Resilience Metrics for Energy Systems

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Resilience is a complex concept
There are many ways to define resilience

- For today, it is not important to debate
  - How terms relate
  - Where terms overlap

- Most important to understand
  - What system is being measured
  - What properties are of interest
  - What audiences seek metrics
  - What decisions are made using metrics
Guidelines for measuring resilience

- Resilience describes the state of service from a system in response to a disruption.
- Metrics should be selected based on who is measuring resilience and why.
Guidelines for measuring resilience

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• Metrics should be selected based on who is measuring resilience and why
Resilience describes the state of service from a system in response to a disruption.
Resilience depends on...

- **Type of service**
  - Line workers to a response
  - Power to a community
  - Transportation for commuters
  - Income to a region

- **Type and extent of disruption**
  - Pandemics, hurricane, floods, earthquake, geomagnetic storms, cyber attacks, events now and in the future

- **System design, operation, and response**
  - Redundancy
  - Maintenance
  - Response
Different systems will have different resilience to the same disruption.
Different responses will lead to different resilience at different costs.
Resilience of a system also depends on the time scale considered.
Guidelines for measuring resilience

• Resilience describes the state of service from a system in response to a disruption

• Best metrics depend on who is measuring resilience and why
Resilience metrics are used for many purposes and at many levels.

What is available?

Examples
• Budgets
• Equipment
• # of spare parts
• # of generators
• # of line workers
Resilience metrics are used for many purposes and at many levels

Inputs

What is available?

Capacities

How are inputs organized?

Examples

• Response teams
• Plans
• Aid agreements
• Smart-grid tech
Resilience metrics are used for many purposes and at many levels

- **Inputs**
  - What is available?

- **Capacities**
  - How are inputs organized?

- **Capabilities**
  - What tasks can be performed?

**Examples**
- Outage detection
- Line repair
- Backup delivery
- Outage restoration
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- **Inputs**
  - What is available?

- **Capacities**
  - How are inputs organized?

- **Capabilities**
  - What tasks can be performed?

- **Performance**
  - What is produced?

**Examples**
- Energy delivery
- Efficiency
- Reliability

- Hardness
- Robustness
- Sustainability
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- **Inputs**
  - What is available?

- **Capacities**
  - How are inputs organized?

- **Capabilities**
  - What tasks can be performed?

- **Performance**
  - What is produced?

- **Outcomes**
  - What is achieved?

**Examples**
- Economic activity
- Costs and damage
- Human welfare
Metrics support both strategic and operational decisionmaking

Operational Perspective

- **Inputs**: What is available?
- **Capacities**: How are inputs organized?
- **Capabilities**: What tasks can be performed?
- **Performance**: What is produced?
- **Outcomes**: What is achieved?

Strategy Perspective
There is not a single set of metrics for all purposes

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Selecting metrics requires balancing validity, reliability, and practicality in as few metrics as possible
Summary

• Resilience can be evaluated for different systems, disruptions, responses, and time-scales

• Metrics can describe inputs, capacities, capabilities, performance, or outcomes

• Metrics must be selected for a purpose

• Selecting metrics requires considering conciseness, comprehensiveness, validity, reliability and practicality
Questions for discussion

• What resilience outcomes are stakeholders most concerned about?

• What are stakeholders’ needs for resilience metrics?

• What analysis are you doing that must take resilience into account?
  – In what context (risk assessment, investment analysis, etc.)
  – How are you doing that?

• Are existing metrics adequate?

• What resilience metrics are currently codified in Federal or state regulations, and are they adequate?

• What specific metrics are most useful?