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A case for a new approach in theorizing and operationalisation of resilience for electrical systems in developing countries

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Session 3: Energy Interventions and the SDGs

Chaired by Dr. Rupert Gammon, IESD

A Case for a Synthesized Framework for Developing Resilience Indicators and Metrics in Electrical Systems in Developing Countries

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Abstract

In most developing countries, the electricity sector policies are chiefly hatched to achieve universal access to electricity. Unfortunately, several implemented projects are characterised with unreliable supply, high cost of energy and multiple vulnerabilities to natural and human threats. Resilience has been mooted as a concept that correspondingly addresses these challenges while fostering sustainable development reforms. Accordingly, several frameworks have been developed but they are atomistic in their classifications of indicators and fail to demonstrate how local actions promote globally defined sustainable development targets. In this study, the terms used in resilience discourses are chronologically explored drawing from them valued capabilities and the critical considerations taken in constructing frameworks. A synthesized framework has been proposed to primarily facilitate the identification and classification of indicators and their attendant metrics. We argue for a case of deploying the framework in a developing country setting, such as Uganda, to facilitate sustainable development.

Keywords: Resilience indicators, Electricity system resilience, Energy resilience

1.0 Introduction

1.1 Background

About 840 million people around the world have no access to electricity of which 68% are in Sub-Saharan Africa where electrification rate stands at 43% compared to the global average of 89% (IEA *et al.*, 2019). The dismal electricity access and utilization is most evident in developing countries, such as Uganda, where household electrification is at a 22.4% and a low per capita consumption of 100 kWh annually (MEMD, 2018). The need to expedite electricity access has been the main driver of several strategies but unfortunately, the electrification rate still remains low (MEMD, 2018). Moreover, electricity consumption has not substantively transcended beyond basic usage from lighting and small appliances, say to, cooking and productive use (UOMA, 2019).

In addition, in conventional electricity systems very little attention is drawn to high-impact threats. Consequently, over the last four years, Uganda has experienced a number of nationwide power system outages attributed to internal technical faults and failures (URN, 2016; UETCL, 2017, 2018), lightning (URN, 2017), vandalism (ERA, 2018), faults on regional interconnections (Tusingwire, 2018; Biryabarema and Obulutsa, 2020), and a floating Island (Kazibwe, 2020).

The electricity system being by nature an enabler for economic productivity and wellbeing, it is vital that it maintains an acceptable level of service regardless of the incessantly changing conditions or threats. To this effect, the resilience paradigm offers the latitude for theorizing and operationalizing strategies and actions that focusses on broader objectives beyond just increasing electricity access and reliability.

Unfortunately, the existing resilience frameworks, have been found to be atomistic with disjointed constituent elements and no clear discernable interconnections. For example, in Roege et al., (2014), they linked a metric signifying a given resilience capacity (necessary responses) to domains (states of indicators) but not to any particular goal neither the institutional scale at which the metric is applicable. Other frameworks are narrow in the extent to which they classify system indicators. They selectively categorize indicators into assets (ARUP and TRF, 2016), performance (Roostaie, Nawari and Kibert, 2019), risks (Preston *et al.*, 2016) and consequences (Watson *et al.*, 2014), rather than juxtaposing all four elements for better examination of causalities. In addition, most of these frameworks evaluate resilience on a single level of organization and are unable to compare resilience in other institutional, spatial or temporal contexts.

Guided by the need to fast-track sustainable development, this study proposes a synthesized framework for measuring, monitoring and enhancing resilience in electricity systems. The paper presents the methods employed, principal concerns that guide the development of frameworks, proposed new framework and argues for its deployment.

1.2 Method

The terms used in resilience discourses reveal the most valued functions of resilience and informs the structure of the frameworks (Manyena, Machingura and O'Keefe, 2019). In this regard, the paper presents the terms used in resilience definitions, its drivers, and the critical elements that constitute some of the most widely used frameworks. It interrogates the structure and weaknesses of some existing frameworks, and finally proposes a synthesized framework that can be deployed in developing countries to promote sustainable development.

2.0 Formulating Resilience Frameworks

2.1 The Meaning of Resilience

To develop a framework, it is important to ascertain the meaning of resilience and the terms used in resilience discourses. To this effect, Manyena et al., (2019) chronicled the definitions of resilience (see Figure 1) and observed that in the 1970s resilience was percieved as persistence and absorption of perturbations. In comparison, in the 1980s, the concept was theorised as the ability to cope, learn, bounce back, and 'return to equilibrium' ensuring that systems emerge from shocks and stresses unchanged. In 1990s, other capabilities such as prevention, anticipation, reorganisation and adaptation were introduced within the concept's description culminating into transition, flexibility, *'bouncing-forward'* and transformability in the 2000s. Currently, resilience outside its classical meaning, is considered a neoliberal instrument for de-politicising disasters, producing governable citizens and acting as a breeding ground for more progress politics (Damgaard, 2018).

The definitions of resilience can be classified in two broad categories; structural (what is it?) and operational (what does it do?). The structural definitions describes the concept as "amount" (Holling and Walker, 2003), "measure" (Holling, 1973), "magnitude" (Walker *et al.*, 2002), and "resistance" (Folke *et al.*, 2004). On the other hand, the functional definitions dominate literature (Adger, 2000; Folke, 2016) in which resilience is referred to as an "ability" or "capacity". In both categories, resilience is objectively described as measure of a disturbance (Folke *et al.*, 2004) or subjectively as a measure of response (Carpenter *et al.*, 2001).

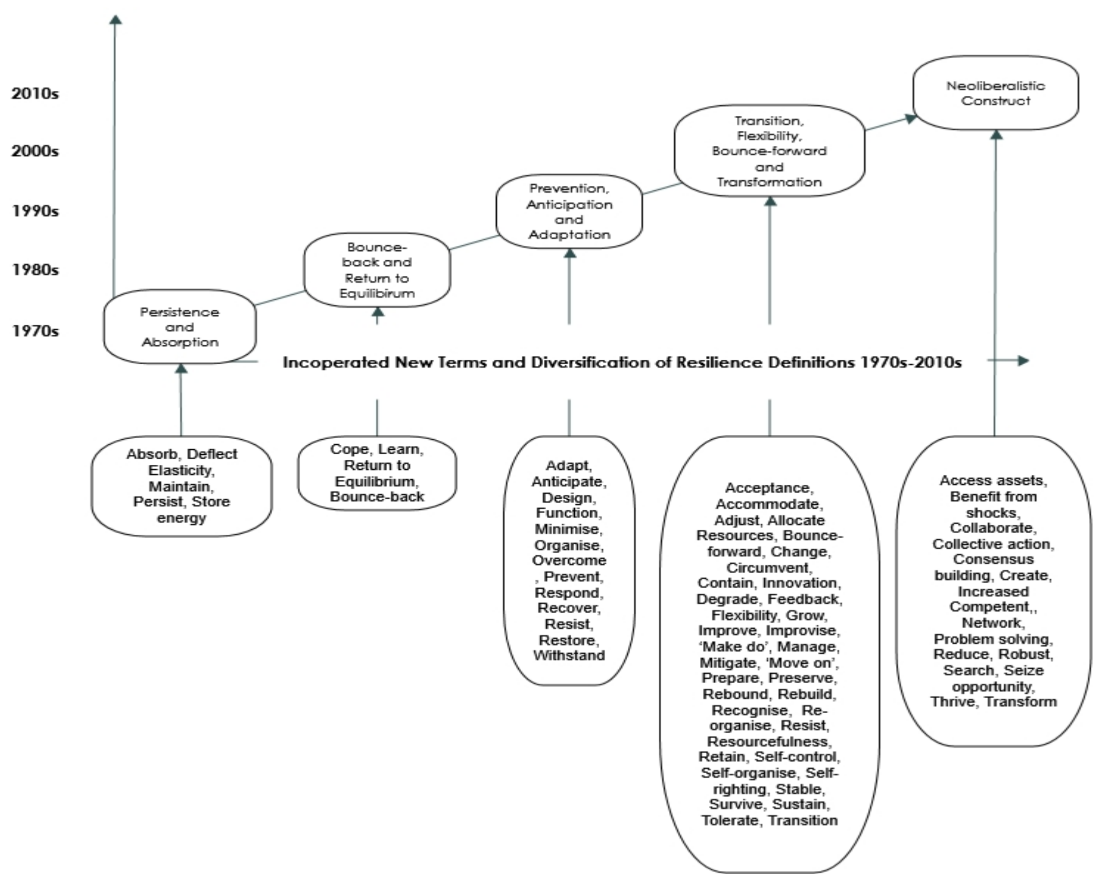

Figure 1: Chronological Demonstration of New Terms Incorporated in Resilience Definitions

(source of information: Manyena et al., (2019), Xu et al., (2015), Roostaie et al., (2019), Damgaard (2018) and Brand and Jax (2007))

This study adopts a definition adapted from Walker et al., (2002) in which resilience is regarded as the amount of change a system can undergo whilst retaining the same control on function and structure, and the degree to which it is able to self-organize, adapt, and transform.

2.2 Key Resilience Drivers

The framework features are, in part, guided by the nature of the anticipated change or disruption. In this study, a text query was conducted on cited literature and the most prominent drivers for resilience were identified as climate change, disruptions and sustainable development (See Figure 2). Most threats in literature are masked as "disruptions" or "incidents" but generally, all drivers can be broadly categorized within natural causes, infrastructure fragilities and human threats. An assessment of these drivers reveals that resilience is regarded as an organizing concept that addresses vulnerabilities within existing systems whilst advancing sustainable development.

Figure 2: Most Common Resilience Drivers in Energy Systems

2.3 Essential Considerations for Frameworks

2.3.1 Multi-stakeholder Engagement

Infrastructure networks tend to have overlapped and interconnected systems with diverse sets of stakeholders at multiple levels of organization. It is critical that frameworks identify and addresses areas of duplications, overlaps and responsibilities amongst various actors. This is intended to bridge gaps in policies and subsequently streamline the administration, coordination, funding, information sharing and accountability during the operationalization of the resilience reforms (ARUP *et al.*, 2019).

Consider the electricity industry, which is affected, interconnected or interdependent on telecommunications, transport, water, oil and gas infrastructure. It necessitates a framework to consider all contingent factors common across the various sectors. For example, the electrical system relies on the telecoms for information and interoperability, but the latter depends on the electrical system for energy supply. A vulnerability in one sector, is implicitly a risk in another.

Therefore, frameworks find their relevance in the formulation of better planning strategies of financing, investment, designing sustainable infrastructure, modification of operations in respect with both existing and unknown threats, and the demands for responding to climate change mitigation and adaptation (Watson *et al.*, 2014). They are developed to primarily diagnose vulnerabilities within key entities, evaluate capabilities for the necessary response, and measure and enhance resilience across institutional, spatial and temporal scales (ARUP *et al.*, 2019).

During high-level planning, stakeholders define broad goals which capture valued development postures pertaining to economic growth, social welfare, environmental conservation and institutional arrangements (Buikstra *et al.*, 2010). It is from these dimensions that much more compact goals and indicators are derived. This pyramidical nature is demonstrated by TRF et al., (2019) whose framework is predicated on 53 indicators from 12 goals derived from 4 dimensions.

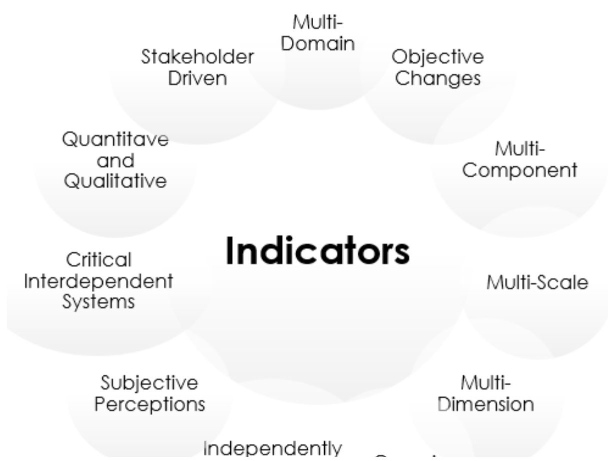

Figure 3: Factors of Indicators

2.3.2 Diversification of Indicators

A more effective approach to measuring and monitoring resilience, should be based on "ecological" rather than "engineering" indicators (Holling, 1996). For "engineering" indicators are primarily concerned with maintaining pre-event system functionality whereas the "ecological" ones emphasize system's survivability, adaptability and interconnectedness (Roege *et al.*, 2014). The more diverse the indicators of the system, the more likely it is to build an effective framework. The caveat , though, is to make tradeoffs with system's output efficiency if sustainability is to be maximized (Lietaer *et al.*, 2010).

Figure 4 shows factors identified in literature (Béné, 2013; Roege et al., 2014; Watson et al., 2014; ARUP and TRF, 2016) use to determine resilience indicators. Indicators should be able to monitor both objective changes (e.g. demand not supplied) and subjective perceptions (e.g. residential outage cost) (Béné, 2013). They should be scalable institutionally, in time and geographical boundaries as well as reflect cross-cutting issues from critical interdependent systems given the contagion effect of most disruptions. Also, they should be generic to the extent of facilitating comparability within the same entity or with others (Béné, 2013).

An effective assessment of resilience and the subsequent strategies of enhancing it, would require a thorough analysis of all systems at subcomponent levels. For an electrical system, these subcomponents are the generation, transmission, distribution and consumer end-use. Relatedly, similar to states of matter, system attributes can be also defined by their domains. A domain describes the *"whatness"* of a particular attribute specifying its substantive essence. Three essences have been identified, namely; the infrastructure (or physical), information and human domains (Linkov, Eisenberg, Bates, *et al.*, 2013).

Multi-scale frameworks are reckoned to have the advantage of presenting indicators relevant for each level thereby aiding analysis of scale-specific complexities (Damgaard, 2018). Béné's (2013) framework was developed to measure and monitor resilience an individual, household, community and the (eco)system level. In contrast, a single scale framework is bound to mask, mix or miss altogether the unique indicators that delineates one organizational level's resilience from another.

Furthermore, qualitative indicators are intended to assess the adequacy of the instituted mechanisms and processes in achieving resilience goals whereas the quantitative metrics are used as proxies for past and current performance (ARUP and TRF, 2016). For example, the existence of redundant generators in a plant alludes to a level of readiness in absorbing sudden peak demand whereas their actual operations can be quantitatively evaluated in terms of capacity offered and energy supplied.

2.3.3 Measuring Resilience

A number of frameworks (Roege *et al.*, 2014; ARUP and TRF, 2016; Preston *et al.*, 2016) are of 2-dimensional matrix type built by evaluating entities' characteristics (attributes/assets, performance, risk and consequences) identified at the cross sections of resilience qualities or capacities and defined goals. In this case, an indicator within the matrix references the vulnerability, exposure, severity or capacity for response. The notion behind each indicator is whether the system's freedoms are enabled to select the best envisaged response when operating under a disruptive or changing environment. In other words, a given cell within the matrix ought to respond to the inquiry of how any changes in measures implemented within a certain component affects the resilience objectives (Roege *et al.*, 2014).

Qualities are thought to be the most fundamental features for any resilient system, and they are essential in underpinning and enabling resilience capacities. These are identified as inclusiveness, integration, reflectiveness, resourcefulness, robustness, redundancy, and flexibility among others (ARUP *et al.*, 2019). On the other hand, capacities are designated as *"stages of change"* (Roege *et al.*, 2014, p. 252) depicting the progressive nature of interventions needed to counter change moving from the simple and routine to the complex and dramatic. Several researchers (Linkov, Eisenberg, Plourde, *et al.*, 2013; Manyena *et al.*, 2019), have opted for prevention and anticipation, absorption, adaptation, recovery and transformation as the core capacities for resilience (see Figure 4).

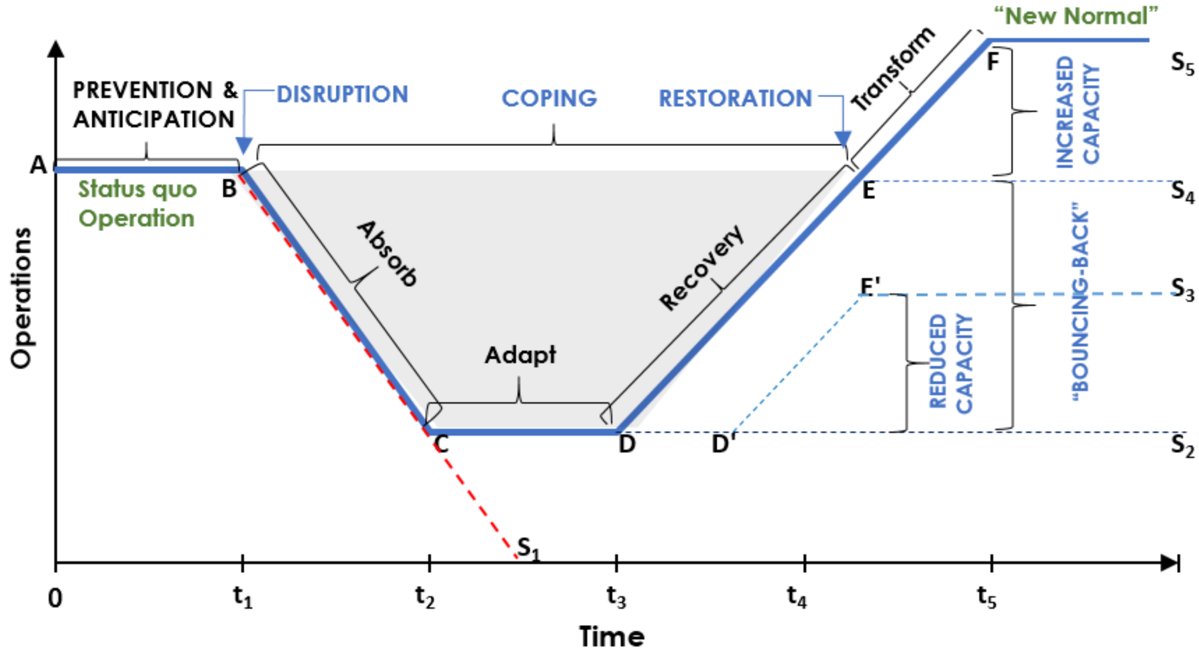

Figure 4: Indicative Scenarios of the Resilience Process through a Disruption

Adapted from (Lin and Bie, 2016)

The resilience process is shown Figure 4; **A-B** represents the normal operation of a system before a disruption; Point **B** Signifies a point where a disruption starts to impinge on the operation of a system; **B-S$_1$** Represents a system which is overwhelmed by the disruption to a complete halt; **B-C-D-S$_2$** shows a system which is sustained through a disruption but does not possess qualities to put it back on a restorative trajectory; **B-C-D'-E'-S$_4$** is indicative of the system which marginally copes, embarks on restoration but never achieves its pre-event status; **B-C-D-E-S$_4$** indicates a system which is restored to pre-event status but it still characterized by the same pre-event vulnerabilities; **B-C-D-E-F-S$_5$** the system ultimately transforms within the process leading to enhanced functionality and resilience.

The indicators are rated against metrics which can be inductives or exogeneous, quantitave or qualitative, and raw or normalised values or in form of probability distributions. At the basic level, metrics are used to characterise threats by quantifying the probability of their occurrence, extent of damage, uncertainities in computation, geographic context, persistence, latency, reversibility and social impacts (Preston *et al.*, 2016). They assess the level of disruption on development goals, evaluate recovery time and are used to simulate system's response to a single or a combination of threats (PPD, 2013). They facilitate evaluation of baseline resilience, comparision of competing investment interests and monitoring of resilience trajectories in respect to defined goals (Watson *et al.*, 2014). Ultimately, they underpin subsequent course of interventions in modifying operations, planning future investments, developing new policies and improving resilience (Lin and Bie, 2016).

2.3.4 Deployment of Frameworks

Resilience reforms are executed within a resilience analysis process (RAP) (Watson *et al.*, 2014). During RAP (see Figure 5), a resilient champion is identified and together with key stakeholders, they develop a common understanding of the resilience definition, goals, scope, interactions within system's components and underlying contextual basis of the resilience agenda. It is necessary that the stakeholders agree on a conceptual model to be used to choose indicators, how they will be used within the framework and the metrics for evaluating them. The consequences of threats, often regarding the economy and social welfare, should be identified and the units for quantifying them should be determined.

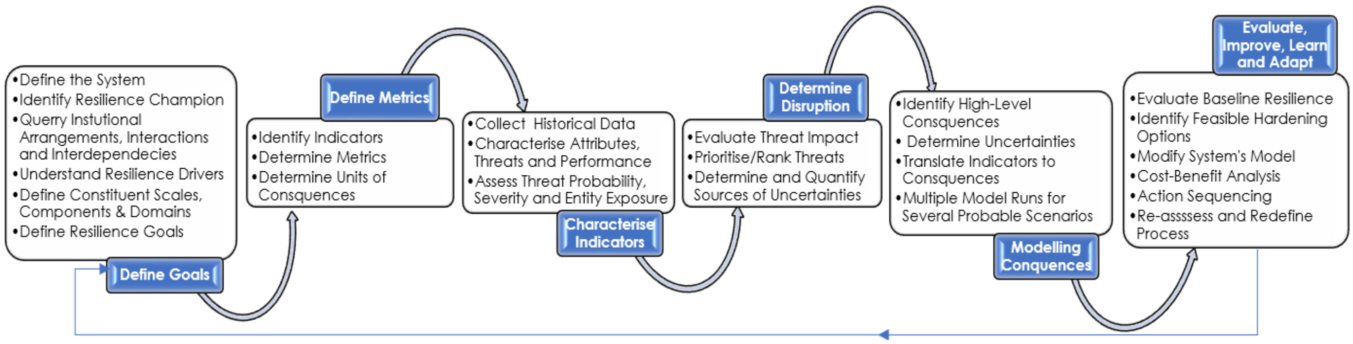

Figure 5: Resilience Analysis Process as an Instrument for Resilience Management

Source: (Walker *et al.*, 2002; Watson *et al.*, 2014; ARUP *et al.*, 2019)

The level of disruption should be explicitly determined since it is a key input into the transformational models which are critical in translating indicators into consequences on the wider consideration of economic performance and social wellbeing (Watson *et al.*, 2014). Consequently, a baseline assessment of resilience can be undertaken from which hardening measures, procedural and policy changes can be proposed to respond to observed vulnerabilities (Lin and Bie, 2016).

The process should be regularly reevaluated in order to incorporate new indicators, validate and improve the framework methodology, and ensure that resilience assessment fairly represents the emergence of new technologies, collected data and changing context.

3.0 A New Synthesized Proposed Framework

3.1 Framework Structure

One of the major observed limitations amongst recently developed frameworks (see a sample in **Table 1**) is that the indicators are enclosed within narrow and vague classifications which fail to cohere with the normative delineation principles of resilience indicators as represented in section 0 above. For example, in Roege et al., (2014, p. 253) one of the indicators necessary for recovery is *"fuel flexibility"* which is identified within the *"Physical"* domain. Within the framework, it is not possible to associate it with its relevant component, responsible institutional scale neither how it links with any goal or quality. This generic and constrictive bundling approach leads to slowed and ineffective deduction and characterization of threats. Therefore, it does necessitate a new framework that captures all significant elements of resilience indicators, and their evaluation in respect with the most valued qualities, capacities and goals.

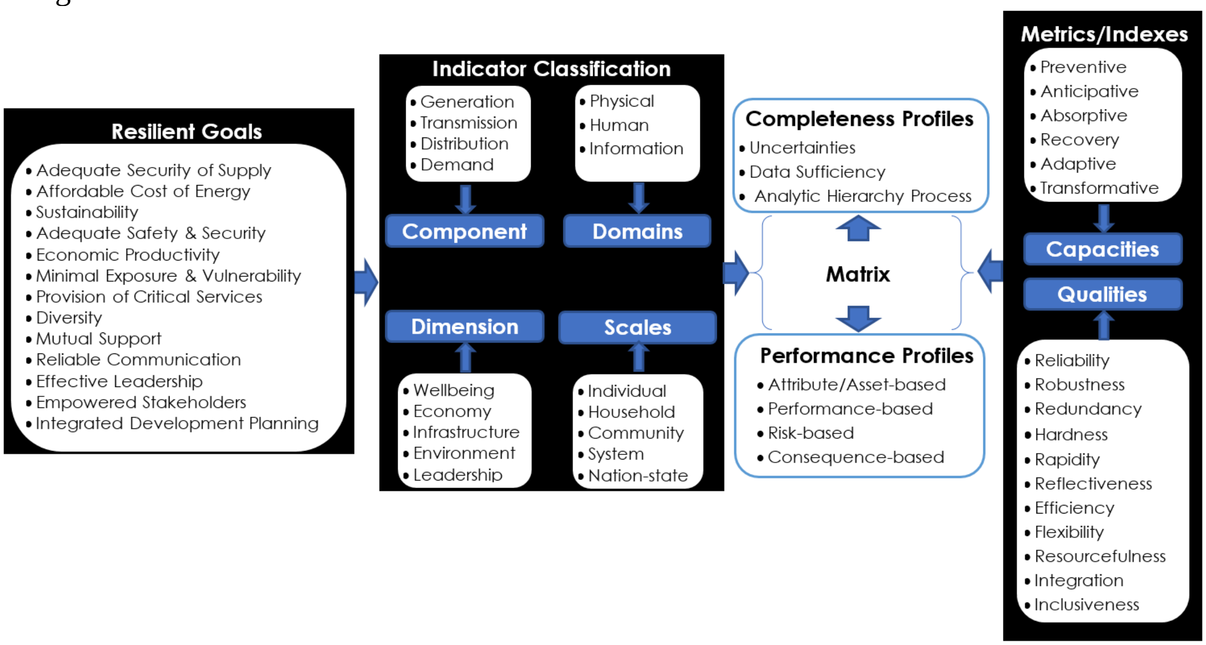

Figure 6: A Framework for Classifying Resilience Indicators in Electricity Systems

The framework (Figure 6) was developed with features identified from several researchers (Béné, 2013; Roege et al., 2014; Watson et al., 2014; ARUP and TRF, 2016; Lin and Bie, 2016; Manyena et al., 2019). The framework works within the RAP structure in which the project champion with key stakeholders' rallies behind common goals which represent their envisaged resilient state. The most preferred goals are those that prioritizes a future with secured and affordable supply whilst fostering ecosystem sustainability (Watson *et al.*, 2014).

Table 1: A Comparison of Frameworks

Framework	Context	Types of Indicators	Dimensions	Scales	Components	Domains	Qualities	Capacities	Evaluation Approach	Framework Limitation
Béné, 2013	Food security	Assets and consequences	Vulnerability reduction, promoting human development	Individual, household, community, (eco)system and national	Not available[1]	Not available	Not available	Absorptive, adaptive, transformative	'Cost' of resilience	The employed resilience index does not normalize the variance of the "worth" of an entity and its prevailing risk when comparing resilience of several entities.
Roege et al., 2014	Energy	Assets and performance	Economic growth, social order, national security	Not available	Not available	Physical, information and human	Redundancy, flexibility, learning, and adaptation	Planning/ preparative, absorptive, recovery and adaptive	Multi-attribute utility approach	The system, its attributes and meta-systems are characterised exclusively by domains.
Watson et al., 2014	Energy	Risks and consequences	National safety, prosperity and wellbeing	System and national	Electricity, oil and gas	Human and computational analysis	Robustness, reliability, affordability, redundancy, resourcefulness, reorganisation, flexibility, inclusiveness	Preparative, withstand, adaptive, and recovery	Probability density functions of consequences	The translation of threats to consequences in the human and information domains is not articulated
Preston et al., 2016	Electricity	Risk	Human well-being, economic growth, national security	National	Generation, transmission, substations, distribution and storage	Not available	Energy delivery, efficiency, reliability, hardness, robustness, and sustainability	Robustness, resourcefulness, recovery, adaptability	Multi-hazard perspective	Adaptation is the end goal. This poses a risk of reinforcing the same vulnerabilities or entrenching existing hegemonic systems and processes. There is no linkage between needed response and capacities
Lin and Bie, 2016	Integrated energy systems	Assets, performance and risk	Improved efficiency, reduced pollution and energy security	Not available	Electricity, Natural gas, heat & cooling	Not available	Hardware hardening, reliability	Anticipative, preparative resistive, absorptive, responsive,	Combined qualitative and quantitative evaluation	No link between the resilience goals, indicators and capacities

[1] "Not available" signifies that the study did not consider that category

Framework	Context	Types of Indicators	Dimensions	Scales	Components	Domains	Qualities	Capacities	Evaluation Approach	Framework Limitation
								adaptive and recovery		
Manyena, Machingura and O'Keefe, 2019	Disaster resilience	Risk	Environment sustainability, economic growth, infrastructure development, social development, and disaster reduction	Local, national and global	Not available	Not available	Planning, organising, learning, networking, improvising, communication, innovative and resourcefulness	Preventive, anticipative, absorptive, adaptive and transformative	Combined qualitative and quantitative indexes	The indicators are too generic to be used to comprehensively assess resilience for electricity systems.
TRF et al., 2019	Urban water systems	Assets and performance	Health and well-being, economy and society, infrastructure and environment, leadership and strategy	City	Infrastructure	Not available	Integration, inclusiveness, reflectiveness, robustness, resourcefulness, redundancy, flexibility and sustainability	Preventive, anticipative, absorptive, adaptive and transformative	Multi-stakeholder assessment and expert opinion	The model assumes that all indicators and goals, contribute to resilience equally. Goals are not linked to desired capacities.

The goals should call to attention reduction of vulnerabilities, provision of energy to critical services and sustained productivity regardless of the intensity or duration of a disruption. Such goals cannot be extricated from constructive human behavior within governance structures which is a product of effective leadership, management and integration, and empowerment of stakeholders.

From goals, indicators naturally flow, and these can be organized within the various components, dimensions, scales and domains. The scales chosen in this case, are institutional, but it is similarly possible to classify the indicators in terms of temporal and spatial scales. By this format, one can describe the goal that a particular attribute fosters, wherein within the system, the associated response and the party responsible for effecting the needed changes.

Metrics can then be presented as measured discrete values or profiles. The profiles are derived from serialized metrics scores of asset quantities, performance, risks and consequences. Meaningful associations and causalities, say between an asset and a consequence, can then be traced.

In addition, completeness profiles represent the uncertainties in the modelling process and the extent of the reliability of data (ARUP and TRF, 2016). The analytic hierarchy process ensures that the subjectivity employed in the evaluation process is consistently applied across the framework

3.1.1 Implementation of the Framework in a Developing Country Setting

Developing countries like Uganda, are faced with a double-edged problem; on one hand to meet the longstanding existing challenges (i.e., supply of electricity to the 78% of unelectrified population (MEMD, 2018)) and on another for such interventions to adhere to international development agendas (IDAs) such as the SDG agenda. The prioritization of the IDA goals can potentially spread thin the resource envelope and in many cases, there are dismal gains in the short term. Unless the goals are aligned, most IDAs targets are flouted. Therefore, it requires a framework used in planning development to harmonize IDAs objectives and local commitments. Secondly, such frameworks would need to harmonize the seemingly incongruous concepts such as resilience and sustainability.

There are varying views within the research community regarding the relationship between sustainability and resilience. Holling and Walker (2003) considers them as synonyms, Roege et al., (2014) as competing concepts, Carpenter et al., (2001) regards resilience as a component of sustainability whereas Lew et al., (2015) views them as separate but complementary concepts. But Xu et al., (2015) noted that a desirable sustainable resilient system is able to maintain stocks of natural capital above existing threshold levels for socio-economic wellbeing without losing structure or control amidst disruptions. It has also been shown that at maximum sustainability resilience is two times more important than efficiency (Lietaer *et al.*, 2010). This reinforces the inextricable relationship of the two concepts as well as their aligned focus on survivability and persistence of the system.

The proposed framework permits its users to define goals for their envisaged future-proofed postures, granting more weight to certain indicators representative of the underlying idiosyncrasies and assessing how local actions feeds into sustainable development goals. It has been demonstrated by Nerini et al., (2017) that 85% of the SDG targets are affected in some form by the energy goal (SDG 7). Accordingly, sustainability metrics can be developed to assess the adherence of local actions within the electricity sector to SDG targets.

4.0 Conclusion

The proposed framework derives its uniqueness from a systematic characterization of resilience indicators and metrics and therefore it enables critical interrogation of causations. It is possible to link any attribute to a goal, the responses it fosters, and in between, cluster it into subdivisions that demonstrate what is it, where is it located and who is responsible for it. The set-out taxonomy of indicators and metrics is meant to support holistic planning, improved operations, evidence-based policymaking and enhancement of resilience within the electricity industry.

The framework is borne out of a synthesis process where several frameworks in literature have been analyzed. It is tailored to be used in context where entities might be conflicted about supporting local commitments or rather be guided by the often-prescriptive international development agendas. Its users should be able to define their resilience goals, monitor and track them in respect to local interventions and ultimately juxtapose them against the international trajectory.

That said, the framework in its current format is not populated. It spells out the categorizations of indicators and metrics but not their constituent elements and neither their interrelations. Such detail that take into considerations of the different relationships, will be a subject for the next stage in the research. Also, it could necessitate to include or eliminate certain features. Nonetheless, the framework suffices to guide the conceptualize of the most critical elements of resilience within the electricity industry.

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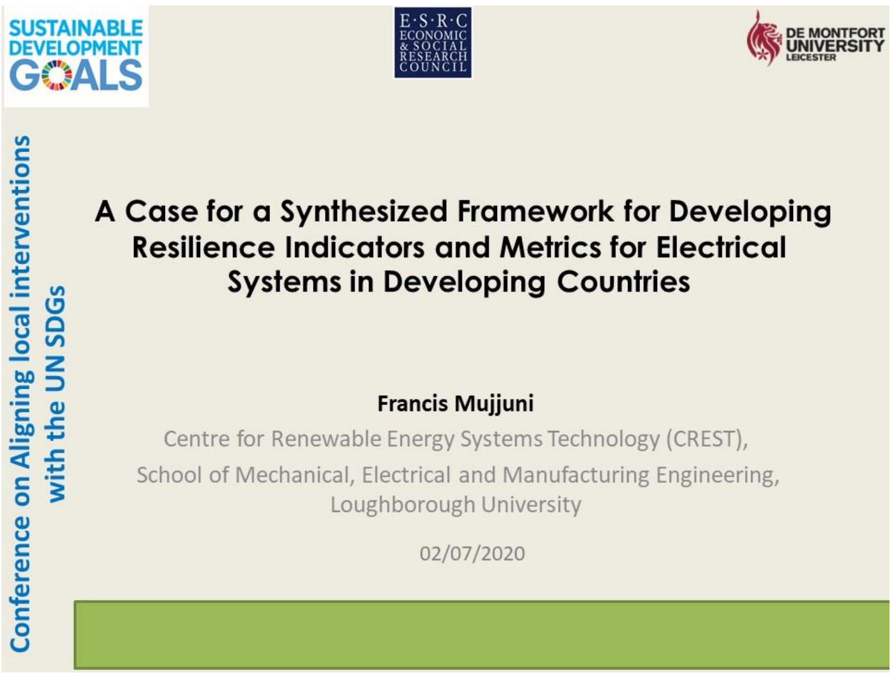
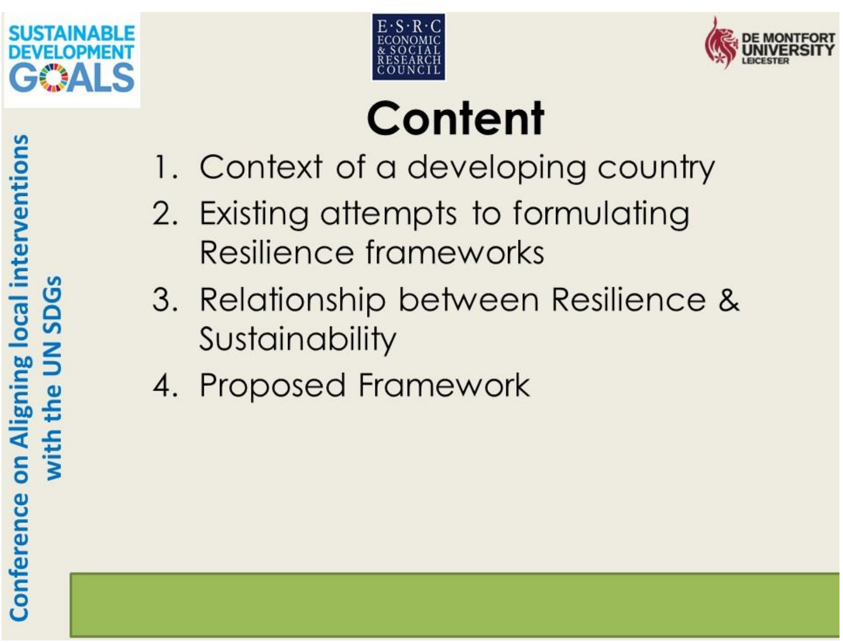
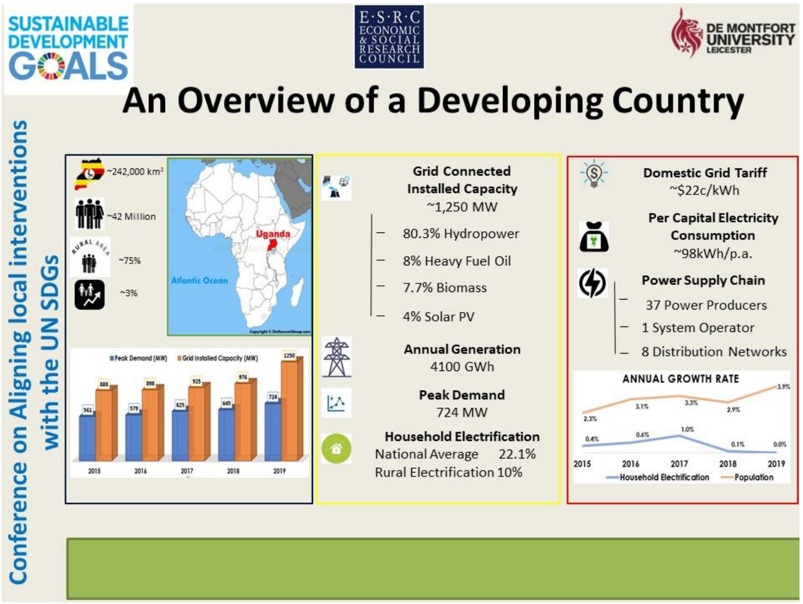
A case for a new approach in theorizing and operationalisation of resilience for electrical systems in developing countries

By Francis Mujjuni, Loughborough University






SUSTAINABLE DEVELOPMENT GOALS
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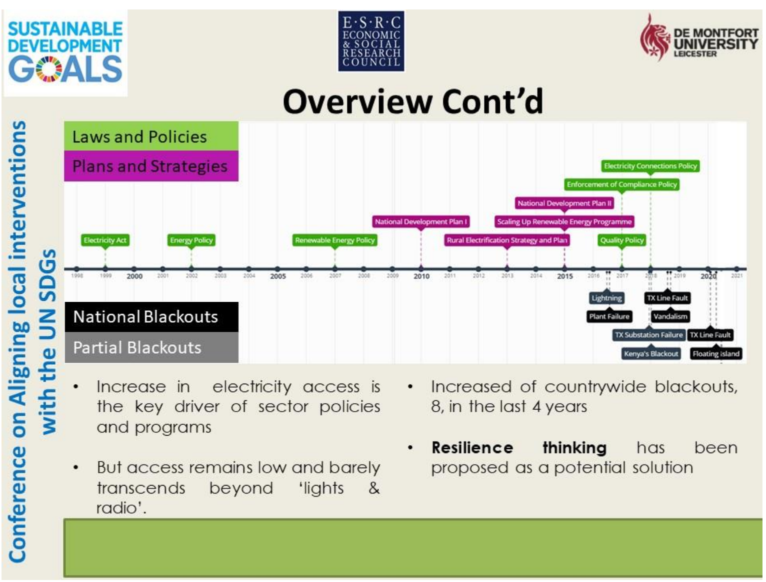
An Overview of a Developing Country
Conference on Aligning local interventions with the UN SDGs
~242,000 km²
~42 Million
~75%
~3%
Uganda
Atlantic Ocean
Grid Connected Installed Capacity ~1,250 MW
80.3% Hydropower
8% Heavy Fuel Oil
7.7% Biomass
4% Solar PV
Annual Generation 4100 GWh
Peak Demand 724 MW
Household Electrification
National Average 22.1%
Rural Electrification 10%
Domestic Grid Tariff ~$22c/kWh
Per Capital Electricity Consumption ~98kWh/p.a.
Power Supply Chain
37 Power Producers
1 System Operator
8 Distribution Networks
ANNUAL GROWTH RATE
2015 2016 2017 2018 2019
Household Electrification
Population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Overview Cont'd
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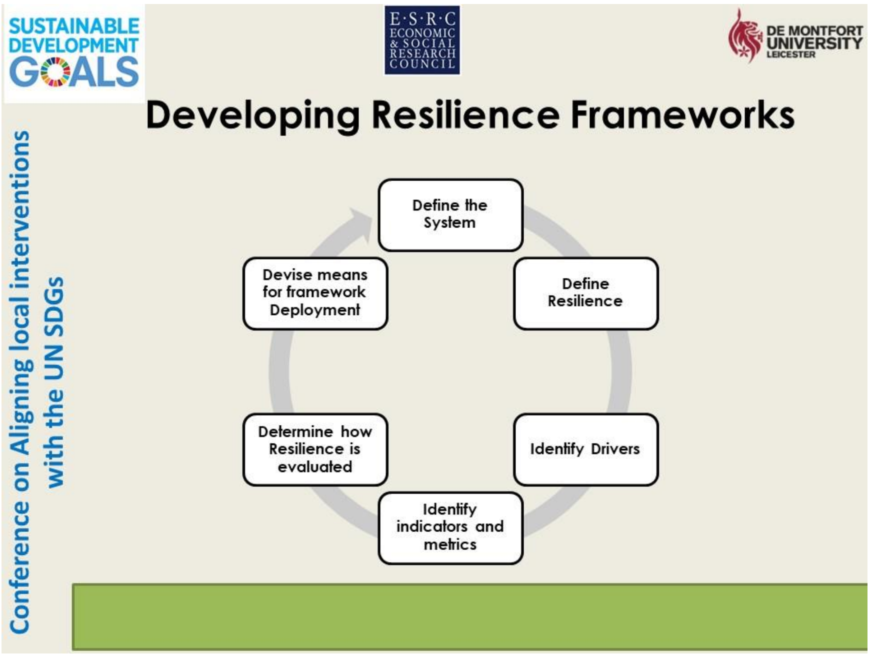
Laws and Policies
Plans and Strategies
Electricity Act
Energy Policy
Renewable Energy Policy
National Development Plan I
Rural Electrification Strategy and Plan
Scaling Up Renewable Energy Programme
National Development Plan II
Quality Policy
Enforcement of Compliance Policy
Electricity Connections Policy
2000 2005 2010 2015 2020
National Blackouts
Partial Blackouts
Lightning
TX Line Fault
Plant Failure
Vandalism
TX Substation Failure
TX Line Fault
Kenya's Blackout
Floating island
• Increase in electricity access is the key driver of sector policies and programs
• But access remains low and barely transcends beyond 'lights & radio'.
• Increased of countrywide blackouts, 8, in the last 4 years
• **Resilience thinking** has been proposed as a potential solution


SUSTAINABLE DEVELOPMENT GOALS
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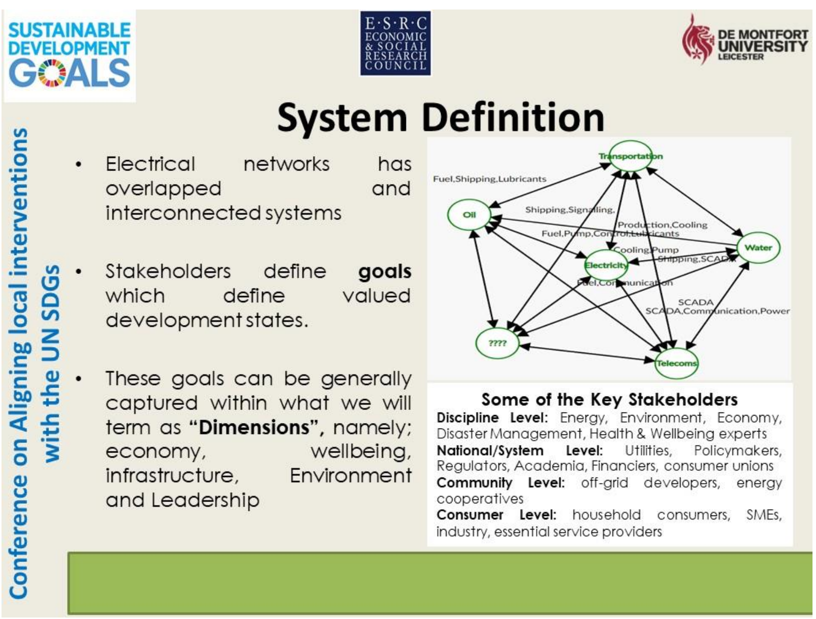
Developing Resilience Frameworks
Define the System
Define Resilience
Identify Drivers
Identify indicators and metrics
Determine how Resilience is evaluated
Devise means for framework Deployment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System Definition
• Electrical networks has overlapped and interconnected systems
• Stakeholders define goals which define valued development states.
• These goals can be generally captured within what we will term as "Dimensions", namely; economy, wellbeing, infrastructure, Environment and Leadership
Transportation
Oil
Water
Electricity
????
Telecoms
Fuel,Shipping,Lubricants
Shipping,Signalling
Production,Cooling
Fuel,Pump,Control,Lubricants
Cooling,Pump
Shipping,SCADA
Fuel,Communication
SCADA
SCADA,Communication,Power
Some of the Key Stakeholders
Discipline Level: Energy, Environment, Economy, Disaster Management, Health & Wellbeing experts
National/System Level: Utilities, Policymakers, Regulators, Academia, Financiers, consumer unions
Community Level: off-grid developers, energy cooperatives
Consumer Level: household consumers, SMEs, industry, essential service providers

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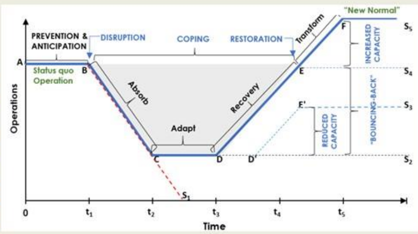
What does Resilience Mean?



- Definitions can be broadly categorized in **structural** (*what is it?*) and **operational** (*what does it do?*).

In general terms, Resilience is objectively described as a **measure of a disturbance** or subjectively as a **measure of response**.

Resilience is regarded as the amount of change a system can undergo whilst retaining the same control on function and structure, and the degree to which it is able to self-organize, adapt, and transform (*adapted from Walker et al., (2002)*)

Figure adapted from Lin and Bie, 2016

Walker, B. et al. (2002) 'Resilience management in social-ecological systems: A working hypothesis for a participatory approach', Ecology and Society, 6(1). doi: 10.5751/es-00356-060114.

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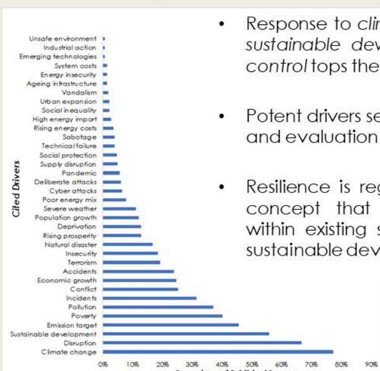
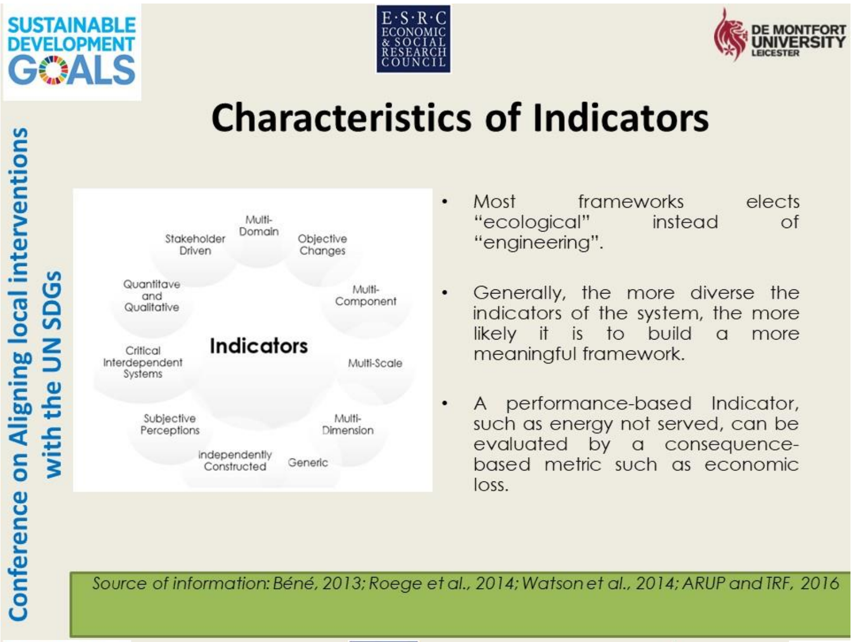
Why Resilience Thinking?



- Response to *climate change*, disruptions, *sustainable development* and *emissions control* tops the list of drivers
- Potent drivers selected from a risk analysis and evaluation exercise
- Resilience is regarded as an organizing concept that addresses vulnerabilities within existing systems whilst advancing sustainable development.

Source of data is from 285 journal papers, collated randomly as part of the chronological study of definitions of resilience, Literature spanning 1919-2020, data extracted from 'word count' conducted within NVIVO


Characteristics of Indicators
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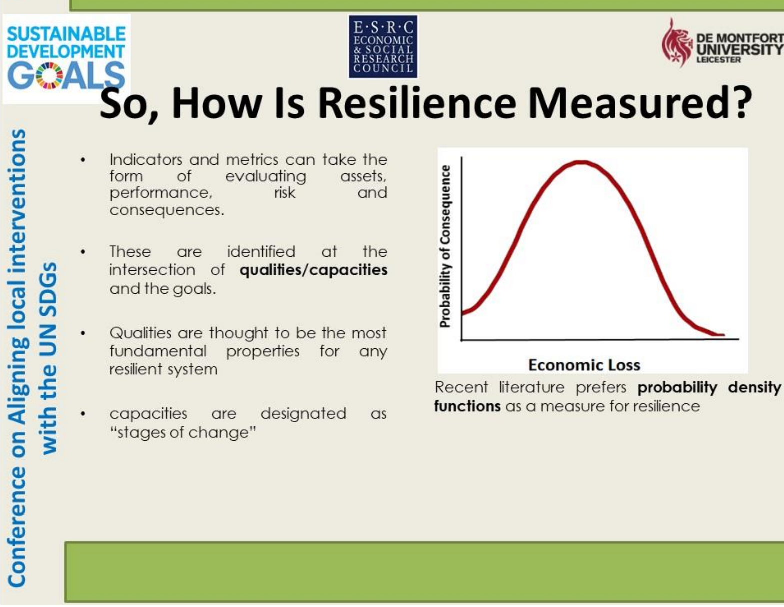
Indicators
Multi-Domain
Stakeholder Driven
Objective Changes
Quantitave and Qualitative
Multi-Component
Critical Interdependent Systems
Multi-Scale
Subjective Perceptions
Multi-Dimension
independently Constructed
Generic
• Most frameworks elects "ecological" instead of "engineering".
• Generally, the more diverse the indicators of the system, the more likely it is to build a more meaningful framework.
• A performance-based Indicator, such as energy not served, can be evaluated by a consequence-based metric such as economic loss.
Source of information: Béné, 2013; Roege et al., 2014; Watson et al., 2014; ARUP and TRF, 2016


So, How Is Resilience Measured?
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• Indicators and metrics can take the form of evaluating assets, performance, risk and consequences.
• These are identified at the intersection of qualities/capacities and the goals.
• Qualities are thought to be the most fundamental properties for any resilient system
• capacities are designated as "stages of change"
Probability of Consequence
Economic Loss
Recent literature prefers probability density functions as a measure for resilience

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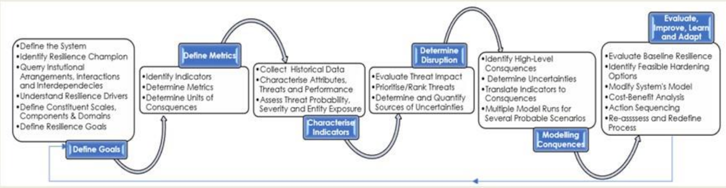
Deployment of Frameworks



- The frameworks are executed within resilience analysis processes.
- The process should yield a baseline assessment from which appropriate action can be taken.

Figure developed with Source of Information: (Walker et al., 2002; Watson et al., 2014; ARUP et al., 2019)

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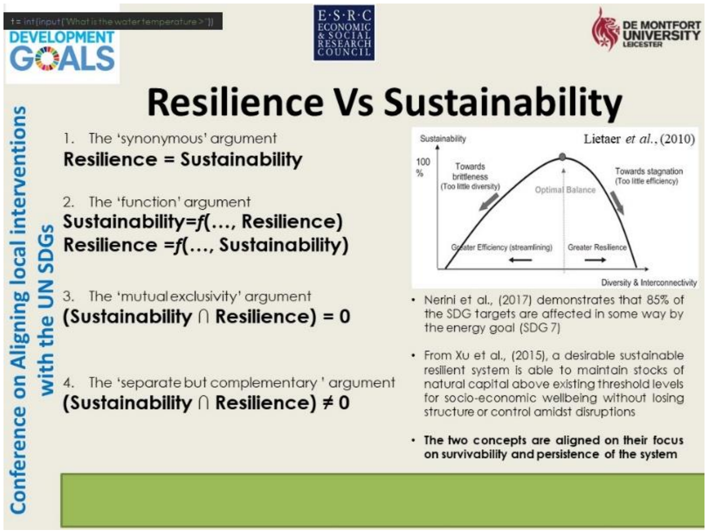
So what are the Limitations with the Existing Frameworks?

Author	Context	Framework Limitation
Béné, 2013	Food security	The 'cost of resilience' is independent of risk and its entirely driven by the outcome
Roege et al., 2014	Energy	The system and its attributes and characterized exclusively by domains.
Manyena et al., 2019	Disaster Mgt.	The indicators are too generic to be used to comprehensively assess resilience for electricity systems.
Watson et al., 2014	Electricity	The transformation models are mainly 'components' centric
Preston et al., 2016	Electricity	Adaptation is the end goal reinforcing pre-event vulnerabilities and no linkage between responses and capacities
TRF et al., 2019	Urban water systems	The model assumes that all indicators and goals, contribute to resilience equally. Goals are not linked to desired capacities.

None of these can comprehensively deal with the ***double-edged problem*** in developing countries; solving the longstanding existing challenges (i.e., increasing of electricity connections) vs adherence to internationally driven development agendas (i.e., SDGs)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Resilience Vs Sustainability
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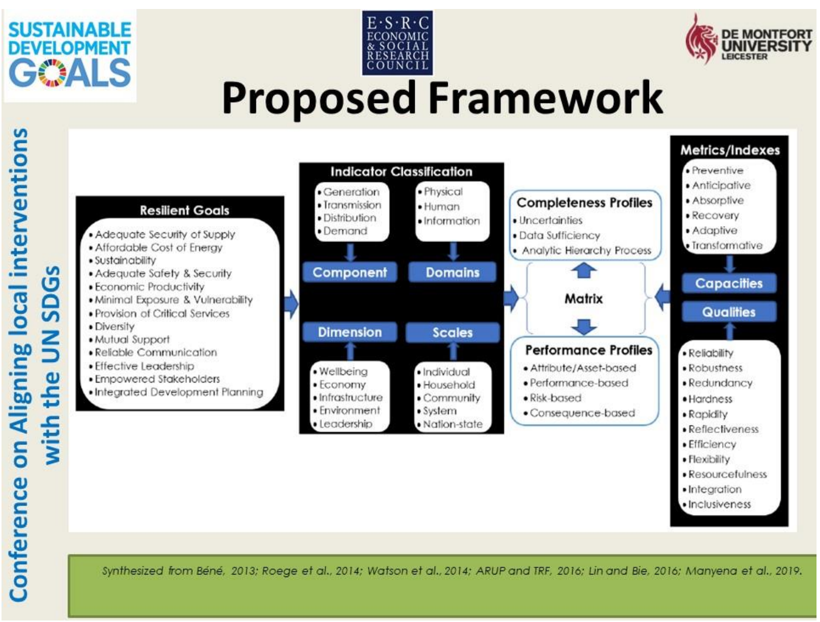
1. The 'synonymous' argument
Resilience = Sustainability
2. The 'function' argument
Sustainability=f(…, Resilience)
Resilience =f(…, Sustainability)
3. The 'mutual exclusivity' argument
(Sustainability ∩ Resilience) = 0
4. The 'separate but complementary ' argument
(Sustainability ∩ Resilience) ≠ 0
Lietaer et al., (2010)
Sustainability
100 %
Towards brittleness (Too little diversity)
Optimal Balance
Towards stagnation (Too little efficiency)
Greater Efficiency (streamlining)
Greater Resilience
Diversity & Interconnectivity
• Nerini et al., (2017) demonstrates that 85% of the SDG targets are affected in some way by the energy goal (SDG 7)
• From Xu et al., (2015), a desirable sustainable resilient system is able to maintain stocks of natural capital above existing threshold levels for socio-economic wellbeing without losing structure or control amidst disruptions
• The two concepts are aligned on their focus on survivability and persistence of the system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Proposed Framework
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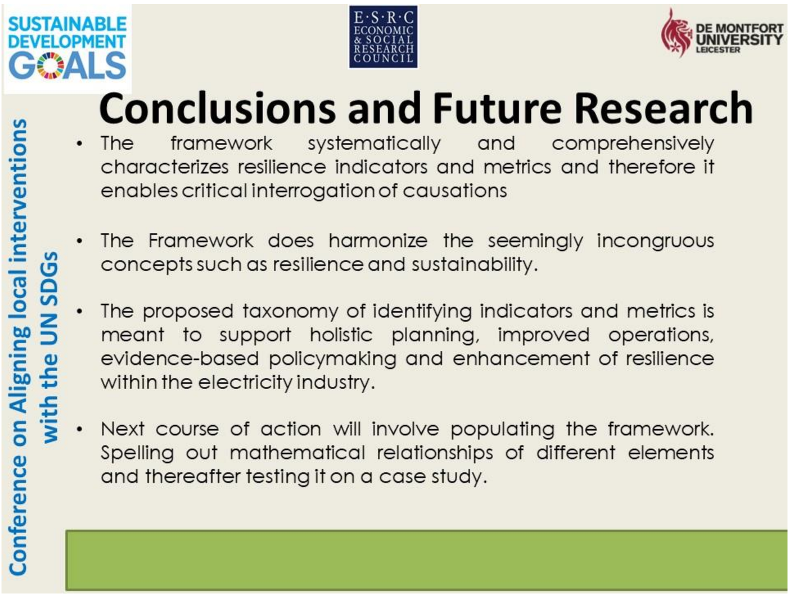
Resilient Goals
• Adequate Security of Supply
• Affordable Cost of Energy
• Sustainability
• Adequate Safety & Security
• Economic Productivity
• Minimal Exposure & Vulnerability
• Provision of Critical Services
• Diversity
• Mutual Support
• Reliable Communication
• Effective Leadership
• Empowered Stakeholders
• Integrated Development Planning
Indicator Classification
• Generation
• Transmission
• Distribution
• Demand
• Physical
• Human
• Information
Component
Domains
Dimension
Scales
• Wellbeing
• Economy
• Infrastructure
• Environment
• Leadership
• Individual
• Household
• Community
• System
• Nation-state
Completeness Profiles
• Uncertainties
• Data Sufficiency
• Analytic Hierarchy Process
Matrix
Performance Profiles
• Attribute/Asset-based
• Performance-based
• Risk-based
• Consequence-based
Metrics/Indexes
• Preventive
• Anticipative
• Absorptive
• Recovery
• Adaptive
• Transformative
Capacities
Qualities
• Reliability
• Robustness
• Redundancy
• Hardness
• Rapidity
• Reflectiveness
• Efficiency
• Flexibility
• Resourcefulness
• Integration
• Inclusiveness
Synthesized from Béné, 2013; Roege et al., 2014; Watson et al., 2014; ARUP and TRF, 2016; Lin and Bie, 2016; Manyena et al., 2019.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Conclusions and Future Research
• The framework systematically and comprehensively characterizes resilience indicators and metrics and therefore it enables critical interrogation of causations
• The Framework does harmonize the seemingly incongruous concepts such as resilience and sustainability.
• The proposed taxonomy of identifying indicators and metrics is meant to support holistic planning, improved operations, evidence-based policymaking and enhancement of resilience within the electricity industry.
• Next course of action will involve populating the framework. Spelling out mathematical relationships of different elements and thereafter testing it on a case study.


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Thank you for Listening
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Suggestions and Questions are welcome
Acknowledgement
Dr. Richard Blanchard, Dr. Tom Betts
CREST
Loughborough University