) |
| Key military facilities w/o power | total number of military facilities w/o power (same comment as above) |

## Emerging

Direct impacts
Customer services

Indirect impacts
Community services

# Differentiation between Reliability and Resilience events

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## Reliability

Ability to provide electric services under normal operating conditions (blue sky)

## Resilience

Ability to operate in full or reduced form during abnormal operating conditions (black sky)


valuation differences between reliability and resilience improvements

Blue sky threat conditions

- Outages: usually <=24 hours
- Statistics of failure and outage duration known (SAIDI, SAIFI)
- Consequence:
    - outage cost for all customers

Black sky threat conditions

- Outages: usually >24 hours
- Statistics of failure and outage duration unknown ~~(SAIDI, SAIFI)~~
- Consequence:
    - outage cost for all customers
    - Loss of community services

# Differentiation between Resilience and Reliability

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Reliability event

## Metrics: Reliability

| | Customer's perspective | Utility's perspective |
|---|---|---|
| SAIDI, SAIFI | Outage cost by customer | Lost revenue |
| CAIDI, CAIFI | | Restoration cost |
| …. | | |

LBNL's ICE calculator
Valid for reliability events
Up to 24 hours

Service interruption

Onset of interruption — 1day — weeks — Timeline of interruption

## Metrics: Resilience

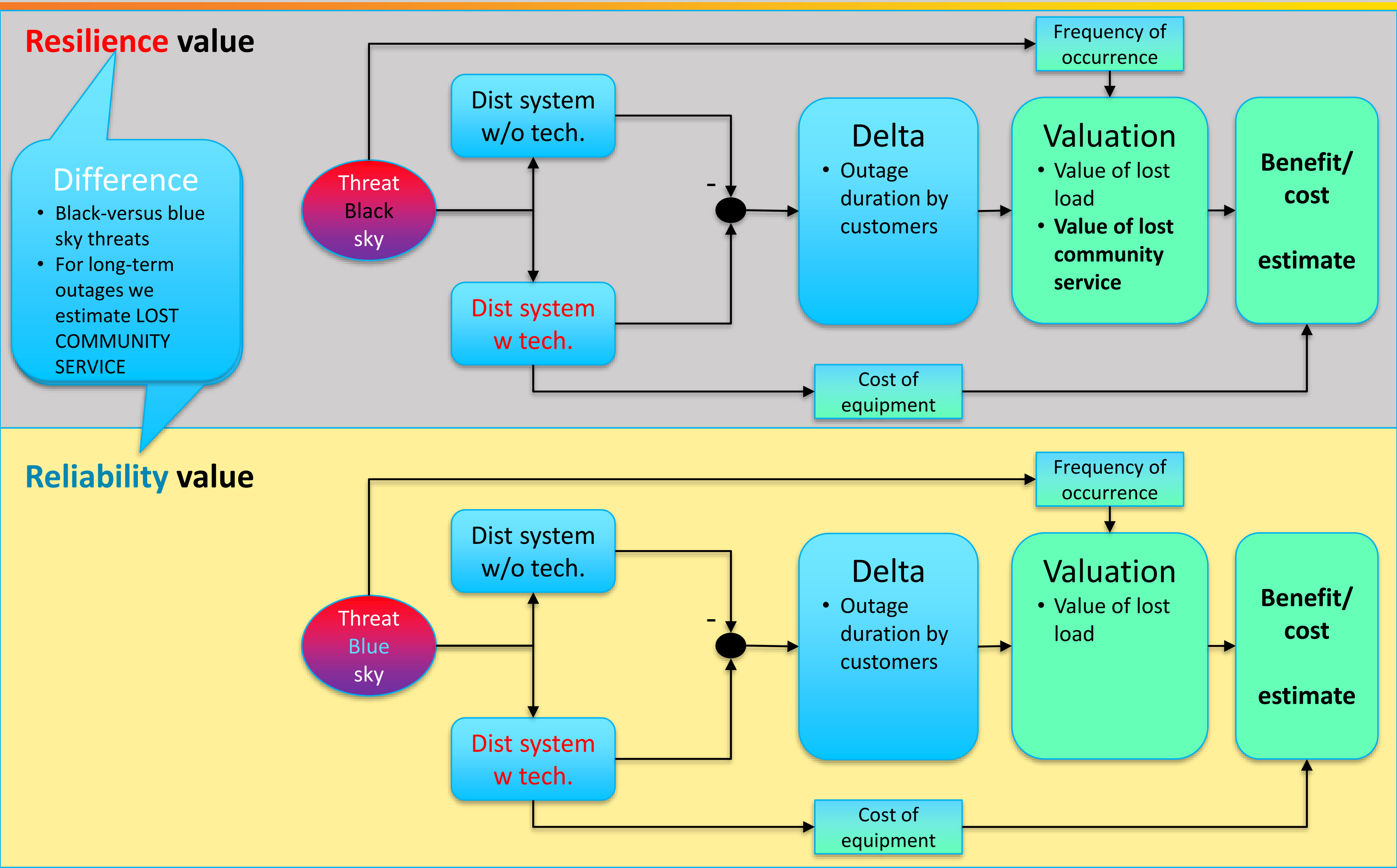
| | Customer's perspective | Utility's perspective | Community's perspective |
|---|---|---|---|
| SAIDI, SAIFI | Outage cost by customer | Lost revenue | Disruption of critical community services |
| CAIDI, CAIFI | | Restoration cost | Impacts of Economic disruptions on Gross Regional Product |
| …. | | | Large reconstruction cost |

Service Interruption

Resilience event

- Direct impacts/consequence: Interruption cost. No data exist for multi-day interruptions. Notionally, damage costs increase more than linearly over time
- Indirect/induced impacts:
    - community disruptions (impact safety, health and wellbeing)
    - Economic disruption costs: percolates through local/regional economy

# Methodology and Data Requirements for Determining Value of Resilience vs. Reliability



# Two Approaches toward Developing Resilience Metrics

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- **Approach 1: Consequence-based**
  - Addresses the consequences of one or multiple threats to an asset or infrastructure
  - Applications: assess consequences (direct and indirect) of threats. And used for assessing mitigation strategies to explore change in consequences. This approach is usually associated with projections and modeling (leading indicators)
  - Purpose: Prioritizing investments for infrastructure hardening and mitigation strategies.
- **Approach 2: Attribute-based**
  - Addresses the survivability posture of an asset or infrastructure to a threat or the ability to recover from a threat; predicated on sets of attributes that describe level of
    - Preparedness
    - Ability to resist and absorb
    - Ability to respond, adapt, and recover
  - Applications: Requires a detailed survey instrument to collect resilience attribute characteristics and an elicitation process to define their contribution to the overall resilience
  - Purpose:
    - Used for monitoring progress on the resilience posture
    - Enables comparability to peers and any other cohorts
- **Synergies between Approach 1 + 2:**
  - Attribute-based approach can be used for screening to identify grid components that could be modified to enhance resilience
  - Consequence-based approach can be used to analyze investment alternatives
  - Will be applied to a New Orleans case study

# Resilient Distribution Systems **Demonstration** with City of Cordova, AK

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- Project Name
  - Resilient Alaskan Distribution System Improvements using Automation, Network Analysis, Controls, and Energy Storage (RADIANCE) Field Validation
- Technology
  - Advanced metering/improvements to situational awareness
  - Upgrades to SCADA systems and/or advanced distribution controls
  - High-resolution fuel metering
  - High-resolution of water metering/penstocks
  - Integration hardware/software for grid-scale battery
  - Pumped hydro storage and solar assessments/modeling
  - Sectionalized hardware and controls for fault isolation
  - Information technology (IT) upgrades to enhance cybersecurity
- Field Validation
  - Multiple tests of device operations
- Use cases to be tested
  - Various configurations of microgrid operations under black sky conditions
- Values to be demonstrated
  - Primarily avoided economic impacts under black sky conditions
- Challenges
  - Projecting frequency of black sky events over the lifecycle of technologies
  - Field validation, inducing faults and demonstrating resilient behavior

Cordova, AK

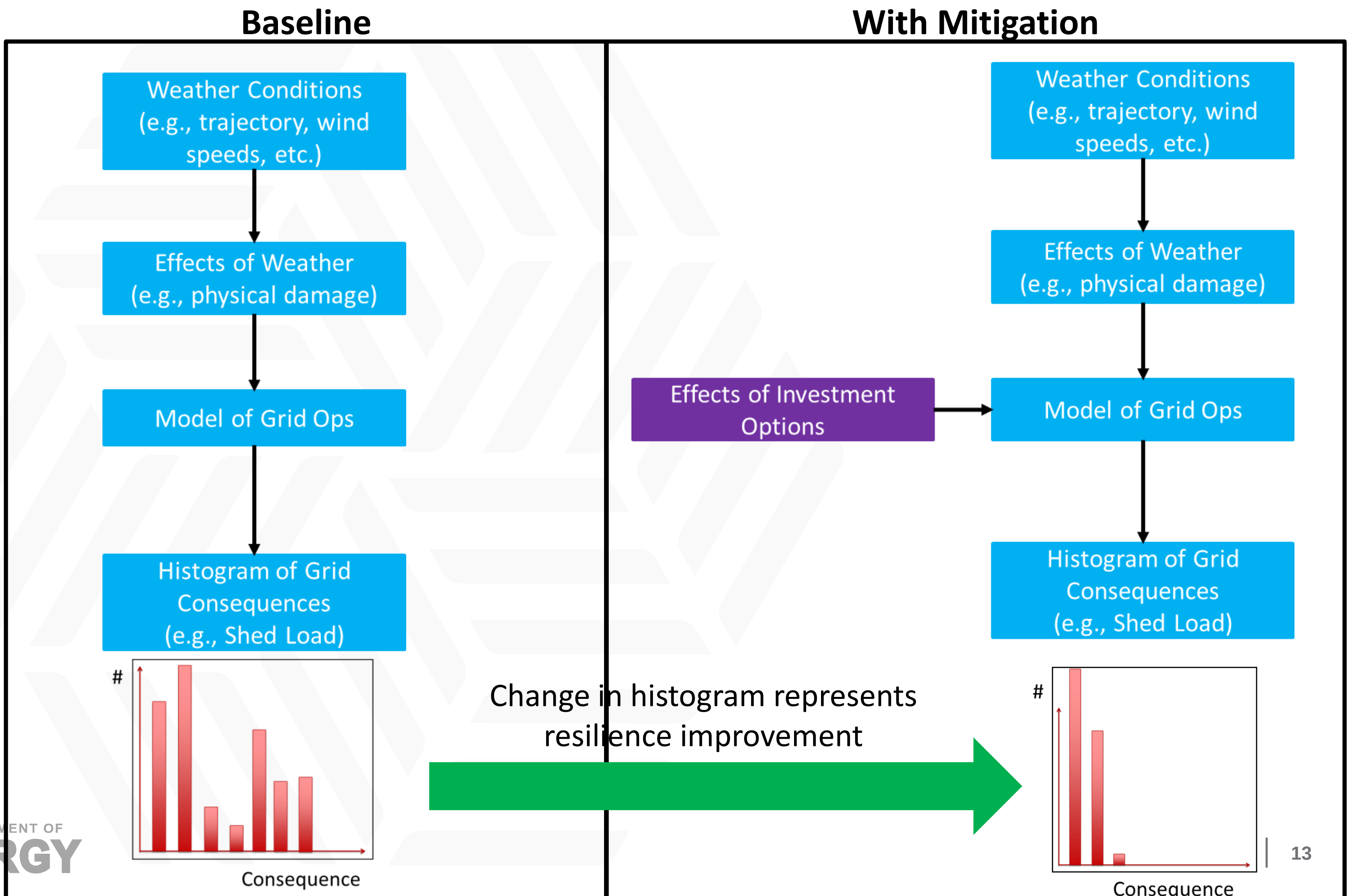
# Take-away messages for Value Estimation of Resilience Improvements



- How do you demonstrate Resilience?
- Most technology solutions include redundant systems (hardening) and additional flexibility assets to reconfigure electric circuits.
- Most Field-tests will focus primarily on low-intrusive device-level functionality. Then infer how system might behave under black-sky conditions using complex simulations
- Biggest challenge in valuation of resilience investments is the estimation of severity and frequency of black sky conditions. Assumptions are key driver for economic justification.

# Backup Slides

# Exploring Investment Options on Consequences to Threats



# Principles of ATTRIBUTE-BASED Approach

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**Resilience index is based on 4 sub-indices**

| | | | | |
|---|---|---|---|---|
| Level 1 | Preparedness | Mitigation Measures | Response Capabilities | Recovery Mechanisms |
| Level 2 | Awareness | Mitigating Construction | Onsite Capabilities | Restoration Agreements |
| | Planning | Utility Mitigation | Offsite Capabilities | Recovery Time |
| | | Resources Mitigation Measures | IMCC Characteristics | |

IMCC: incident and management control center