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Short Communication

Metrics for energy resilience

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HIGHLIGHTS

- Resilience is the ability of a system to recover from adversity.
- There is a need for methods to quantify and measure system resilience.
- We developed a matrix-based approach to generate energy resilience metrics.
- These metrics can be used in energy planning, system design, and operations.

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ABSTRACT

Energy lies at the backbone of any advanced society and constitutes an essential prerequisite for economic growth, social order and national defense. However there is an Achilles heel to today's energy and technology relationship; namely a precarious intimacy between energy and the fiscal, social, and technical systems it supports. Recently, widespread and persistent disruptions in energy systems have highlighted the extent of this dependence and the vulnerability of increasingly optimized systems to changing conditions. Resilience is an emerging concept that offers to reconcile considerations of performance under dynamic environments and across multiple time frames by supplementing traditionally static system performance measures to consider behaviors under changing conditions and complex interactions among physical, information and human domains. This paper identifies metrics useful to implement guidance for energy-related planning, design, investment, and operation. Recommendations are presented using a matrix format to provide a structured and comprehensive framework of metrics relevant to a system's energy resilience. The study synthesizes previously proposed metrics and emergent resilience literature to provide a multi-dimensional model intended for use by leaders and practitioners as they transform our energy posture from one of stasis and reaction to one that is proactive and which fosters sustainable growth.

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1. Introduction

1.1. Energy and resilience

The wealth and health of a nation are often measured through the extent and accessibility of its energy reserves; the capability of its energy distribution infrastructure; and the efficiency by which it leverages energy into economic output (National Infrastructure Advisory Council, 2013). Conversely, to the degree that these capabilities may be disrupted due to changing conditions, be they near or long-term, that nation becomes disproportionately vulnerable. High-profile events such as Deep Water Horizon, Hurricanes Katrina and Irene, and super-storm Sandy have encouraged the nation to re-examine the vulnerabilities of its energy systems; and to reevaluate how these systems are designed, configured, and managed to cope with frequent small variations, long-term trends and significant disruptive events.

The national power grid presents a case-in-point: The National Academy of Engineering has identified the US electrical power grid as the supreme engineering achievement of the 20th Century (National Academy of Engineering, 2014). It comprises the "largest interconnected machine on earth", including 200,000 miles of high voltage transmission lines and 5.5 million miles of local distribution lines (National Academy of Sciences, 2013). More than 20 percent of all electrical infrastructure purchases on Earth are used

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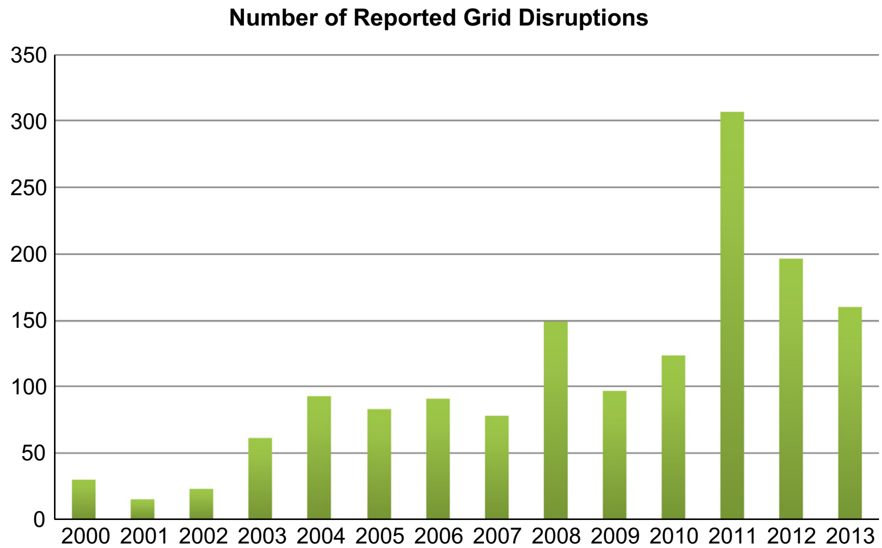

Fig. 1. North American Power Disruption Frequency (Data Collected from Office of Electricity Delivery & Energy Reliability (2014))

just to keep the North American grid operating (Zolli and Healy, 2012). However, despite that massive investment, regulatory authorities have noted a disconcerting increase in the frequency and severity of electrical grid disruptions (Fig. 1). Moreover, although the increasing *number* of disruptions may be attributed primarily to changing environmental and climactic conditions, the grid's increasing technological complexity and operational “interconnectedness” have significantly exacerbated the *severity, geographic distribution,* and *societal ramifications* of those outages. For example, in August 2003, the heat-induced sagging of several local power lines in northern Ohio – a situation that might otherwise result in a temporary local power outage – resulted in a massive regional collapse of the power transmission and delivery system. *Within eight minutes*, the blackout affected over 50 million people in eight states and one Canadian province and ultimately resulted in a US financial impact of between $4 and $10B (US–Canada Power System Outage Task Force, 2004).

In response to the increasing trend in grid disruption frequency and severity, energy system owners and operators, regulatory authorities, and policy makers have mandated and initiated significant infrastructure improvements and operational changes. Predominantly, these actions sought to meet two main objectives: reinforce physical energy infrastructure and reduce recovery time. However, the uniqueness of energy attributes, the complexity of system and sub-system interactions, and the near-instantaneous time frames involved in modern system responses creates particular challenges for decision-makers. Prudent measures can protect against anticipated conditions such as high winds and earthquake; however, the current ad hoc approach to system hardening, which typically seeks to address past failure scenarios, does not necessarily assure protection from unexpected future scenarios. Moreover, the focus on optimizing performance and protecting the design condition fails to address energy system performance under varying conditions, emergency or otherwise, beyond a binary, all-or-nothing, approach. Subtle-yet-critical issues of energy quality (and tolerance), criticality, and efficiency are not adequately incorporated into the system design/preparation, response, and recovery processes.

Resilience offers an alternative to the current status quo (Linkov et al., 2014). Executive Order 13636 (2013) prescribes resilience as a risk management approach for critical infrastructure and Executive Order 13653 (2013) invokes the principle in the context of climate preparedness. In various contexts, resilience has been used to describe an individual's capacity to cope with adversity, a community's posture to weather disasters, or a species' adaptability in response to environmental change. Presidential Policy Directive 21 defines resilience as “*the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents*” (2013) (Presidential Policy Directive 2013). With respect to systems associated with essential social functions, a National Academy of Science (NAS) report identifies four basic resilience components: *plan/prepare, absorb, recover*, and *adapt* to anticipated and unanticipated conditions (2012). The Department of Homeland Security adds that “*Having accurate information and analysis about risk is essential to achieving resilience. Resilient infrastructure assets, systems, and networks must also be robust, agile, and adaptable. Mitigation, response, and recovery activities contribute to strengthening critical infrastructure resilience*” (2013) (Department of Homeland Security, 2013).

As the concept of resilience advances in prominence, discussion about effective resilience management and quantitative resilience metrics continues to grow. Thomas and Kerner (2010) characterize the need for energy resilience metrics, stressing examination of system response to change. General ideas have been advanced, for example the concept of a “secure energy premium” (US Army, 2009). To date, attempts to quantify such a value have been limited to actuarial risk estimates – estimating the probability and cost impacts of electrical power interruptions to a community or military installation. Recognizing the complexity and dynamic nature of resilience, Flynn and Burke (2012) consider system interactions such as resources, security, and policy at a national level. Folke et al. (2002) call for active adaptive management techniques that invoke the use of structured scenarios and monitoring to gauge overall system response, and to provide learning and adaptation opportunities. O'Brien and Hope (2010) emphasize interactions among physical and socio-economic domains, attributing resilience advantages to democratic systems involving distributed ownership and control compared to traditional centralized schema.

Responding to the lack of established resilience models and tools to implement the new generation of resilience policies and initiatives, Linkov et al. (2013a) set forth a taxonomy for metrics that accommodates both change and interactions among physical, information, and human domains. Further work (Linkov et al. 2013b) applied the taxonomy to cyber threats, which interact with energy resilience, but reflect substantial differences. Following the

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work of Linkov et al. (2013a, 2013b), the purpose of the current work is to provide a framework for relevant metrics as a basis for development of coordinated energy-related solutions in the physical, information and human domains, with a stronger focus on adaptive management to foster learning and adaptation. We seek to inform models which in turn fill the gaps in energy-related design and resourcing processes, thus enabling leaders and investors to reconcile chronically disconnected considerations through the unifying lens of resilience.

1.2. Resilience principles

Like most treatments of resilience, the NAS definition describes resilience in the context of changing conditions. Systems inevitably perform most effectively at a specific point or range of conditions; but in complex real-world systems, operational conditions almost always deviate from optimum design points. When the environment deviates from the design point, performance decreases. Small perturbations are much more frequent than dramatic ones. Even for typical stable systems, performance sensitivity to such incremental change impacts cumulative outcomes. As a generalized concept, a system that experiences a comparatively smaller decline under changing conditions displays increased *resistance* (Walker et al., 2004). Once displaced from its optimum point, Walker et al. describe *latitude* as the system's ability to restore performance. Factors influencing this behavior include sensitivity of the basic physical process to environmental conditions, diversity of processes or simple design margin (Fig. 2). Less frequent but more dramatic events bring the prospect of catastrophic disruption; under such circumstances, safety margins and dependencies become key. Substantial perturbations expose the importance of *precariousness*, or the margin from the system's current state to a performance threshold or "tipping point" in the rate of performance degradation.

Long-term change, either gradual or dramatic, calls for learning and adaptation to ensure performance under "new normal" conditions. Such fundamental ideas inform the identification of change-based metrics. As conditions change over time, a resilient system must be able to adapt inherent processes to optimize performance and maintain valued system outputs under the "new normal" conditions (Fig. 3). System attributes such as diversity, flexibility, and interoperability; rich information; knowledge/creativity; and innovative cultures foster such adaptive capacity. In fact, change is essential, and the process of learning and adaptation is key to survival in the real world (Taleb, 2012).

Finally, resilience must address the potential for substantial or dramatic changes. Given the complexity of modern infrastructure and systems, and the significant system disruptions posed by hostile acts (e.g., physical or cyber attack), it is reasonable to

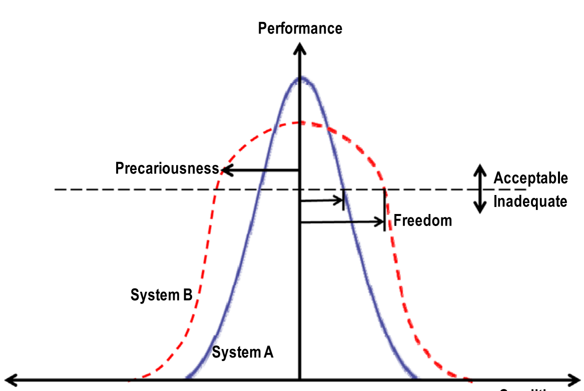

Fig. 2. Performance dependency on condition.

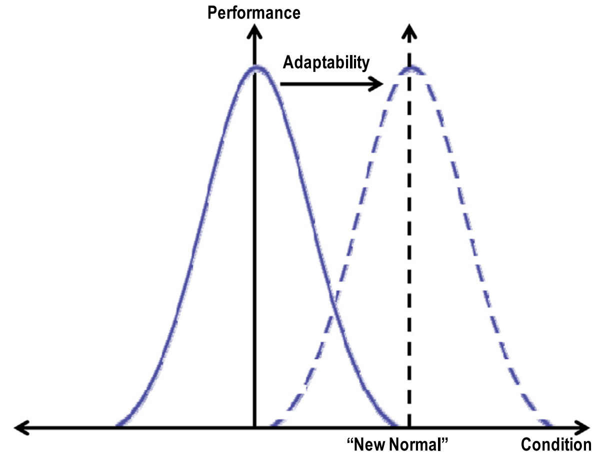

Fig. 3. Adaptability.

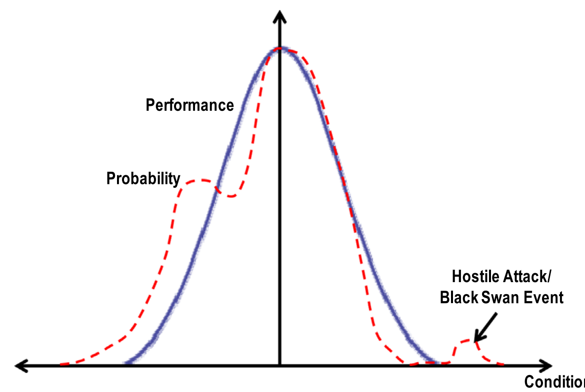

Fig. 4. Uncertainty.

expect multimodal responses to change; with such responses exhibiting rate changes or even trend reversals (decreasing, then increasing performance) in key system pathways and parameters. Furthermore, the environmental conditions under which the system functions are often dynamic and notoriously difficult to accurately predict. All of these factors contribute to the apparently increasing incidence of unpredictable or "black swan" events (Fig. 4). In general, this category of change warrants explicit consideration to ensure the overall system can absorb, recover, and adapt from major disruptions, outside the realm of incremental adjustment. This principle complicates the challenge of timely recognition of true system conditions and status, and increases the importance of building sufficient flexibility to function under more extreme conditions.

In addition to characterizing change and system responses, it is worth examining alternative views of resilience as they relate to systems under consideration. Holling (1996) distinguishes between resilience metrics which focus on maintaining the underlying system functionality (such as energy) – a focus he terms engineering resilience – versus an "ecological" view that considers more holistic concepts emphasizing survival and adaptation of the overall system. Molyneaux et al. (2012) offers composite resilience indices, distinguishing between the scenarios of maintaining functionality under limited change versus the need for adaptive response to disruptive conditions. These diverse views can be useful in practical system analysis because resilience concepts inherently involve consideration of systems on hierarchal scales with complex interdependencies, with the inevitable focus on outcomes that transcend simply maintaining the status quo. While we seek to design robust systems and protect them from known threats, our ultimate

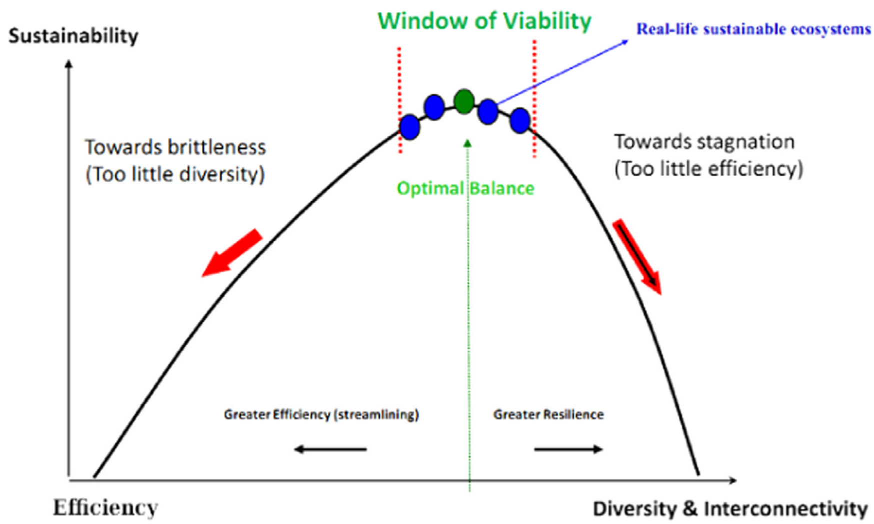

Fig. 5. Resilience versus efficiency in ecosystems (from Lietaer et al., 2010).

goal nearly always lies in a larger good of survival, social order, or advancement.

Finally, we must acknowledge that which is intuitively obvious – there is no free lunch at the resilience buffet. Lietaer et al. (2010) demonstrated that increases in system diversity and interconnectedness – factors that generally enhance overall system resilience – involve tradeoffs with respect to the system's output efficiency (Fig. 5). However, closer inspection of Lietaer's curve reveals that the efficiency versus resilience curve is not bell-shaped. Rather, the optimal “window of viability” (i.e., the region where long-term system output sustainability is maximized) is skewed toward greater system resilience as opposed to greater system efficiency (Fig. 5). Viewed from this perspective, Lietaer's findings may have profound implications for the financing, design, and operation of energy infrastructure and other critical systems.

2. Materials and methods

Linkov et al. (2013a) described a framework for resilience metrics which aligns with the National Academy of Sciences (2012) definition of disaster resilience, while invoking multi-domain aspects captured in Network Centric Operations (NCO) doctrine (Alberts, 2002). The result is a matrix with metrics organized with respect to the four NAS-identified stages of change:

- Plan/Prepare: Lay the foundation to keep services available and assets functioning during a disruptive event (malfunction or attack).
- Absorb: Maintain most critical asset function and service availability while repelling or isolating the disruption.
- Recover: Restore all asset function and service availability to their pre-event functionality.
- Adapt: Using knowledge from the event, alter protocol, configuration of the system, personnel training or other aspects to become more resilient.

The second matrix dimension corresponds to four domains described in NCO doctrine, which emphasizes situational awareness and decentralized decision-making:

- Physical: Physical resources and the capabilities and design of those resources.
- Information: Information and information development about the Physical domain.
- Cognitive: Use of the Information and Physical domains to make decisions.
- Social: Organizational structure and communication for making Cognitive decisions.

A matrix can be created that relates these two components in a unifying framework. Each cell, representing a metric, considers the system's energy-related posture or response to change, addressing the interacting physical systems, information, cognitive and social domains. The plan/prepare column relates to deliberate activities such as resource development, design, planning and education; the latter three columns measure the response to change as it occurs over various time frames.

The matrix was populated through a review of resilience research to identify recommended measures or metrics attributed to various aspects of resilient posture or performance. Some references (e.g., Flynn and Burke, 2012; Hay, 2013), focus on concrete examples such as disaster response in communities while other researchers (e.g., Holling, 1996; Thomas and Kerner, 2010) offer more generalized perspectives about the resilient system attributes and responses. In order to provide comprehensive structure for future use, the authors have grouped and restated metrics from these diverse sources into a consistent syntax and organized them into the present two-dimensional framework. Each cell within the matrix represents the thought, “How can the system's ability to [*plan/prepare, absorb, recover* and *adapt*] to an energy-related change be improved by measures taken in the [*physical, information, cognitive and social*] domain?”

3. Results

Because energy is a fundamental contributor to capabilities and considering the diversity of near and long-term change, the associated resilience metrics presented in Table 1 are oriented to substantially address constructive flexibility, learning, and adaptation rather than focusing on resistance to short-term adverse conditions.

Each cell within the matrix can be used to examine a limited aspect of capabilities and posture while the comprehensive overall structure provides for holistic treatment of inter-related systems with end objectives in mind. For example, energy resilience planning for a hospital executive, a regional utility manager, or a military installation commander would naturally reflect different values, even corresponding to the same matrix cells, considering their distinct responsibilities and system dynamics. Hospital

Table 1
Energy resilience matrix.

	Plan and Prepare for	Refs	Absorb	Refs	Recover from	Refs	Adapt to	Refs
Physical	Reduced reliance on energy/increased efficiency	A,B, E,F, H	Design margin to accommodate range of conditions	B,C, I,J,K	System flexibility for reconfiguration and/or temporary system installation	C,D, F,H, K	Flexible network architecture to facilitate modernization and new energy sources	C,D, F,K
	Energy source diversity/ local sources	A,E, F,H, K	Limited performance degradation under changing conditions	B,C, F,I,K	Capability to monitor and control portions of system	B,I, K	Sensors, data collection and visualization capabilities to support system performance trending	D,E, I,K
	Energy storage capabilities/ presaged equipment	B,H, K	Operational system protection (e.g., pressure relief, circuit breakers)	I,K	Fuel flexibility	C,D, E,F	Ability to use new/alternative energy sources	C,F, H
	Redundancy of critical capabilities	D,E, I,K	Installed/ready redundant components (e.g., generators, pumps)	D,I, K	Capability to re-route energy from available sources	C,D, F,I,K	Update system configuration/ functionality based upon lessons learned	C,D, L,F,I, K
	Preventative maintenance on energy systems	I,K	Ability to isolate damaged/ degraded systems/ components (automatic/ manual)	E,I,K	Investigate and repair malfunctioning controls or sensors	I	Phase out obsolete or damaged assets and introduce new assets	A,C, D,I, K
	Sensors, controls and communication links to support awareness and response	H,I, K	Capability for independent local/sub-network operation	D,K	Energy network flexibility to re-establish service by priority.	F,I,K	Integrate new interface standards and operating system upgrades	D,I, K
	Protective measures from external attack (physical/ cyber)	A,D, I,K	Alternative methods/ equipment (e.g., paper copy, flashlights, radios)	B,H, K	Backup communication, lighting, power systems for repair/recovery operations	I,K	Update response equipment/ supplies based upon lessons learned	D,L
Information	Capabilities and services prioritized based on criticality or performance requirements	B	Environmental condition forecast and event warnings broadcast	E,H, I	Information available to authorities and crews regarding customer/community needs/ status	D,I	Initiating event, incident point of entry, associated vulnerabilities and impacts identified	A,D, H,I, K
	Internal and external system dependencies identified	B,G, H	System status, trends, margins available to operators, managers and customers	D,E, H,I, K	Recovery progress tracked, synthesized and available to decision-makers and stakeholders	D,I	Event data and operating environment forecasts utilized to anticipate future conditions/ events	D,H, I,K
	Design, control, operational and maintenance data archived and protected	B,I	Critical system data monitored, anomalies alarmed	D,E, I,K	Design, repair parts, substitution information available to recovery teams	K	Updated information about energy resources, alternatives and emergent technologies available to managers and stakeholders	D,F, H,I
	Vendor information available	B	Operational/troubleshooting/ response procedures available	I,K	Location, availability and ownership of energy, hardware and services available to restoration teams	K	Design, operating and maintenance information updated consistent with system modifications	F,I,K
	Control systems operational and protected with anti-virus and other safeguards	B,I, K	Status/trend limits trigger safeguards and isolate components to stop cascade effect	E,H, K	Resource needs, sources and authorities available to decision-makers	D	Consumer/stakeholder awareness of energy alternatives, cost/ benefits and implementation requirements	B,F, H
	Operating environment forecasts captured in planning scenarios	A,B, I,K	Status/response/mitigation information transmitted effectively and efficiently to stakeholders/decision makers	B	Information regarding centralized facilities, and distribution of essential supplies and services available to community	D	Community impacts, priorities, interdependencies updated to capture lessons learned	B,D, I
	Response/recovery plans established and distributed	B,I, K	Coordinating information, communications throughout supply chain	K	Coordinating information, communications available among recovery organizations	D	Response plans updated with lessons learned	D,H, I,K
Cognitive	Understand performance trade-offs of organizational goals	A,H	Awareness and focus of effort on identified critical assets and services	B,D, K	Utilize data and decision making aids to quickly select recovery options	L	Document and review management response and decision making processes	D,H, K
	Broadly-based operational and maintenance training	I,K	Decision making protocol or aid to determine proper course of action	L,H, K	Recovery crews mange incremental recovery with available equipment	K	Periodically revisit organizational risk tolerance and mission priorities, adjusting as necessary	B,H
	Periodic operator, management and community drills	D,I, K	Operators and managers utilize critical thinking and maintain proactive posture to recognize and arrest events	H,K	Community members utilize available resources and improvise to meet local needs	B,D, F,H	Integrate lessons learned and best practices from internal and external sources	D,L, H,I, K
	Develop individual expertise in energy impacts, techniques and alternatives (energy-informed culture)	B	Community response to mitigate impacts (e.g. demand curtailment)	B,D, K	Community members manage constrained energy resources responsibly and consistent with public guidance	B,D, F	Customers and stakeholders take action to implement more resilient energy solutions	B,F, H,I, K
Social	Identify stakeholders (internal and external)	D,K	Priorities and operating limits mitigate disruption to energy needs for key community functions	A,D, K	Recovery organizations and communities follow contingency recovery plans	B,L, H	Reallocate human resources to better address adverse events	D,H

Table 1 (*continued*)

Plan and Prepare for	Refs	Absorb	Refs	Recover from	Refs	Adapt to	Refs
Use of scenario based war gaming to develop understanding of system dependencies and interactions	D,L, H,J, K	Pre-defined protective actions limit external influences in physical, information domains	B,H, K	Community stakeholders participate in establishment of energy priorities and coordination of restoration actions	B,L, K	Local governments and stakeholders stay informed about threats, changing environment, protective methods and technologies	A,B, D,H, I,K
Robust risk analysis and decision support capabilities to facilitate response	A,B, D,H, I,K	Agile operational management enables rapid and effective response under changing conditions	H,K	Shelters and other centralized services increase efficiency and control of scarce energy resources to meet critical needs	K	Local governments and stakeholders collaborate to develop, prioritize and implement energy portfolio improvements	A,B, D,F, H,I, K
Decrease overall reliance upon energy or specific sources of energy	A,B, E	Individuals and organizations implement response plans	B,D, H,K	Public/private entities coordinate to deliver aid to affected parties	L	Incentivize customers and stakeholders to implement more resilient energy solutions	A,B, D,E, F,H, I,K
Priorities and policies established for event response	A,B, D,H, I,K	Individuals and organizations take action in response to observations and/or direction from authorities	B,D	Proactive neighborhood assistance, volunteerism, compliance with energy response manager direction	L	Energy-informed culture leads to collective decisions and investments which continually improve energy effectiveness	D,E, F,K

Reference key: A: Flynn and Burke (2012); B: Hay (2013); C: Holling, (1996); D: National Infrastructure Advisory Council (2013); E: Molyneaux et al. (2012); F: O'Brien and Hope (2010); G: Pederson et al. (2006); H: Thomas and Kerner (2010); I: US–Canada Power System Outage Task Force, (2004); J: Walker et al. (2004); K: Perfect Power Institute, (2013); L: National Infrastructure Advisory Council, (2013).

a

The Ability to Absorb is partially determined by *Functional Redundancy*

Score	Definition -- The capacity of functionally similar elements to partly or fully substitute for each other.
7	System components are fully complementary, can be readily substituted, and have similar capacity.
6	System components are mostly complementary, can be readily substituted, and have similar capacity.
5	System components are mostly complementary, can be substituted with minimal delay, and have similar capacity.
4	System components are mostly complementary and can be substituted with minimal delay, but have differing capacities.
3	Most system components are not complementary. Some could be be substituted with minimal delay and or they have differing capacities.
2	Most system components are not complementary. Some could be be substituted but with substantial delay and or they have differing capacities.
1	Each system component has a distinct function with no known functional redundancy.

b

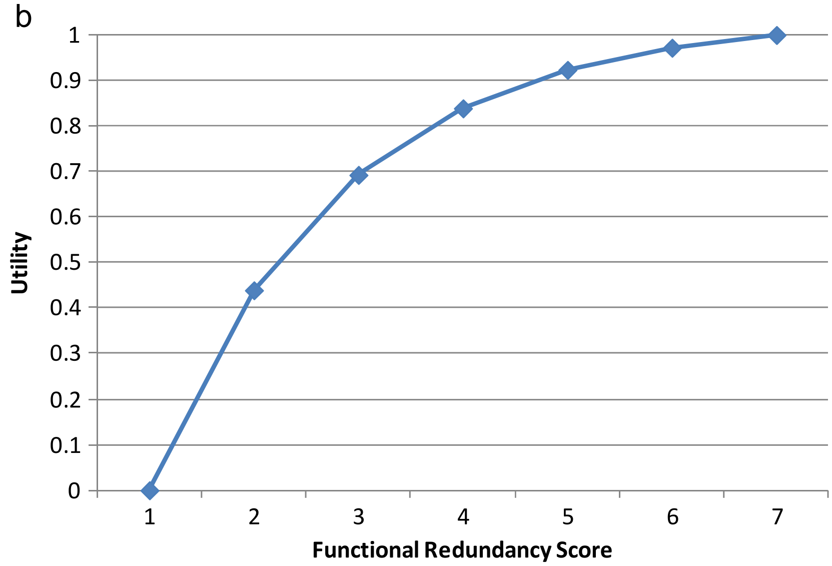

Fig. 6. (a) Scores assigned to a system's level of functional redundancy and (b) resultant utility curve to be used in a multi-criteria assessment.

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managers should consider planning and training for increased emergency care coincident with disrupted electrical service; selecting equipment with flexibility to operate with alternative energy sources; and establishing mechanisms to monitor for major incidents or disease outbreak. Corresponding measures for a utility manager might include planning prioritized power restoration after a storm; designing distribution systems for flexibility in routing and backup generator connection; and monitoring power system performance for anomalies which could indicate malfunctions, maintenance needs or cyber attack. Contingency planning by a military installation energy staff must address not only explicit military missions but sustainment issues, family needs, and emergency support to the community. Energy flexibility should consider routine conditions (e.g., weather variations affecting renewable generation) as well as extended power grid disruptions. Monitoring needs would encompass circumstances ranging from severe weather to community events, hostile threats, urban encroachment, and climate change. Perhaps as important as tailoring these metrics, these stakeholders can substantially increase community resilience by sharing insights and coordinating respective efforts in order to inform an overall outcome focus.

4. Discussion

The proposed metrics are general and must be adapted by the user to the application at hand. No set of specific metrics will fit all situations. The elements of the matrix are intended to address the range of energy systems, attributes and meta-systems which manifest in the physical, information and human domains, as they significantly influence nearly any modern technology system. Recognizing the focus on change response and the complexity of energy interactions within infrastructure, community, and regional systems, active adaptive management techniques provide important implementation tools. The addition of one metric may affect other metrics – for example, sensors and controls in the physical domain may require information storage in the information domain, and the information may have reporting requirements in the social domain. Valid assessments and comparisons must consider these interacting systems in actual or realistic scenarios, including cross-domain (physical/information/human) interactions. For example, effective planning and timely delivery of energy-related information could enable informed personnel to maintain critical communications links under emergency conditions, if regulations and authorities allow. Moreover, attributes such as design capacities, margins, and flexibility may be analyzed quantitatively; but confirmation of more complex interactions and response to change requires more qualitative methods. Technical experts and stakeholders may be needed to supplement data where physical measurements cannot be obtained.

The resilience matrix has several practical uses. The metrics can be assessed across multiple systems for a comparative evaluation via multi-criteria decision analysis (MCDA) (e.g., Belton and Stewart, 2002; Linkov and Moberg, 2011). To illustrate, Fig. 6a, reflects system scoring against a single criterion (Functional Redundancy) relevant to “absorbing” change, using a seven-point scale. This score is then represented using a multi-attribute utility (or value) approach (Keeney and Raiffa, 1976) by assigning a utility (or value) score to each of the assessed levels, showing the marginal benefits gained from increasing the system's Functional Redundancy (Fig. 6b). Each criterion can similarly be scored in this way. From there, each criterion is assigned a relative weight, and finally the weighted scores are integrated into an overall resilience score to comparatively rank different systems.

5. Conclusions and policy implications

Policy aimed at building a resilient posture requires consideration of physical systems, information, and individual and collective human behaviors. Resilience provides a framework through which to manage the complex interactions of energy among social, economic, and security considerations. Existing approaches that invoke distinct processes for cost minimization, critical infrastructure protection, and sustainability often produce internally competitive views of the system. These narrow and disjointed processes tend to entrench previously established values; thus failing to address outcomes of importance and stifling the ability of a community to learn and adapt.

The resilience matrix can inform leaders and practitioners among Government, nongovernment, and industry entities to improve in a coordinated way their energy-related systems, information processes, plans, procedures, and policies. A deliberate two-dimensional metric structure emphasizes that the focus is not on one phase of an event, or on such organizational-level solutions as physical system design, emergency plans, and policies; but to integrate all aspects, including individual (cognitive) capabilities and posture. Resilience is relevant at all levels; and decentralized capabilities often facilitate flexible and timely response and adaptation. Similarly, the interactive nature of energy within the respective domains requires that we consider higher-order impacts of proposed changes. Implementation necessarily includes steps to organize and socialize understanding of community relationships through stakeholder interaction and deliberate analysis. Such activity not only exposes important insights, but also builds relationships and communication channels, themselves essential to resilience.

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