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Una mirada integral a la transición del sector eléctrico.

Power System Resilience: Experiences and Applications from International Projects

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17th March 2022

Resilience is not a recent concept...

Taylor & Francis

The Philosophical Magazine

Series 1

ISSN: 1941-5796 (Print) 1941-580x (Online) Journal homepage: https://www.tandfonline.com/loi/tphm12

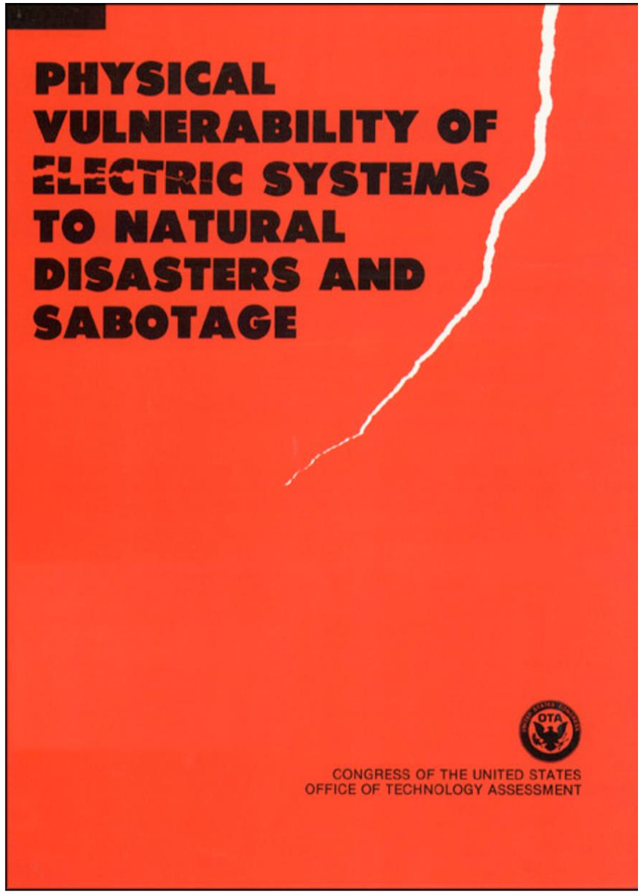
XXXVII. *On the transverse strength and resilience of timber*

Mr. Thomas Tredgold

To cite this article: Mr. Thomas Tredgold (1818) XXXVII. *On the transverse strength and resilience of timber* , The Philosophical Magazine, 51:239, 214-216, DOI: 10.1080/14786441808637536

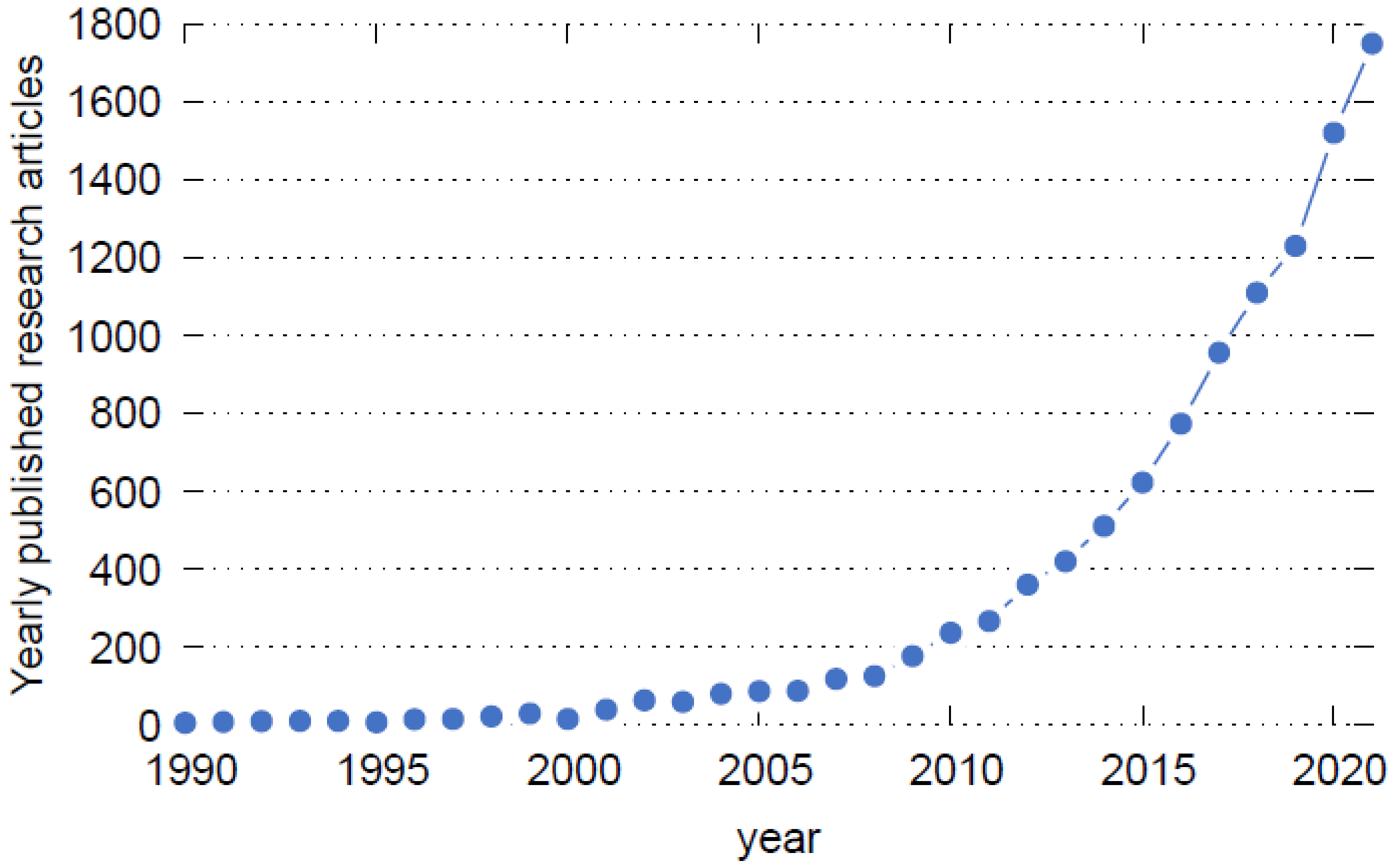
To link to this article: https://doi.org/10.1080/14786441808637536

First reference to resilience in 1818!!



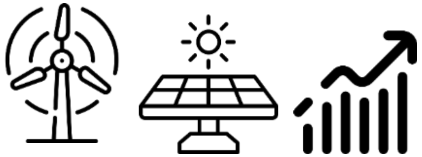
June 1990

Google Scholar Search – "Power Network/System Resilience"

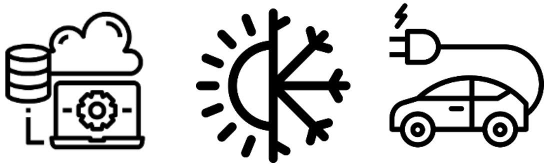


Increasing Shocks and Stresses

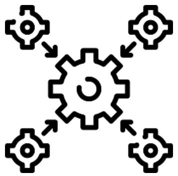
Rapid changes and stresses in energy landscape



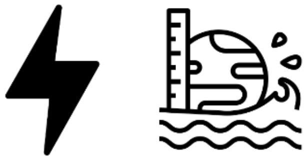
Increasing Reliance on Reliable and Resilient Electricity



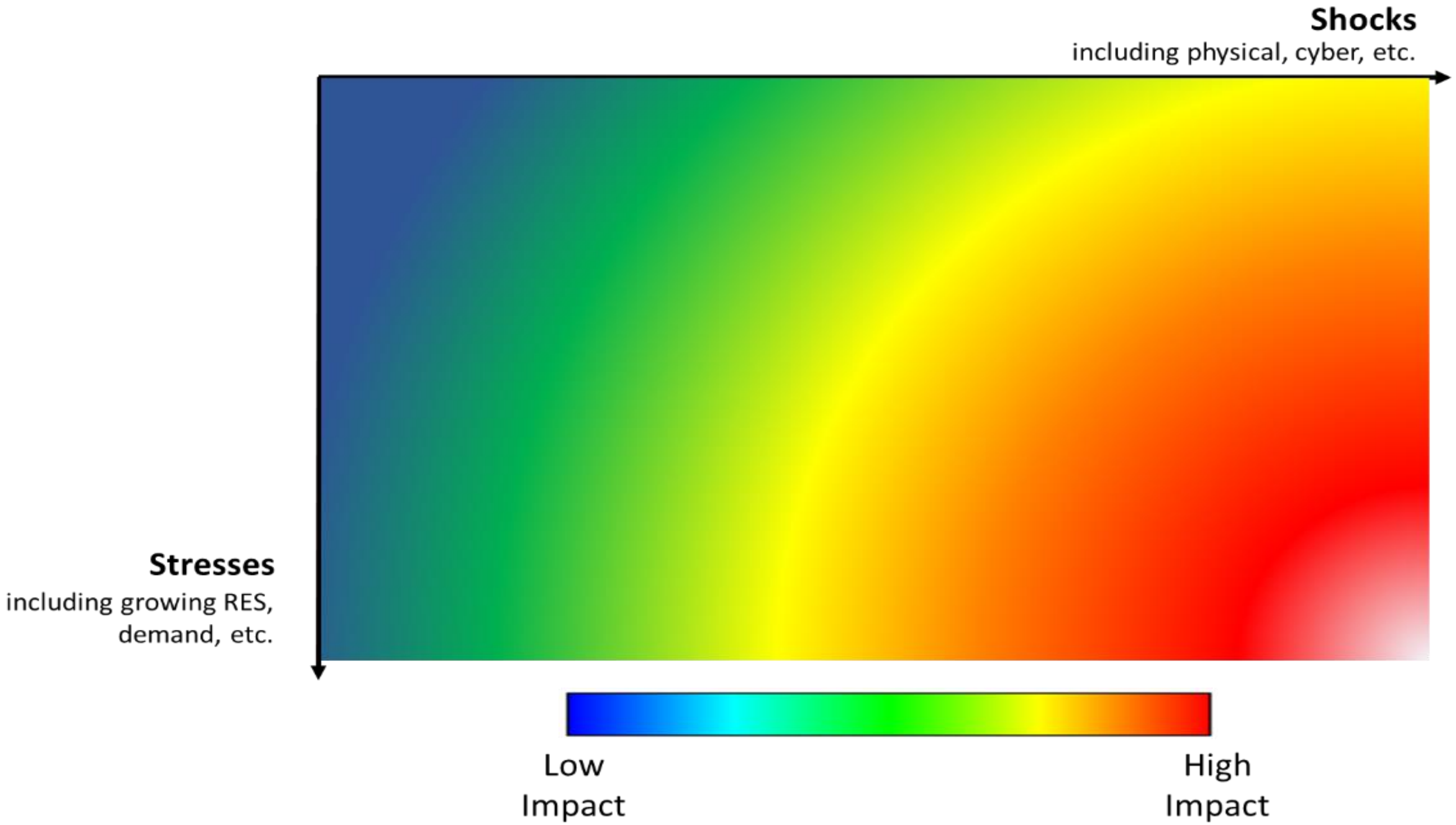
Increasing and Complex Interdependencies Between Critical Infrastructures



Threats and Shocks to Electricity Infrastructure



Increasing Shocks and Stresses



Una mirada integral a la transición del sector eléctrico.

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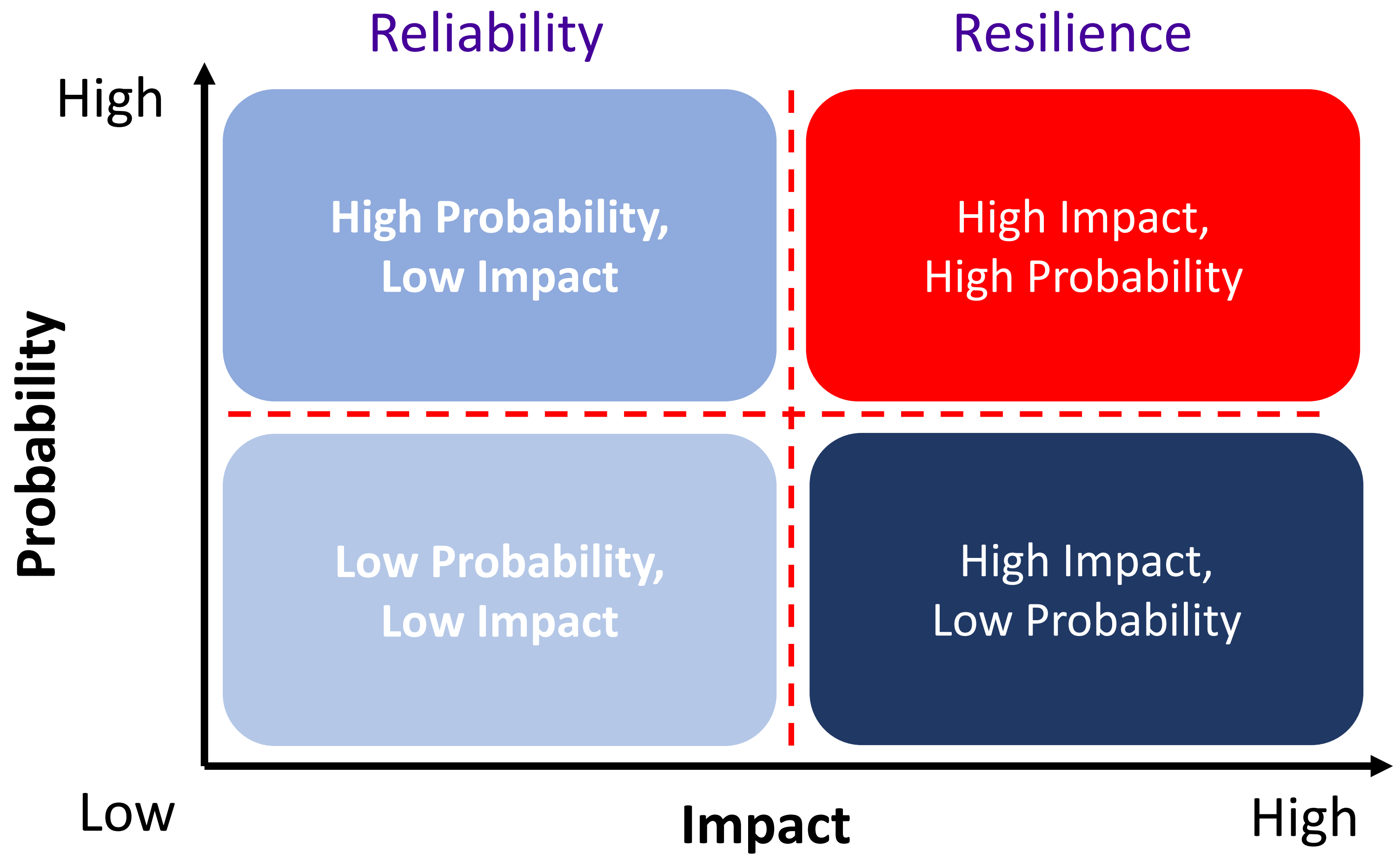
Conceptual Classification of Threats



What is really a HILP event?

“A bull with an itchy bottom knocked a transformer off an electricity pole as he tried to scratch his backside - and cut power to 800 homes.”

"We went up to feed our cows and it was my husband that noticed the transformer box had been knocked off the pole.

"We put two and two together and realised our bull had been scratching against the telegraph pole and he had knocked the box off the pole. All the wires were down in the field as well."

“Four-year-old Ron managed to avoid the box as it landed in his field, and escaped an 11,000 volt shock from the tumbling cables.”

Bull's bid to scratch 'itchy bum' cuts off power to 800 homes

8 May 2020 Share

Ron has been relaxing in his field after his near-death experience

Source: https://www.bbc.co.uk/news/uk-scotland-glasgow-west-52591605

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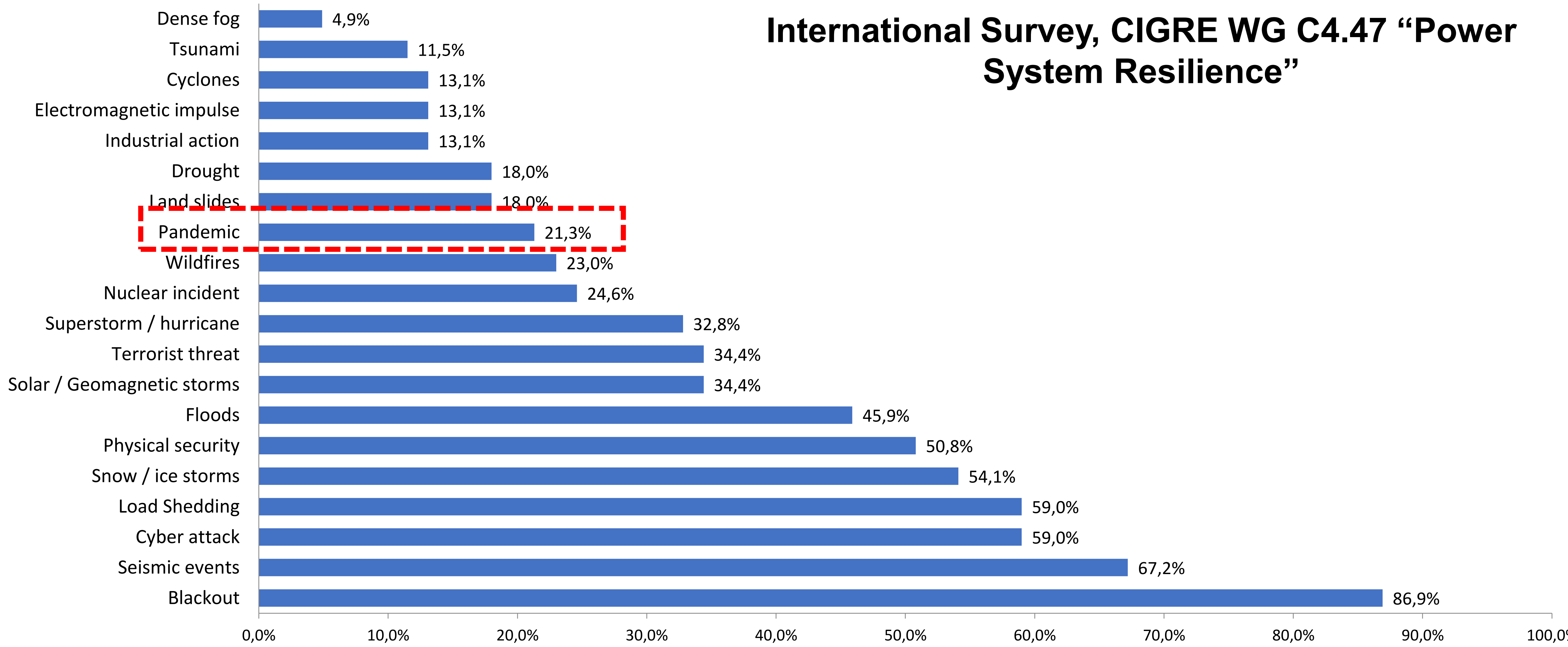
HILP Events in Power Systems



International Survey, CIGRE WG C4.47 "Power System Resilience"

International Survey, CIGRE WG C4.47 “Power System Resilience”

Introduction

- Understand the profile of the participant entity

Resilience definition

- Is resilience incorporated within their entity, how it is understood, is it differentiated from reliability, etc.?

Methods and Metrics

- What are the methods and metrics used for resilience purposes and how they are utilised?

Boosting Resilience

- What is the approach adopted for reinforcing resilience?

Regulatory Frameworks

- Obtain insights in the regulatory frameworks that exist to encourage and incentivise resilience reinforcement

For more information on international survey

cigre

Symposium Aalborg, Denmark
4th-7th June 2019

146

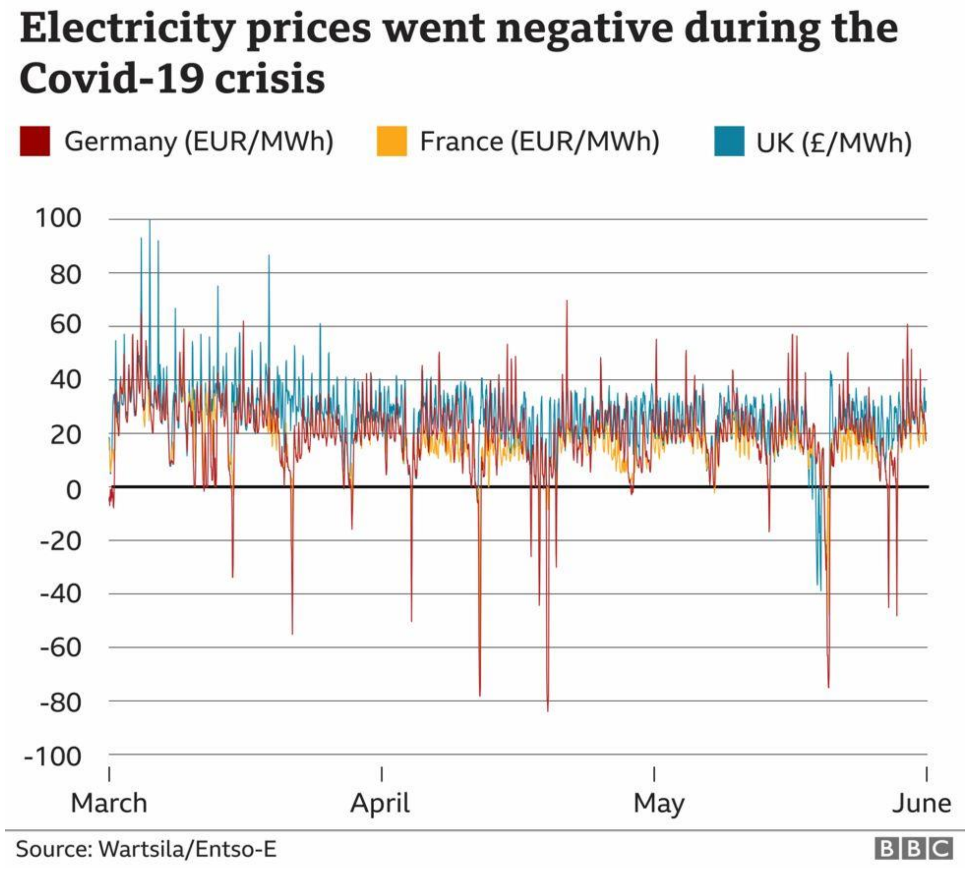
International Survey on adoption of resilience within the Electricity Sector

CIGRE C4.47 Working Group on Power System Resilience

Covid-19 Pandemic: Going beyond "typical" HILP events

- During the coronavirus lockdown, electricity consumption was down across Europe by around 15%.
- Wholesale electricity across Europe is priced on an hourly basis for the day ahead, so abundant (renewable) supplies and weak demand saw prices go below zero at times.
- Consumers who had signed up to flexible, real time tariffs with one UK energy supplier found themselves encouraged to use electricity when it went negative.
- Social, generation and network planning/maintenance impacts, etc. etc.

"But faced with this, and the challenges of staff getting ill and having to go off into isolation, just keeping the lights on and keeping the electricity system operating through this is a minor miracle in itself."



Source: https://www.bbc.com/news/science-environment-52943037

CIGRE WG C4.47 Definition of Resilience

the ability to limit the ***extent, severity*** *and* ***duration*** *of* ***system degradation*** *following an* ***extreme event****.*

Anticipation	Preparation	Absorption	Adaptation	Rapid recovery	Sustainment of critical system operation
• the process by which newly incorporated knowledge gained is used to foresee possible crises and disasters	• the process through which grid operators establish a set of actions to be deployed in case the critical operating condition occurs	• the process through which a set of measures is deployed to limit the extent, the severity and the slope of the degradation of power system performance	• the process through which changes are carried out in the power system management procedures, on the basis of past disruptions, in order to adjust the system to undesirable situations	• the process through which the energy supply to the customers is restored and the damages to the grid infrastructure are repaired	• the process which deploys the measures allowing an impaired power system to supply a minimum system load level in order to maintain a reduced but acceptable functioning of everyday life

For more information on CIGRE WG C4.47 resilience definition

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Community Knowledge Programme

Defining power system resilience

The definition of resilience has alluded utilities and standard authorities. Resilience is more than just "bouncing back". CIGRE Working Group SC C4.47 has researched and formulated a definition as well as key actionable measures as an integral part of the definition. This paper covers the process and derivation of the definition as well as the actionable measures. It compares reliability to resilience and discusses application of the definition in the electricity sector.

Despite several attempts by organisations worldwide in the power and energy engineering communities to define resilience, there is no universally accepted definition. Resilience is a multi-dimensional and dynamic concept. Resilience is more than simply "the ability to bounce back".

In 2017 CIGRE SC C4 formed a Working Group consisting of experts from 19 countries. The purpose was to formulate a standard definition and approach to resilience. An international survey was undertaken and the inputs consolidated into an internationally agreed definition. The group also discussed the difference between reliability and resilience as these terms are often confused.

https://www.cigre.org/article/GB/news/the_latest_news/defining-power-system-resilience

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Rethinking power grid resilience: experiences and lessons from the COVID-19 pandemic

02 June 2020, prepared by Mathaios Panteli and Malcolm Van Harte, CIGRE Working Group C4.47 "Power System Resilience"

In November 2019, the first cases of a new disease, later named COVID-19 by the World Health Organisation, were reported by health care workers in Wuhan, China. In December 2019, researchers from Wuhan reported a cluster of pneumonia cases caused by a novel coronavirus. The COVID-19 pandemic has resulted since then in severe stresses on essential services and operations of critical infrastructures around the world. The battle against this virus pandemic has placed and is placing tremendous pressure on countries' healthcare system, the economy, activities in general society, and especially on the ability of utilities to perform their operations and duties entrusted to them. Electricity utilities have swiftly mobilised across the world to implement measures to support, protect and empower their employees with reliable and accurate information about COVID-19, while keeping the lights on for critical essential service providers. Various measures have been taken in order to limit exposure or spread of the virus to their employees or public.

https://www.cigre.org/article/GB/rethinking-power-grid-resilience-experiences-and-lessons-from-the-covid-19-pandemic

REFERENCE PAPER

Defining power system resilience

By E. CIAPESSONI (IT), D. CIRIO (IT), A. PITTO (IT), M. PANTELI (UK), M. VAN HARTE (SA), C. MAK (CA) on behalf of C4.47 WG Members

https://e-cigre.org/publication/RP_306_1-defining-power-system-resilience

Multi-Phase Resilience Assessment

- **Phase 1.** Threat characterization

Geographic profiles

Fragility-driven approach

- **Phase 2.** Vulnerability assessment of system components

- **Phase 3.** Reaction of the system

Power systems analysis

Probabilistic recovery

- **Phase 4.** Restoration of the system

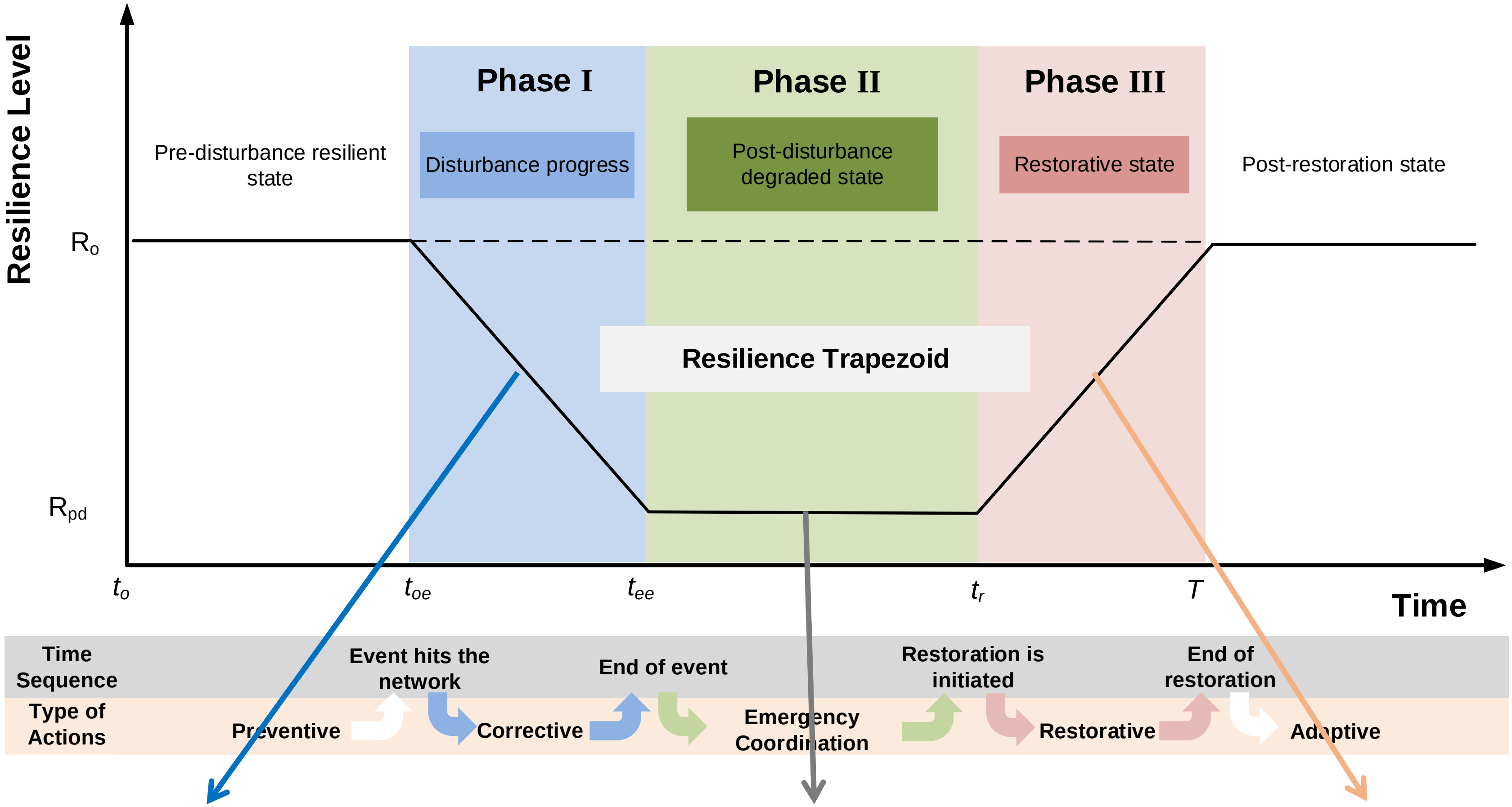
- Spatiotemporal threat modelling
- Empirical data and simulation of thousands scenarios

- Time- and hazard dependent failure probabilities
- Fragility-based assessment

- Spatio-temporal impact assessment
- Component and region criticality assessment

- Operational and infrastructure restoration and recovery modelling

Resilience Metrics – FLEP Resilience Metric System

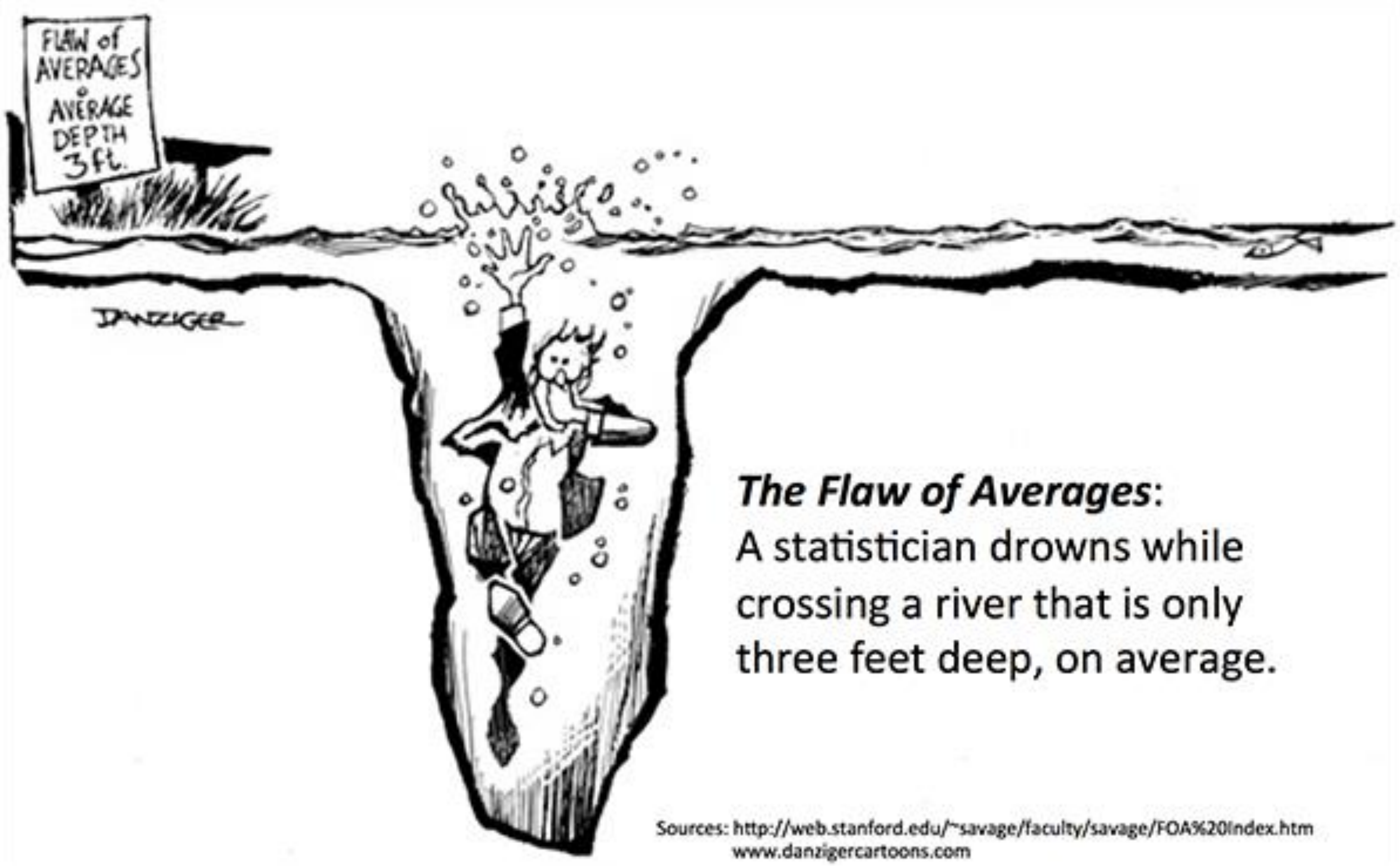


how **f**ast resilience declines?
how **l**ow resilience drops?

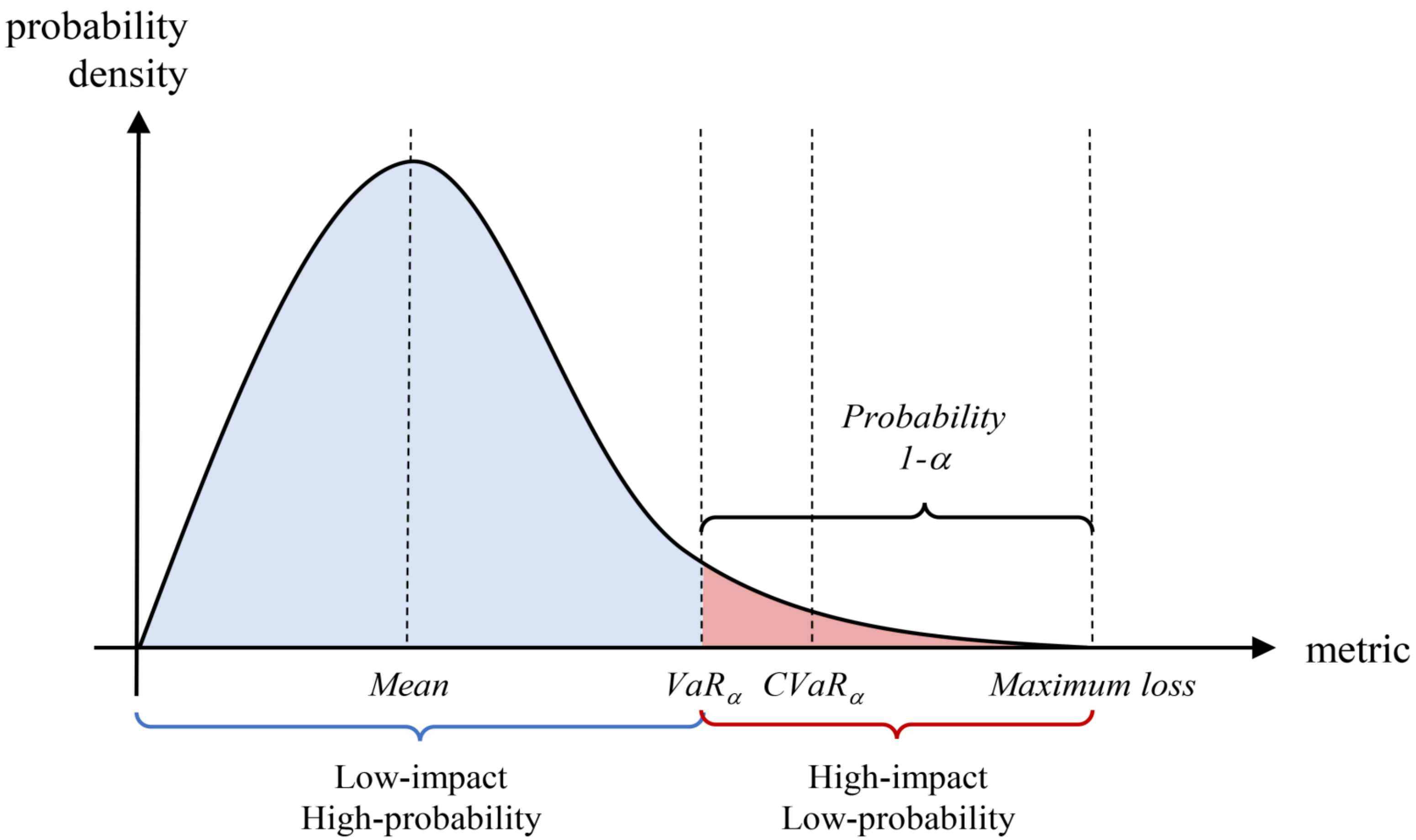
how **e**xtensive is this state?

how **p**romptly does the network recover?

Resilience Metrics – Problem of using average values



Average and Conditional Values of Performance Metrics



Value at Risk

$$VaR_{\alpha}\,(x) = min\{x \mid f_x(z) \geq \alpha\}$$

Conditional Value at Risk

$$\mathrm{CVaR}_{\alpha}(x) = E[x \mid x \geq VaR_{\alpha}(x)]$$

"Forward Resilience Measures" project, UK

Πανεπιστήμιο Κύπρου
University of Cyprus

MANCHESTER 1824
The University of Manchester

nationalgrid

ARUP

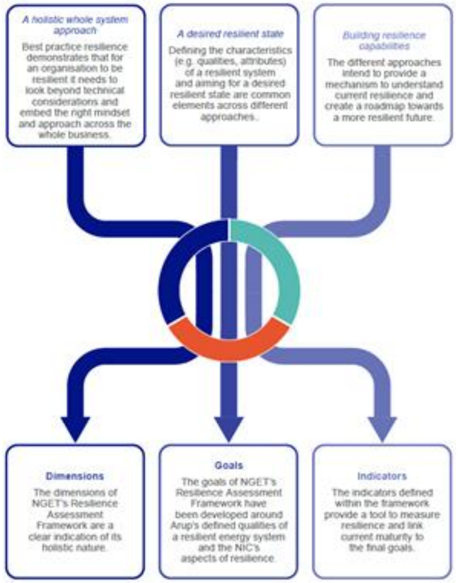
Resilience Tiered Approach

Tier 1 – Resilience Assessment Framework

A breakdown structure of the elements that matter for NGET's resilience allows for a holistic understanding of resilience maturity.

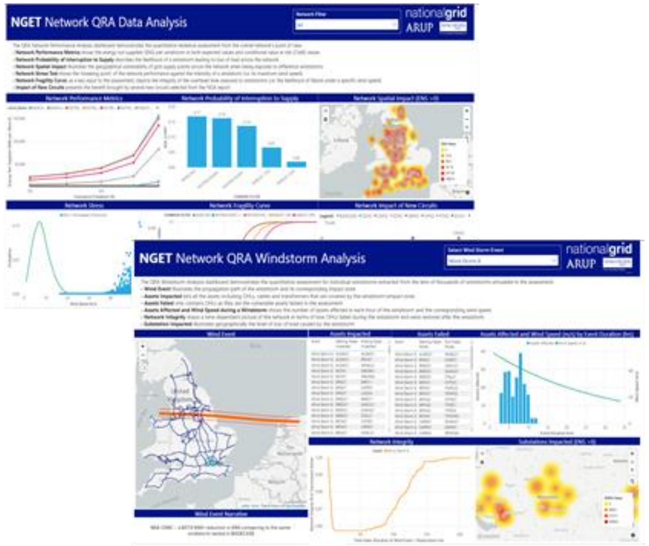
Tier 2 – Link to Existing and Planned Initiatives

The scoring of the different indicators is informed by existing and planned initiatives across the organisation.



Tier 3 – Quantitative Resilience Assessment Tool

Quantify coupled effects of physical shocks and network stresses on NGET's resilience, using a wide range of metrics.



Quantitative Resilience Assessment Tool

1
NGET Network Model Development and Validation

2
Design and Modelling of External Shocks and Network Stresses

3
Risk and resilience assessment and enhancement

NGET Network Model

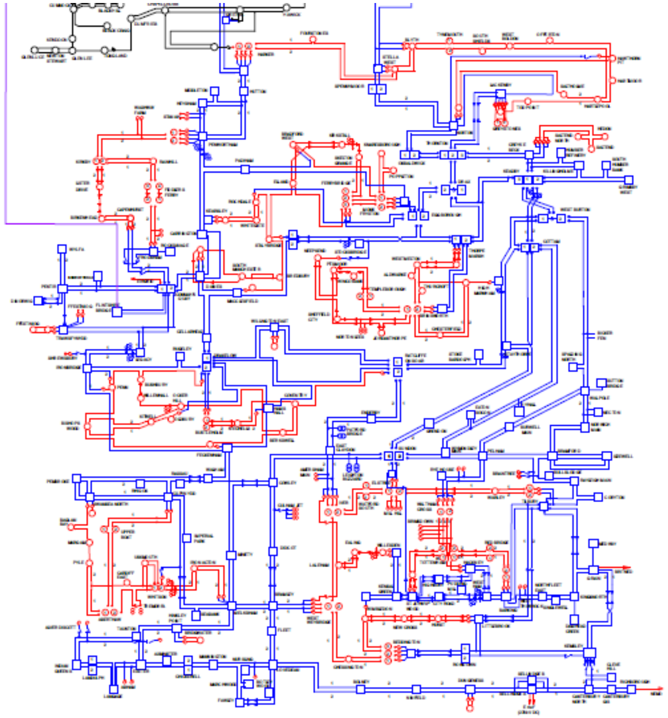
Hazard Modelling

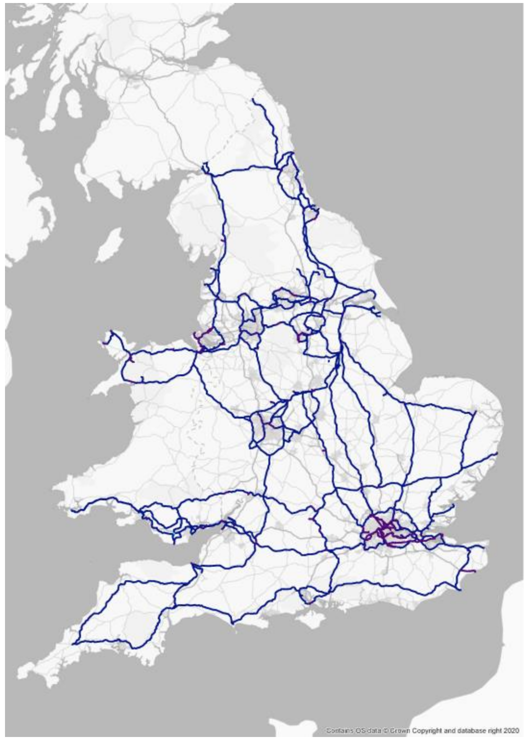
Future Energy Scenarios

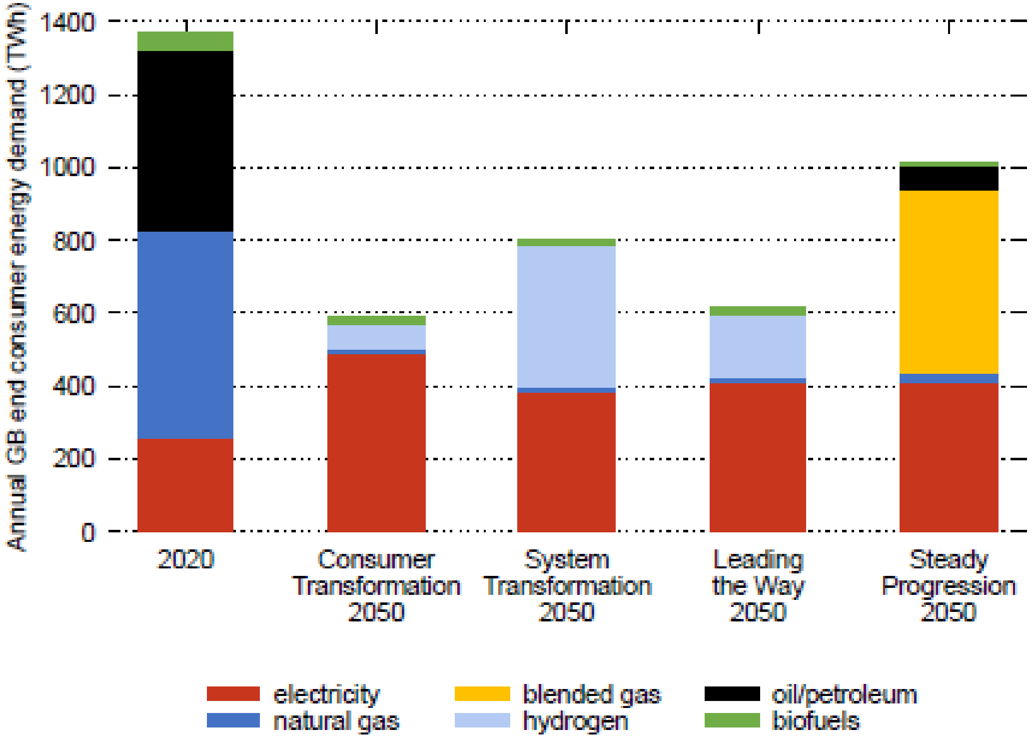
Risk and Resilience Metrics

Network Enhancement

Network Model and Data



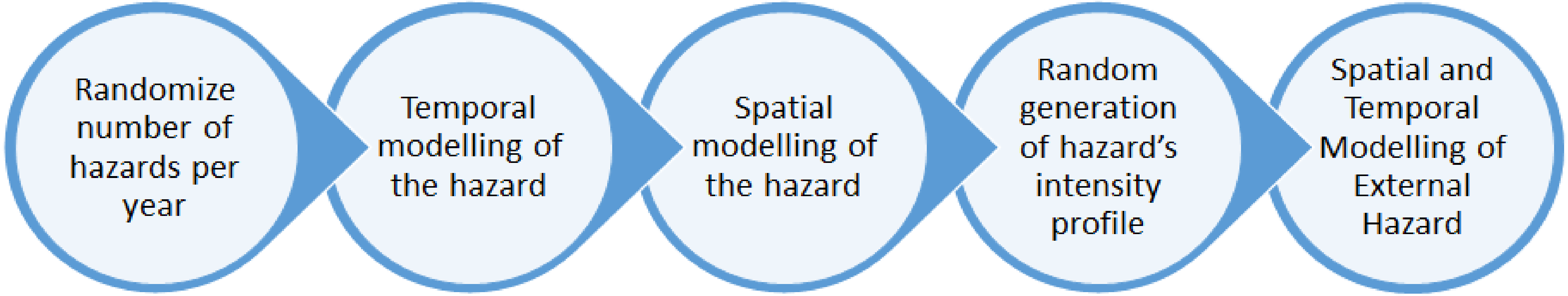




Network Features: 572 transmission lines, 758 transformers, 741 nodes (busbars), 270 substations, HVDC link Scottish Boundary

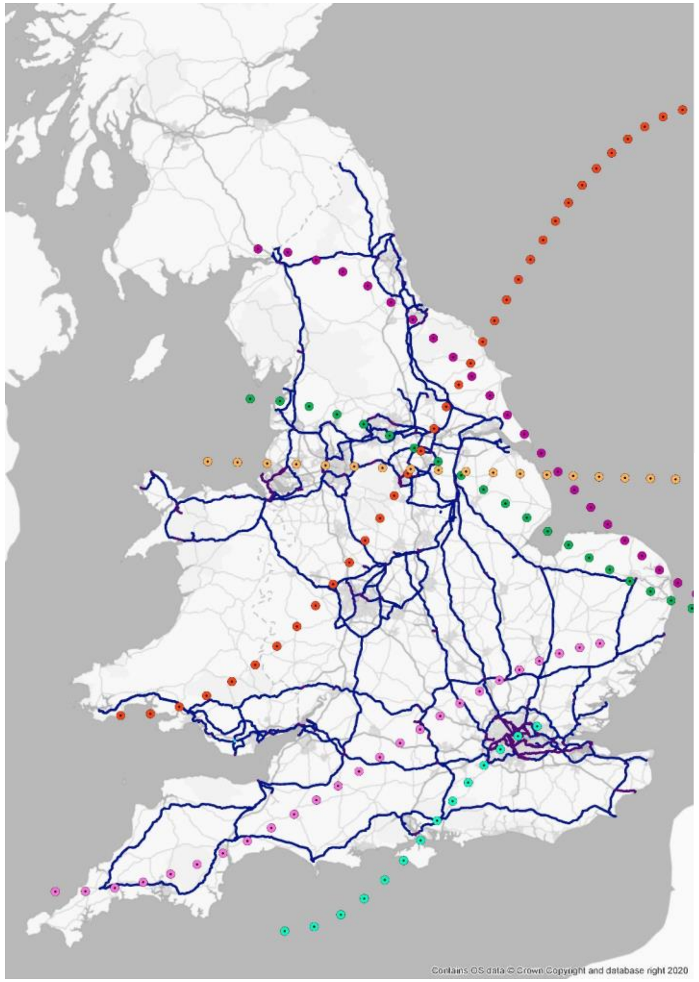
National Grid Future Energy Scenarios

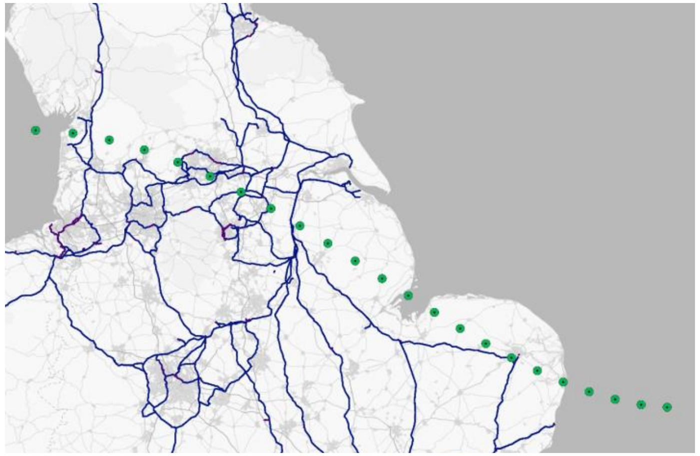
Spatial and Temporal Hazard Simulator

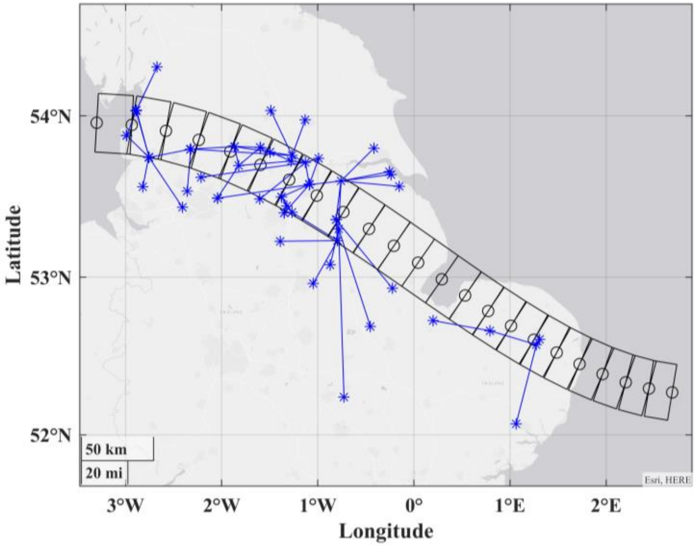


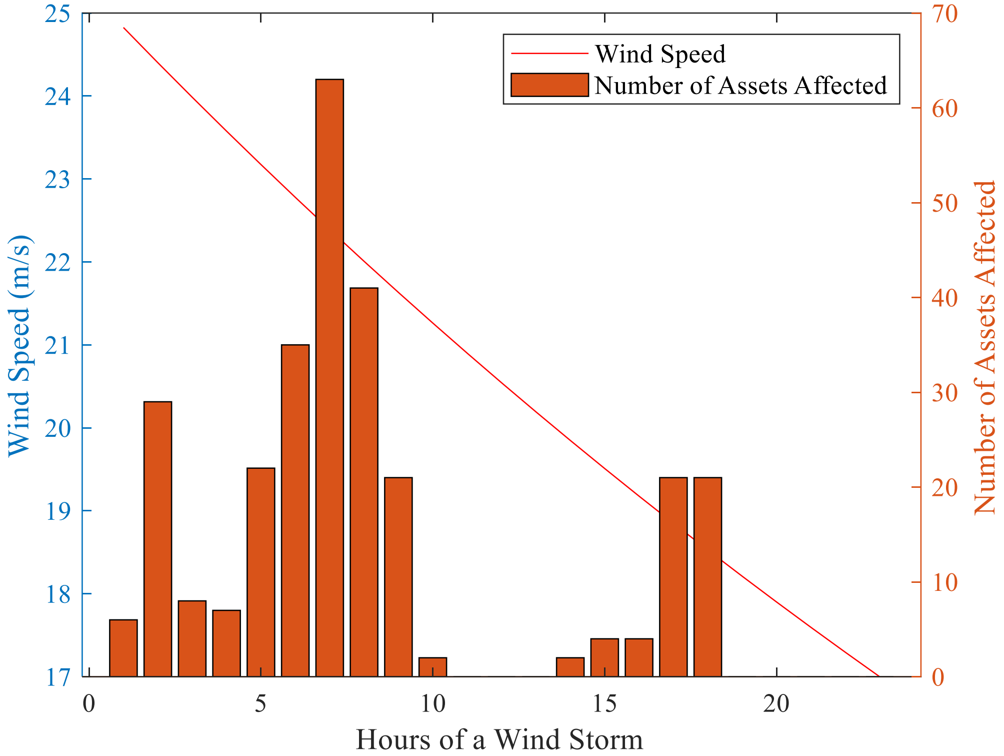
- Fully flexible and modular simulator of extreme weather events
- Enables the user to define several critical features, and simulate random events as well as historical ones.

Spatial and Temporal Hazard Simulator

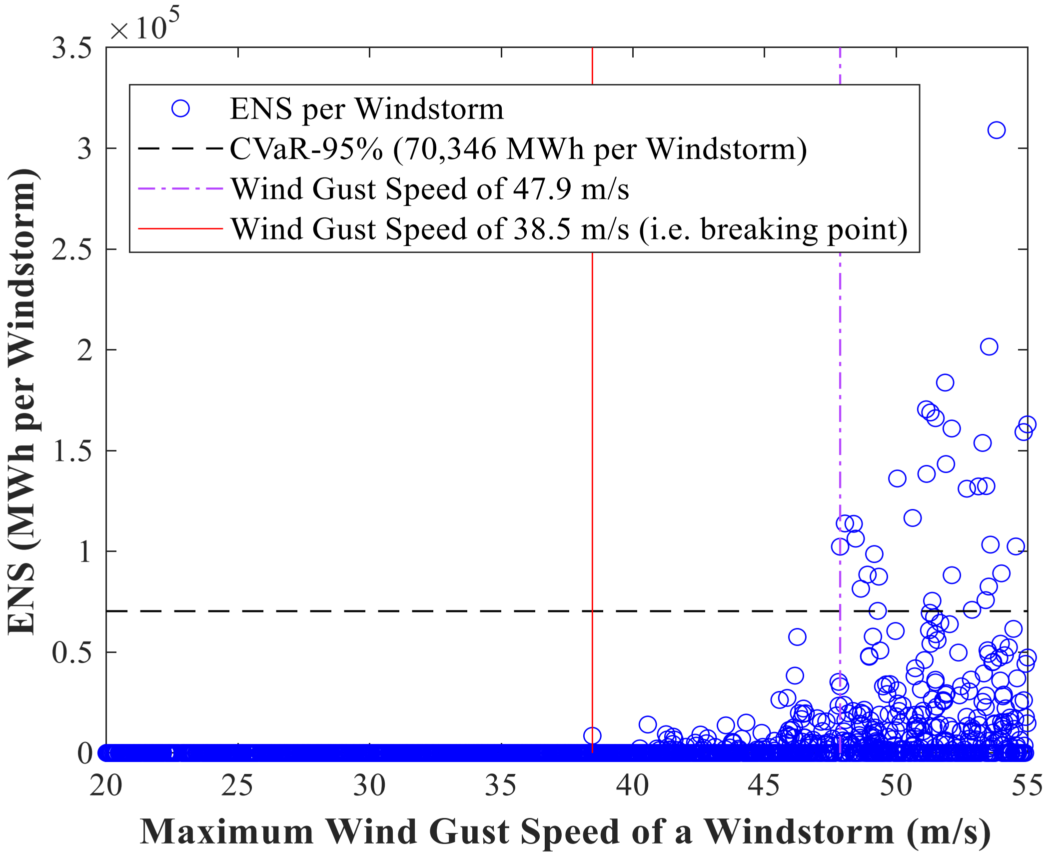


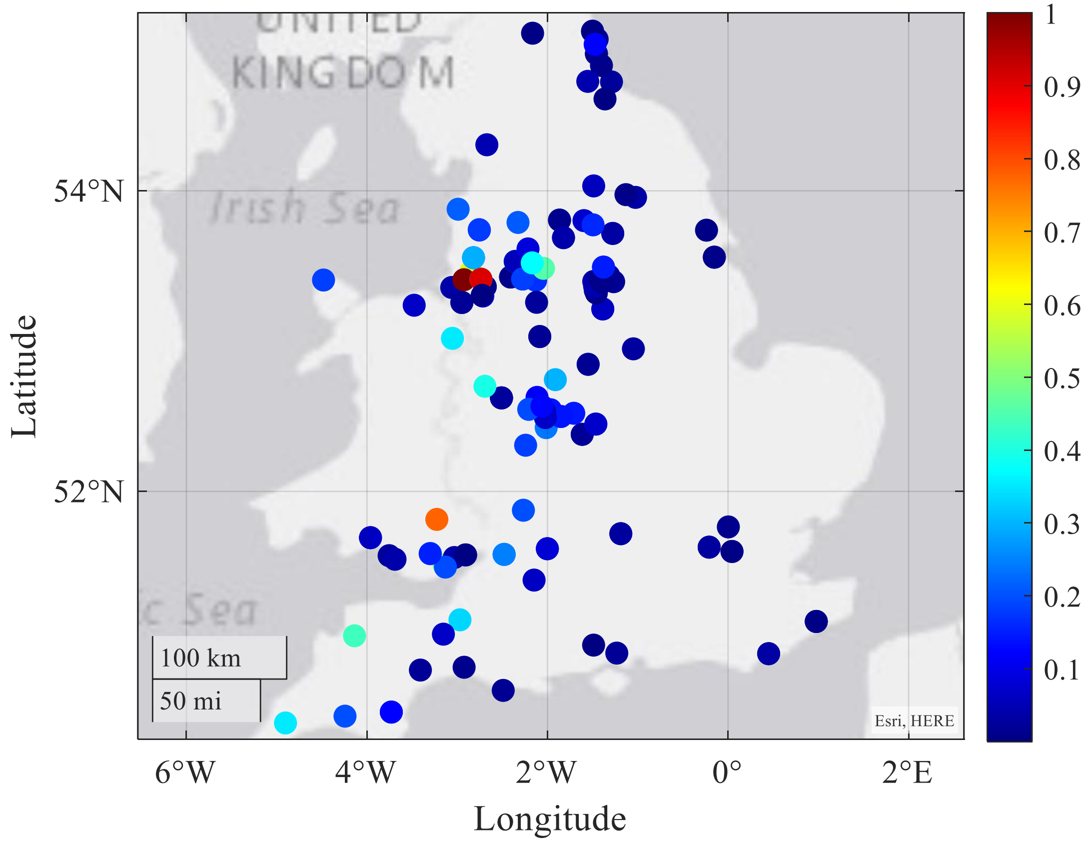




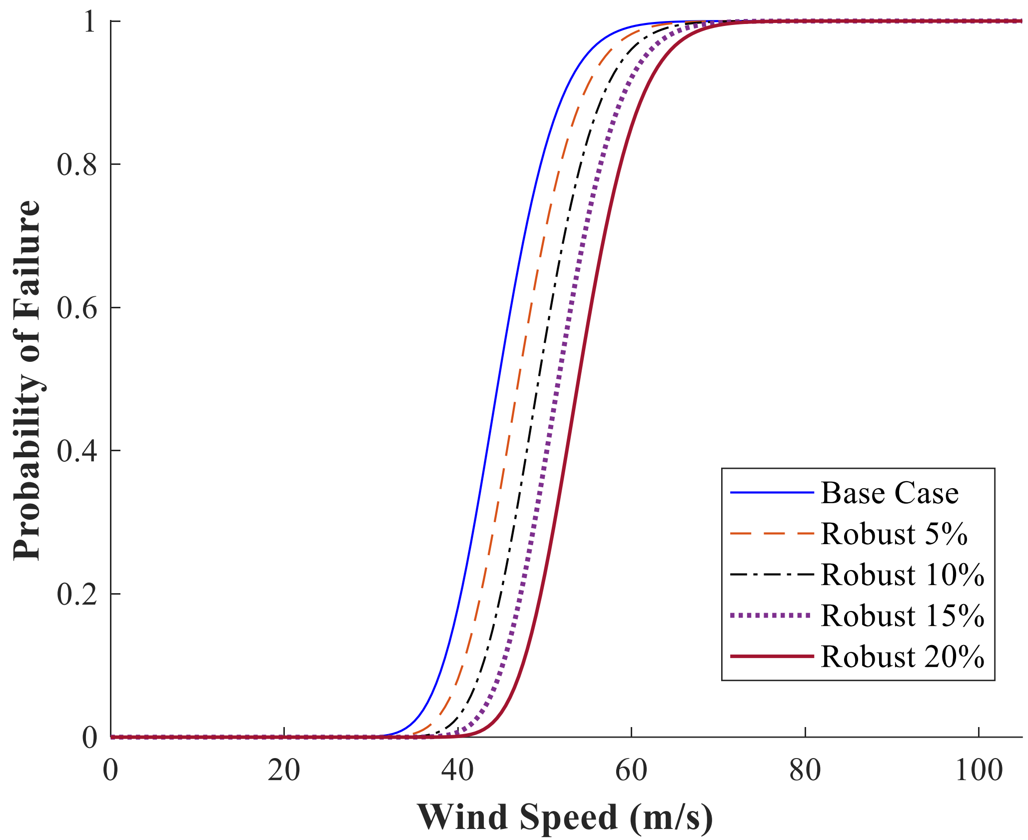


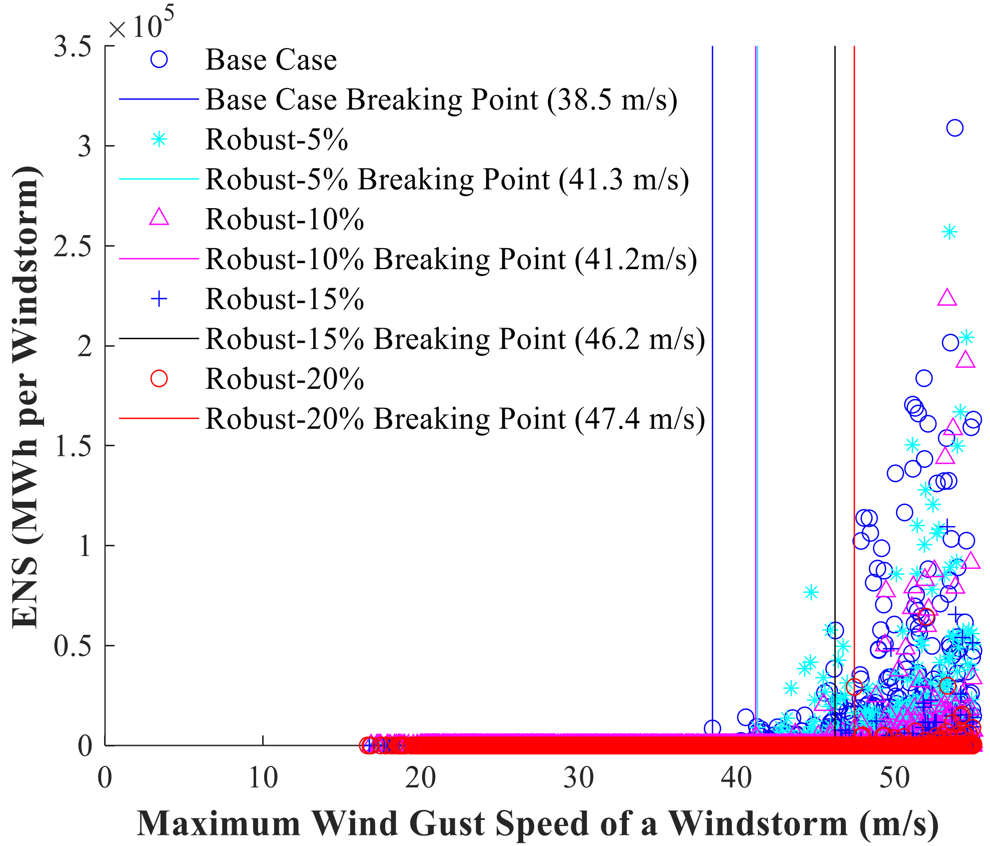
Breaking Point and Spatial Energy Not Supplied



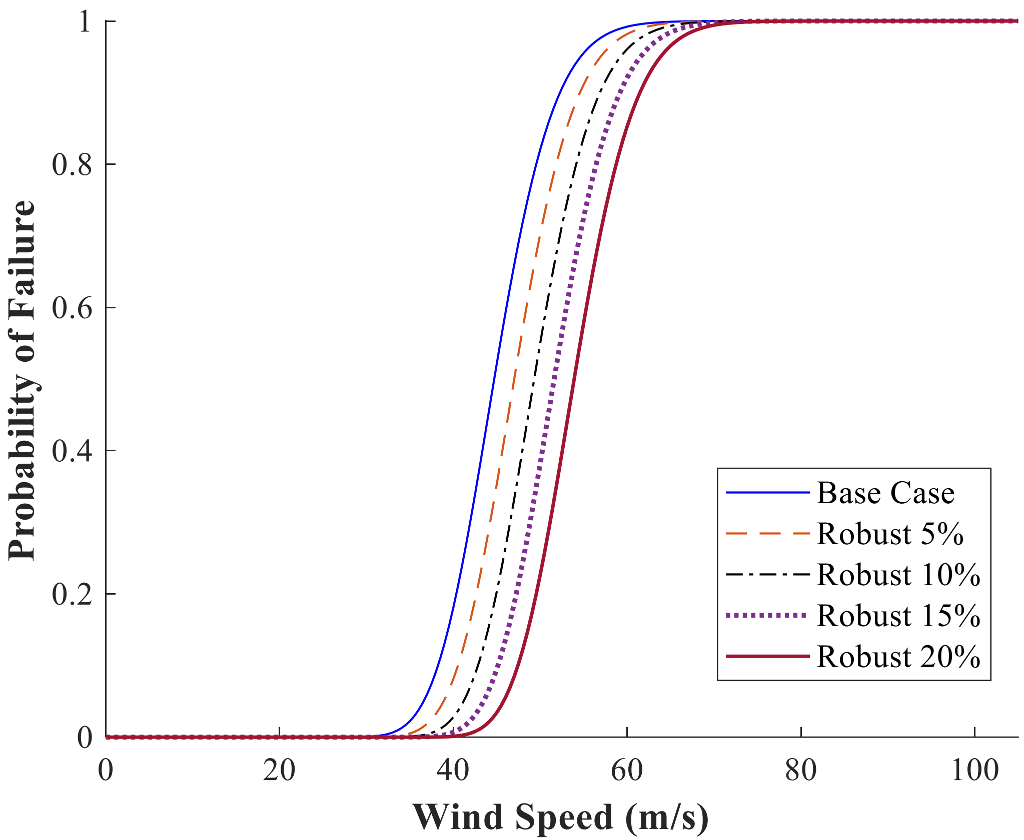


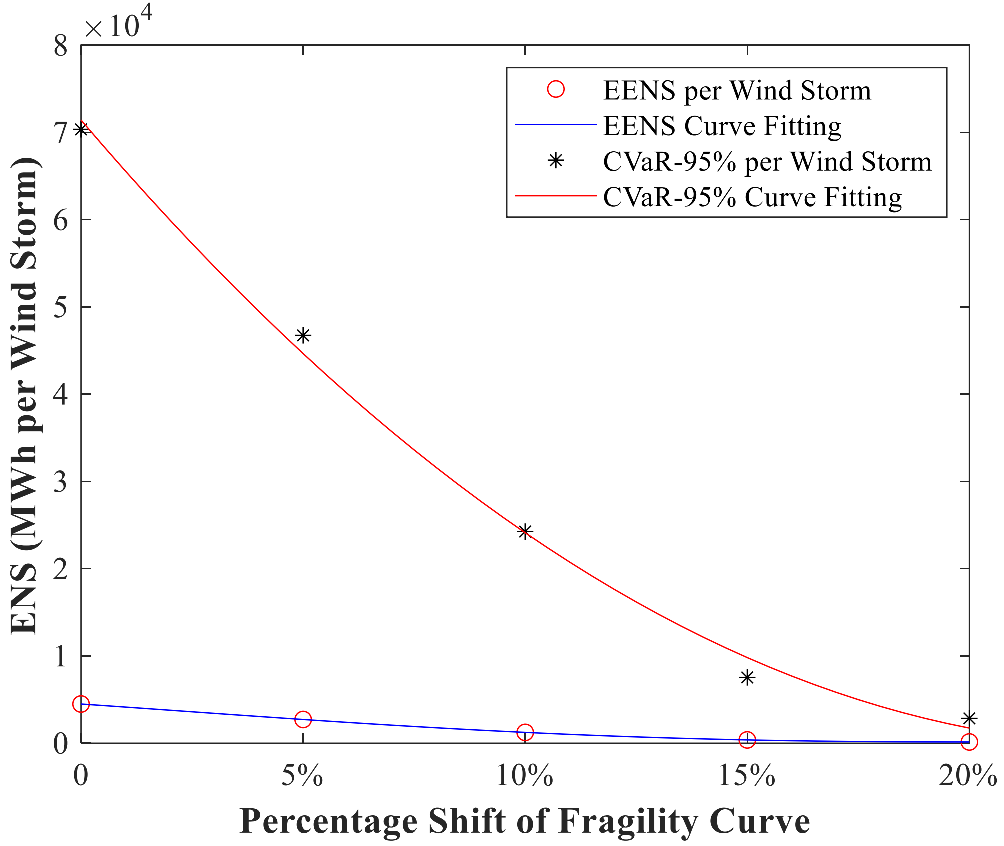
Making the Network More Robust





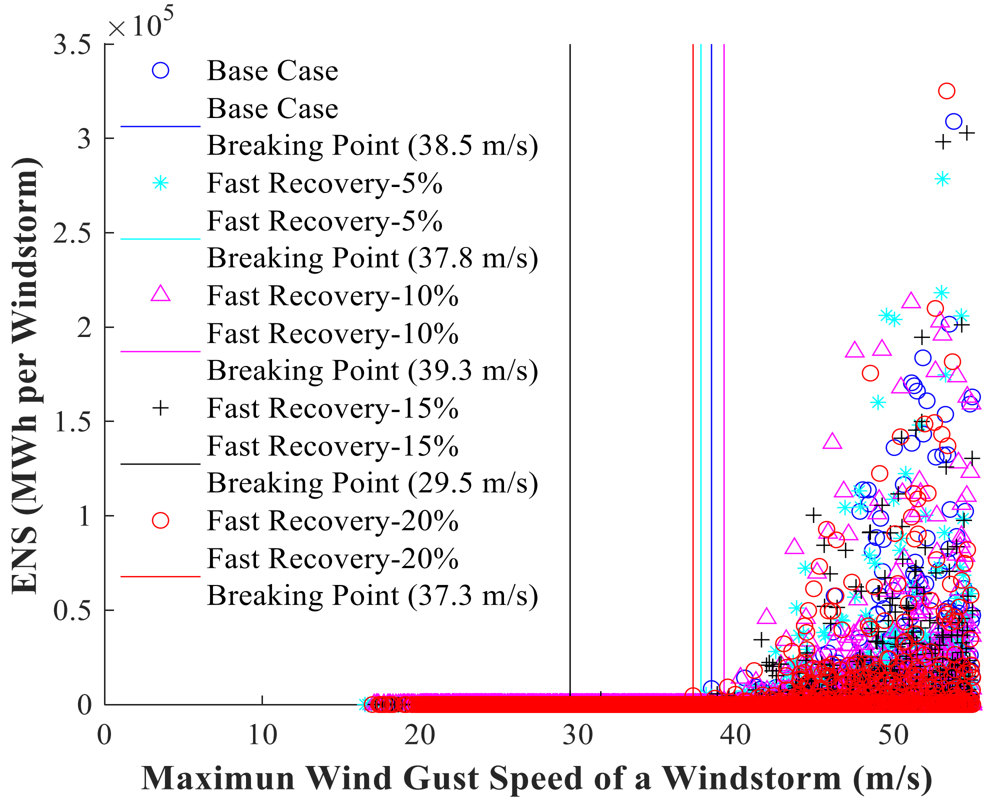
Making the Network More Robust





Increasing Restoration and Recovery Times

	Minimum Duration for Restoration	Maximum Duration for Restoration
Base Case	24 hours	168 hours (i.e. a week)
Fast Recovery 5%	23 hours	160 hours
Fast Recovery 10%	22 hours	151 hours
Fast Recovery 15%	20 hours	143 hours
Fast Recovery 20%	19 hours	134 hours



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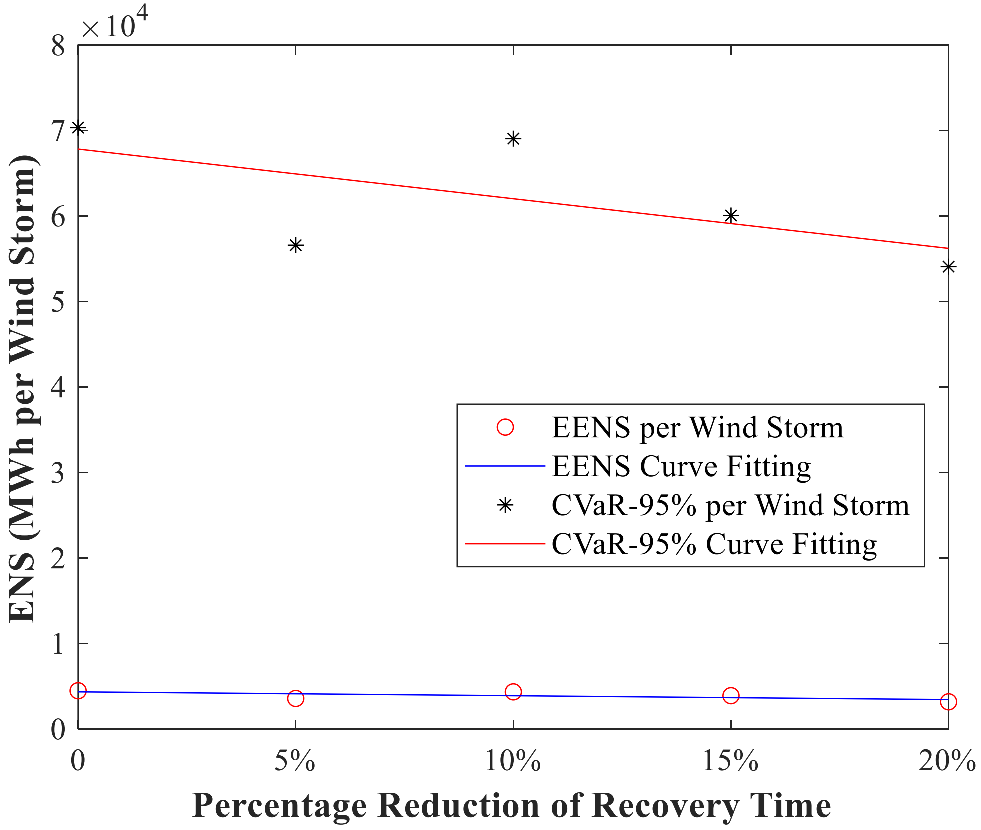

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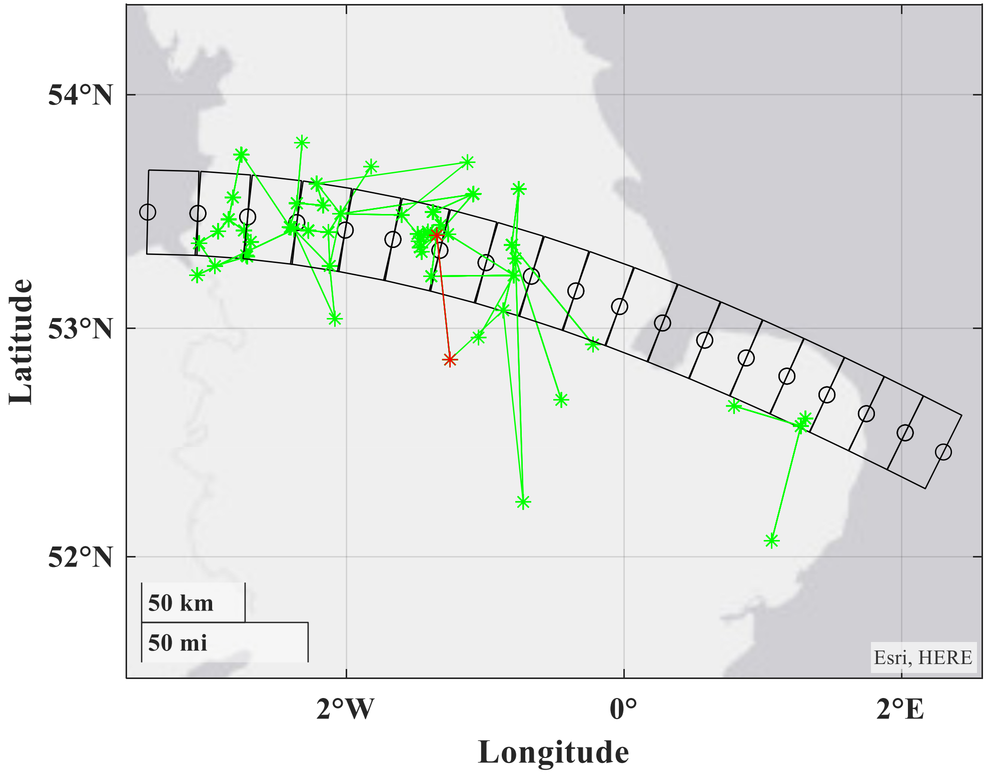
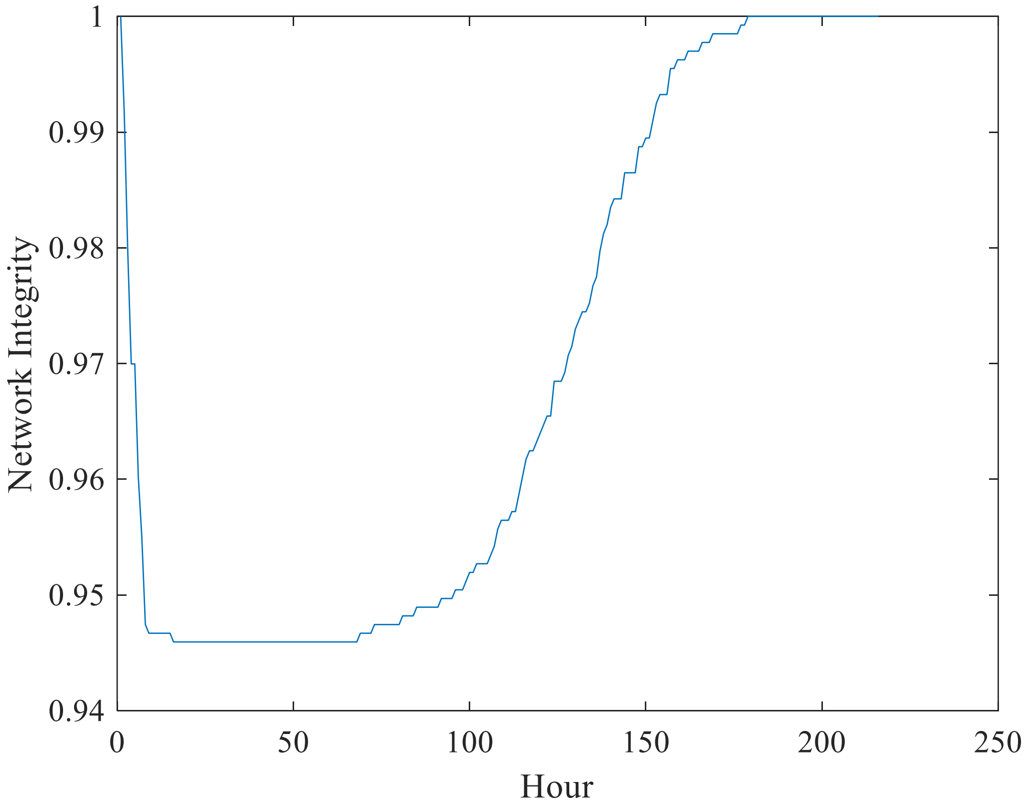
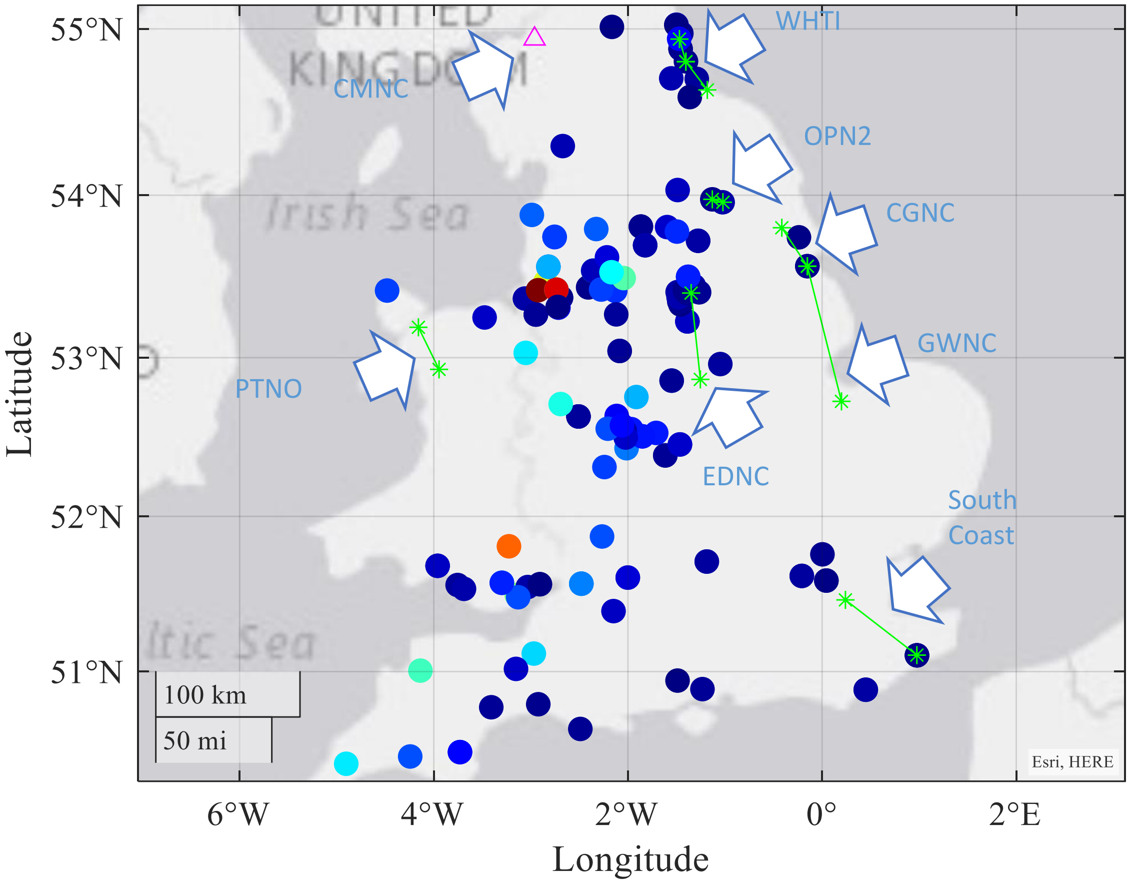
Temporal Network Integrity Assessment

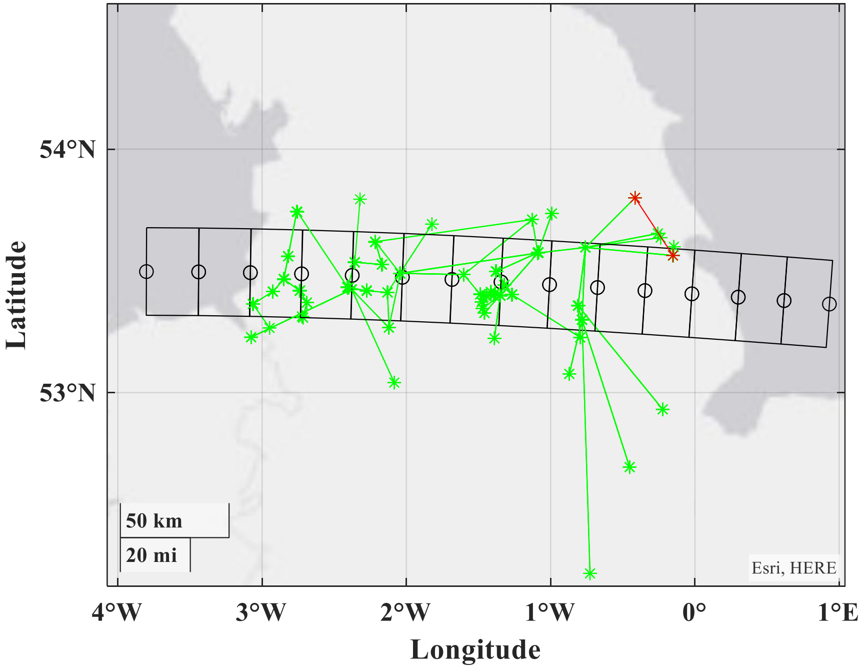




Network Options Assessment (NOA)

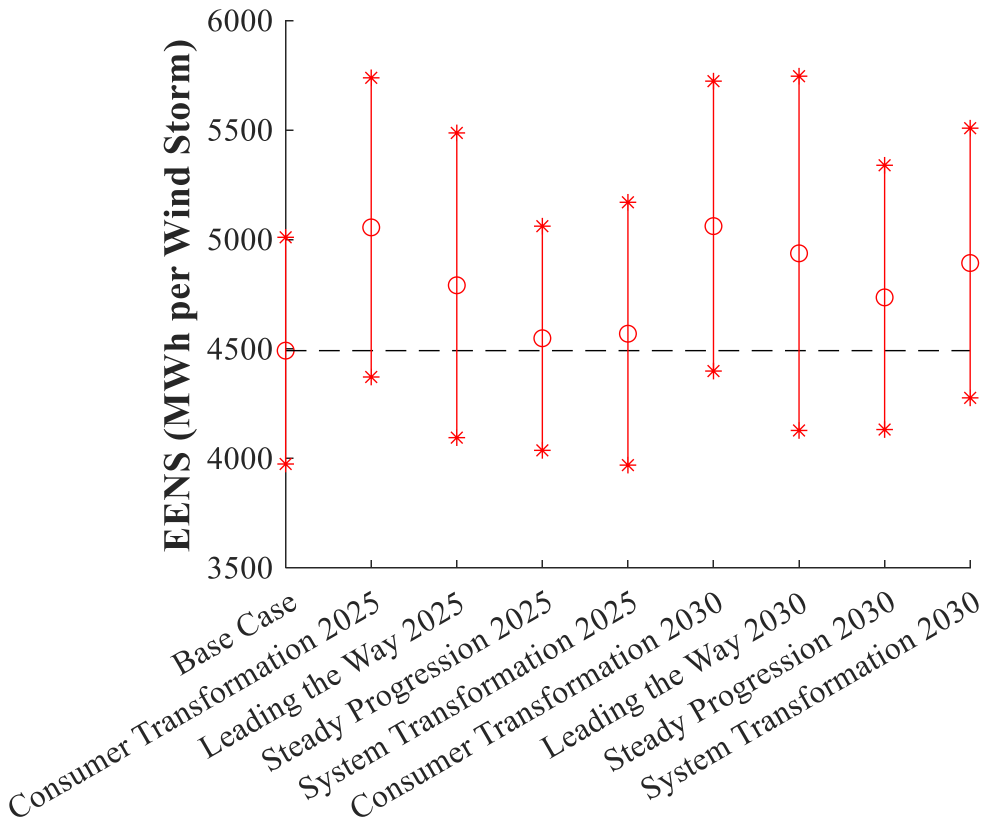


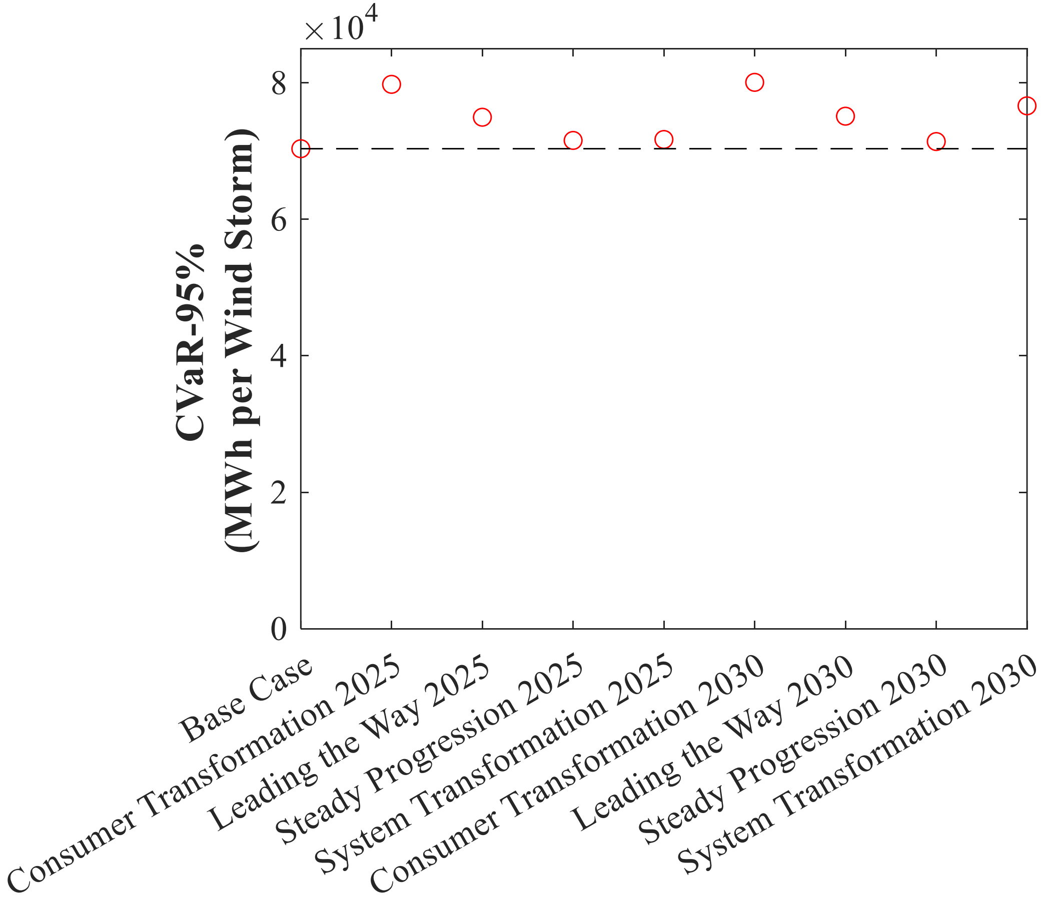
NOA Options – CGNC



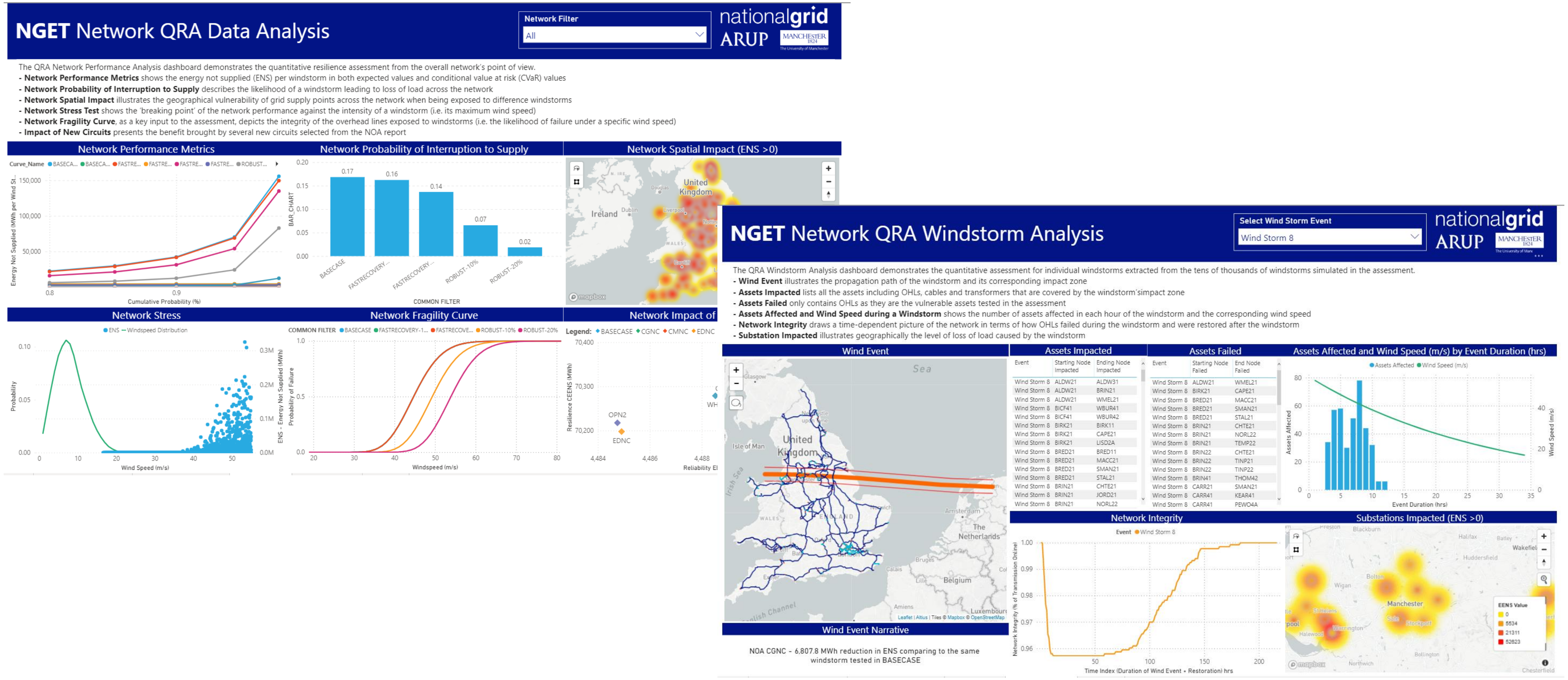
Reduced ENS during this windstorm by 6807.8 MWh

Future Energy Scenarios



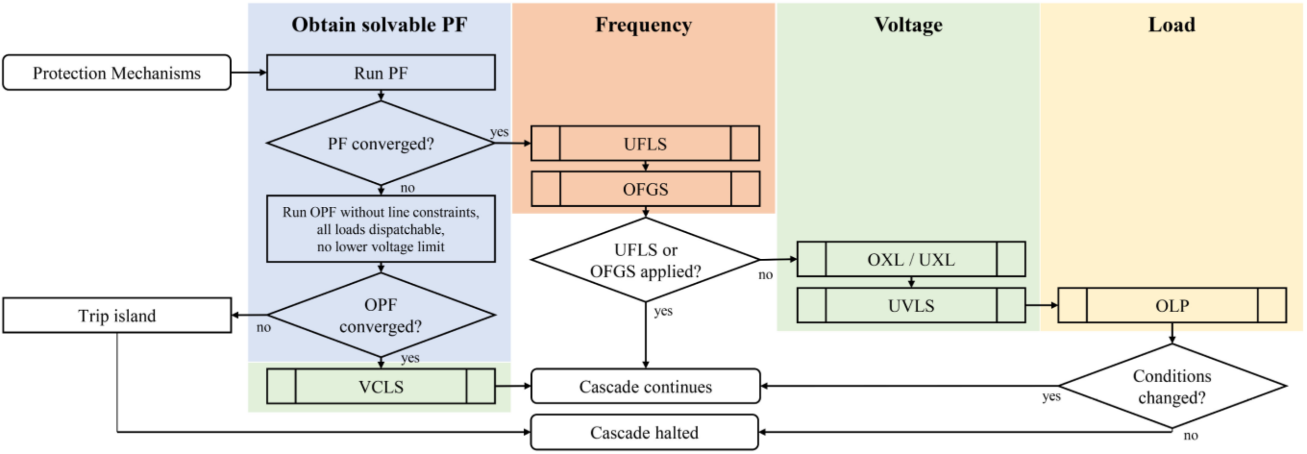


User Web-Interface

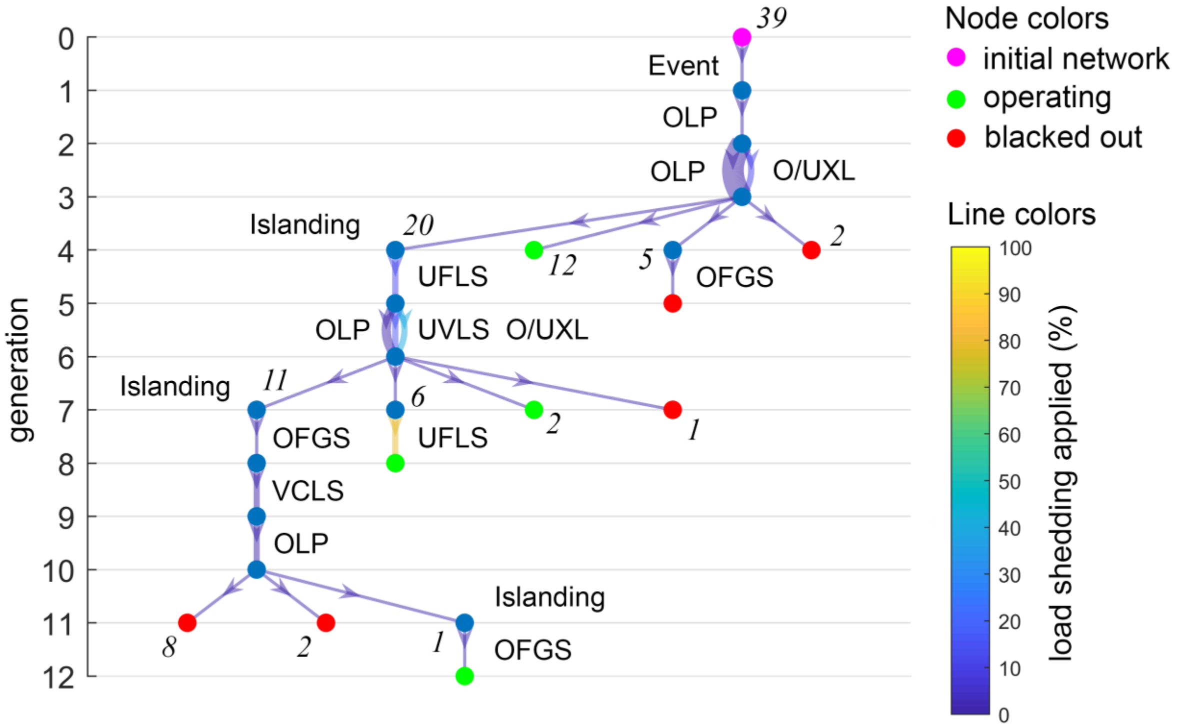


AC Cascading Modelling for Resilience Applications

Modelling of Protection Mechanisms



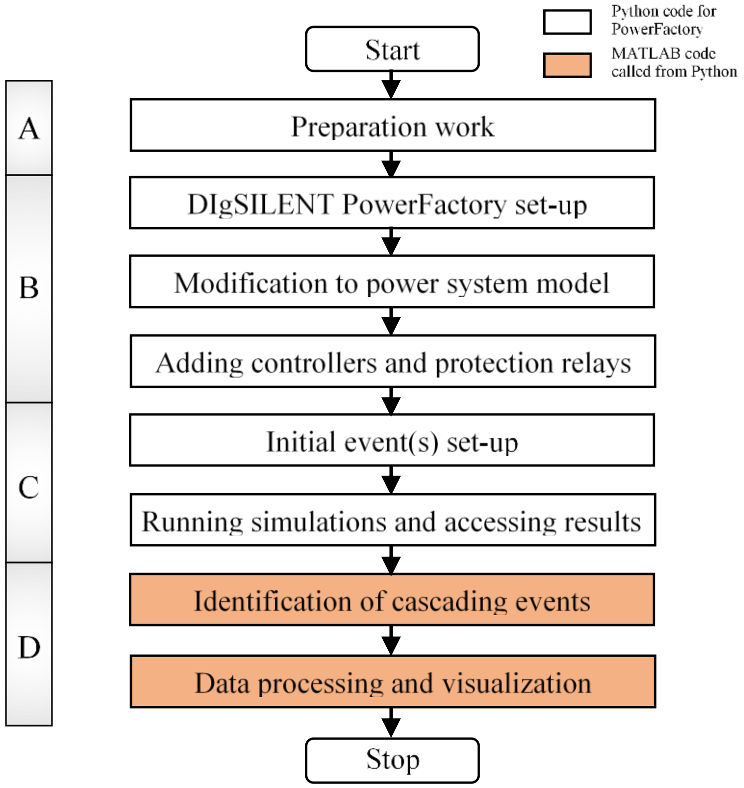
Cascading Propagation



Open Source:
https://github.com/mnoebels/AC-CFM

M. Noebels, R. Preece, M. Panteli, “AC Cascading Failure Model for Resilience Analysis in Power Networks”, IEEE Systems Journal (2020)

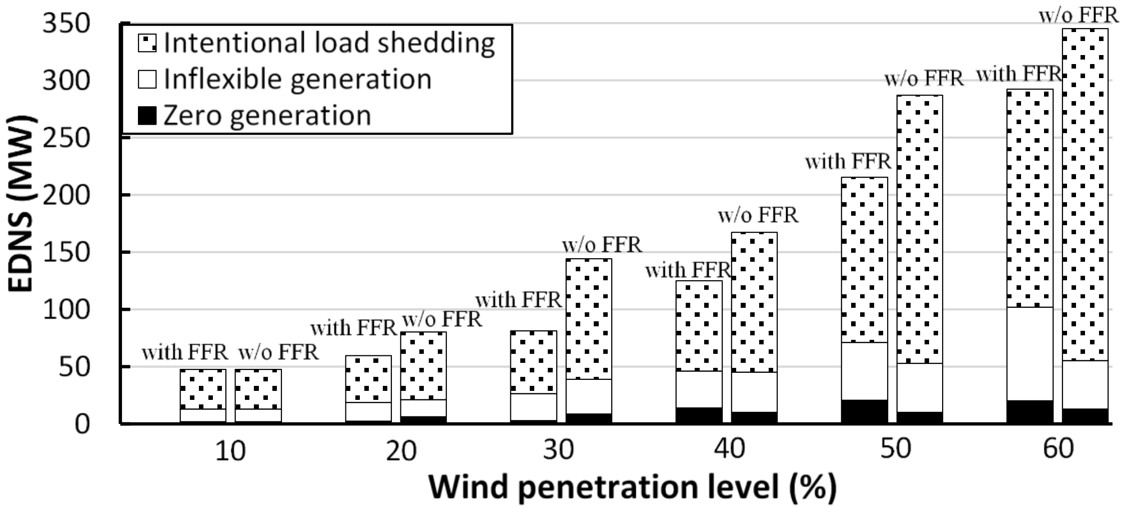
Dynamic Cascading Failure Simulator for Renewable-Rich Systems



https://github.com/YitianDai/Dynamic-cascading-failure-simulator

Application on Texas Power System

RES Penetration level (%)		10	20	30	40	50	60
Inertia level (GVA·s)		17.01	16.33	14.38	13.57	12.88	9.05
COI frequency nadir without FFR (p.u.)		0.991	0.987	0.985	0.981	0.977	0.976
Required BESS capacity (MW)	Near RES	0	12	36	60	132	192
	Near demand	0	12	30	66	132	186



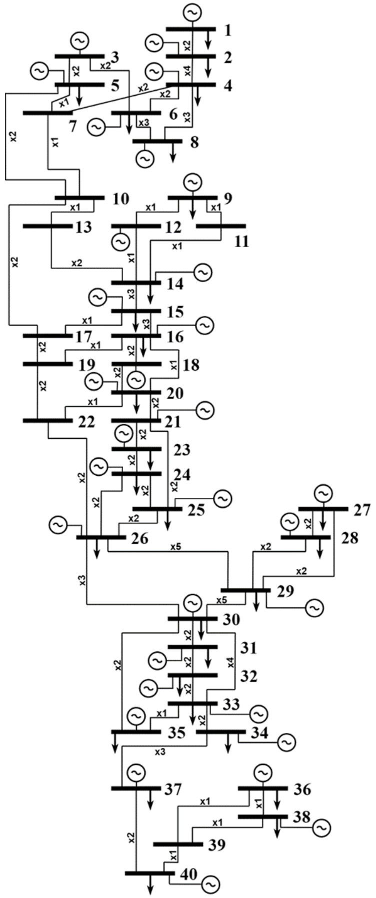
Resilience-Driven Investment Planning and Decision-Making: Application to Chilean Transmission System - Earthquakes

First stage
Propositions of new system enhancement options through optimization of resilience metric

Enhancement option →

Second stage
Simulations of system impact and response and restoration after random natural hazards occur

← Resilience metric



1 Tarapaca
2 Lagunas
3 Kapatur
4 Crucero & Encuentro
5 Los Changos 220
6 Laberinto & Domeyko
7 Los Changos 500
8 Atacama & Mejillones
9 Paposo
10 Cumbre 500
11 Lalackama
12 Etaltal
13 Cumbre 220
14 Diego de Almagro
15 Cardones 220
16 Maitencillo 220
17 Cardones 500
18 Punta Colorada
19 Maitencillo 500
20 Pan de Azucar 220
21 Las Palmas
22 Pan de Azucar 500
23 Los Vilos
24 Nogales
25 Quillota
26 Polpaico
27 Rapel
28 Melipilla
29 Cerro Navia & Lo Aguirre
30 Alto Jahuel
31 Tinguiririca
32 Itahue
33 Ancoa
34 Charrua
35 Colbun
36 Puerto Montt
37 Cautin & Temuco
38 Rahue
39 Pichirropulli
40 Ciruelos & Valdivia

R. Moreno et al., "From Reliability to Resilience: Planning the Grid Against the Extremes," IEEE Power and Energy Magazine, vol. 18, no. 4, pp. 41-53, July-Aug. 2020

Investment Options

- **New lines and transformers**
  - to create alternative “routes” to transfer power and provide redundancy, or additional reactive power to operate the network under “weaker” conditions when several network assets are outaged due to HILP events (“bigger”).
- **Substation, tower, and other equipment hardening**
  - to make the system more robust and “stronger” against HILP events.
- **Shorten response times**
  - by increasing expenditure in enhanced stocks of network assets and equipment, more repair crews, and more online monitoring and control solutions.
- **Installation of new flexible network technologies**
  - such as special protection schemes, energy storage units, FACTS, HVDC, etc. so as to make the system more flexible to adapt to different conditions post-fault, helping to mitigate consequences of HILP events.
- **Installation of distributed energy resources**
  - such as microgrids, distributed generation, etc., to provide localized energy solutions when the main system fails.

Ranking of reliable and resilient network enhancement options

Reliability

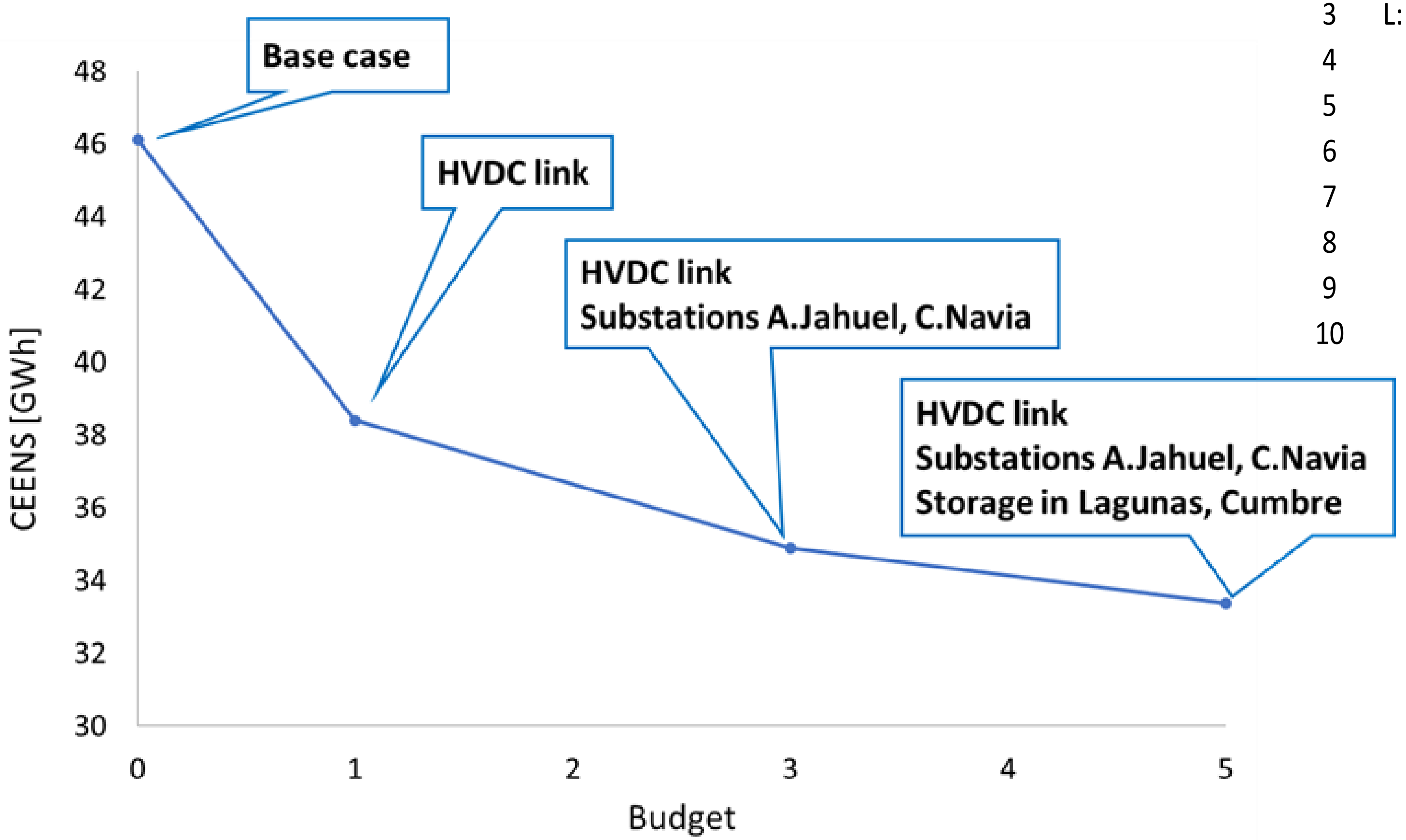
Rank	Enhancement	EENS [MWh]
1	L: HVDC link	348
2	L: Laberinto - Cumbre	392
3	L: Ciruelos - Pichirropulli	523
4	L: Cautin - Charrua	580
5	L: Ciruelos - Cautin	617
6	Ss: Crucero	696
7	Ss: C. Navia	696
8	Ss: A. Jahuel	696
9	Ss: Charrua	696
10	Base case	696

Resilience

Rank	Enhancement	CEENS [GWh]
1	L: HVDC link	38
2	Ss: C. Navia	43
3	Ss: A. Jahuel	43
4	Ss: Charrua	44
5	Ss: Crucero	45
6	L: Laberinto - Cumbre	46
7	L: Ciruelos - Cautin	46
8	L: Cautin - Charrua	46
9	L: Ciruelos - Pichirropulli	46
10	Base case	46

Tomas Lagos, Rodrigo Moreno, Alejandro Navarro, Mathaios Panteli, Rafael Sacaan, Fernando Ordonez, Hugh Rudnick, and Pierluigi Mancarella, “Identifying Optimal Portfolios of Resilient Network Investments Against Natural Hazards, With Applications to Earthquakes”, IEEE Transactions on Power Systems, Oct. 2019

Optimal portfolio solutions for resilience enhancement for different budgets



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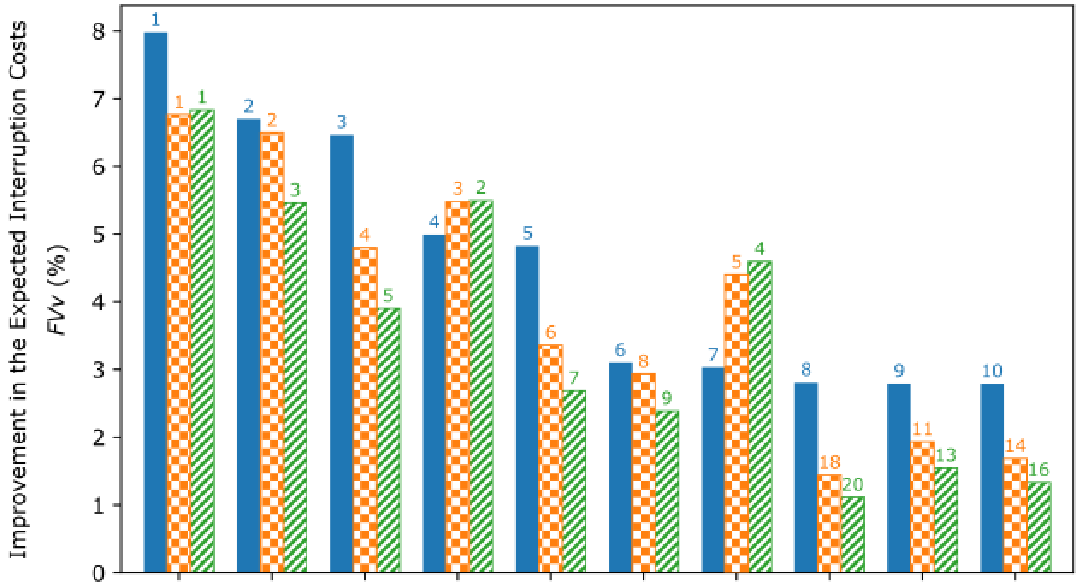
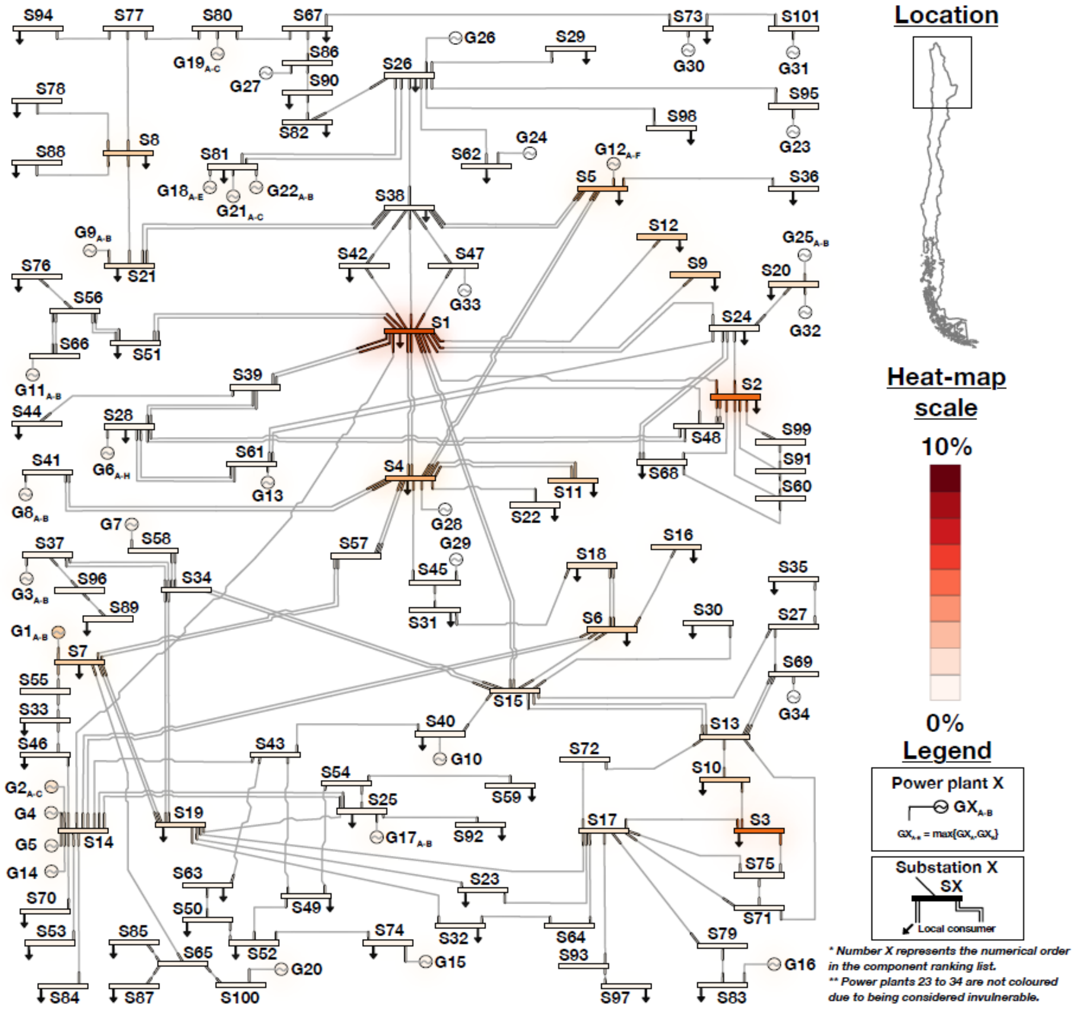
Criticality Identification and Ranking



Component code	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Demand (GWh)	6	1865	2027	535	1270	327	760	755	706	498
Lines connected	15	8	3	12	5	6	6	4	1	2



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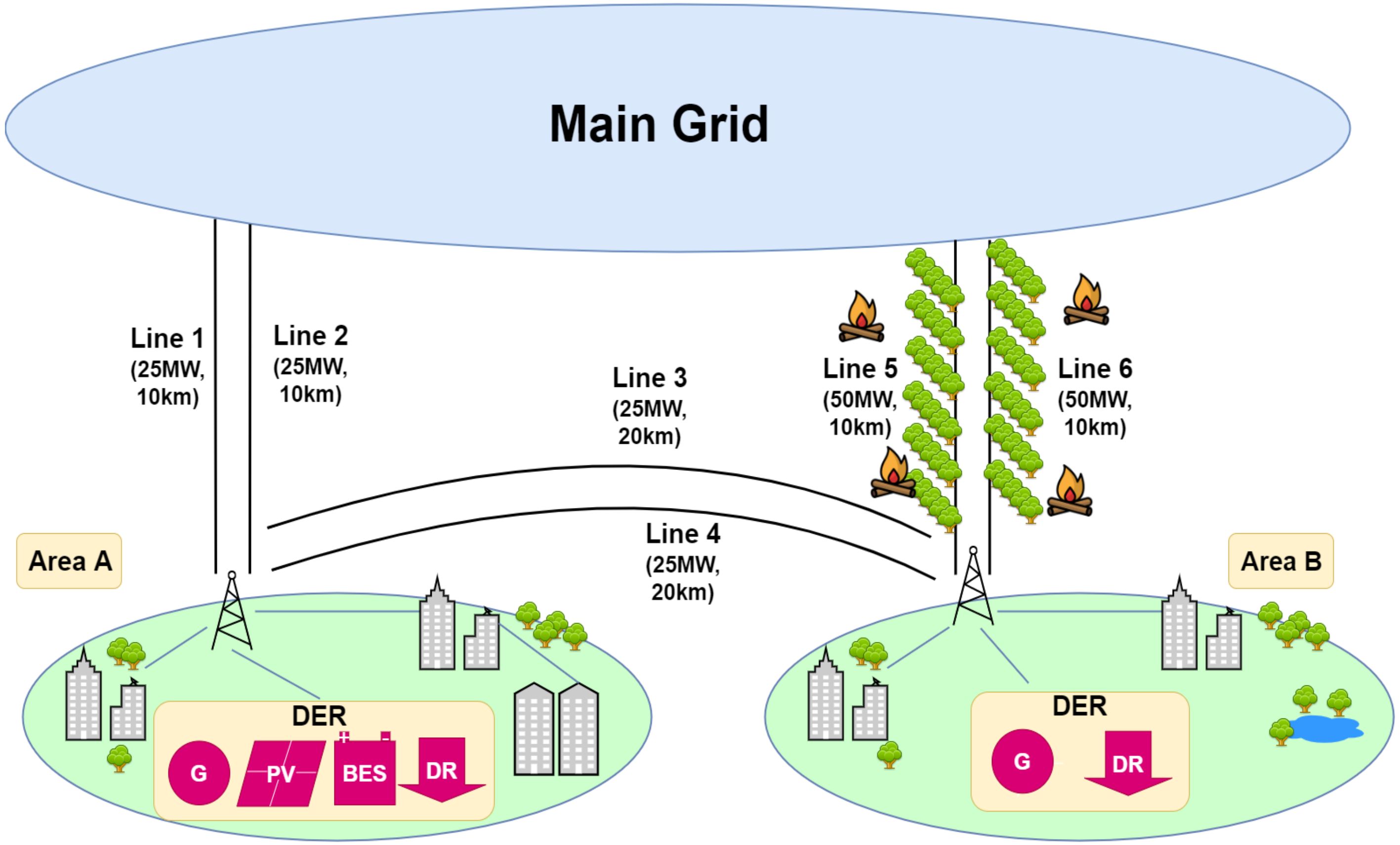
Resilience from Distributed Generation: Case of Wildfires



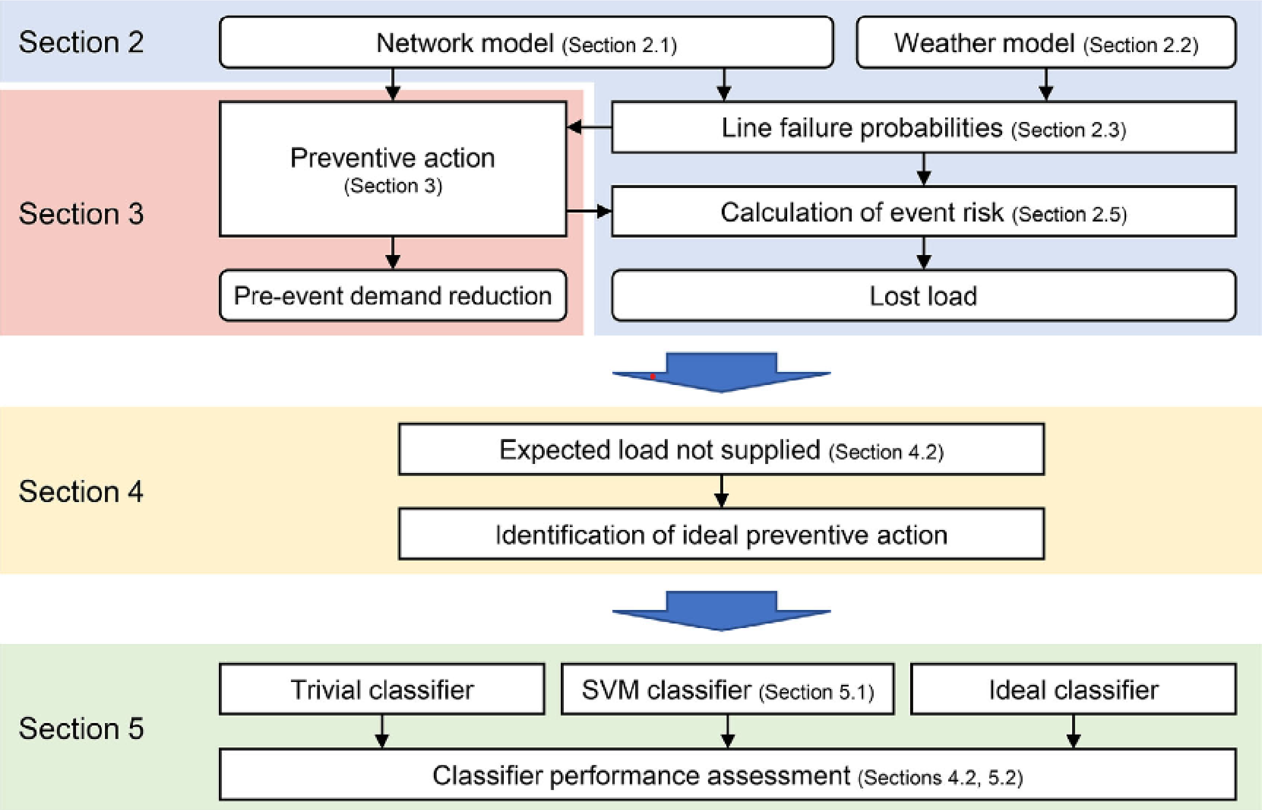
R. Moreno, D. N. Trakas, M. Jamieson, M. Panteli, P. Mancarella, G. Strbac, C. Marnay, and N. Hatziargyriou, “Microgrids against Wildfires: Distributed Energy Resources Enhancing System Resilience”, IEEE Power and Energy Magazine, 2022 January/February issue

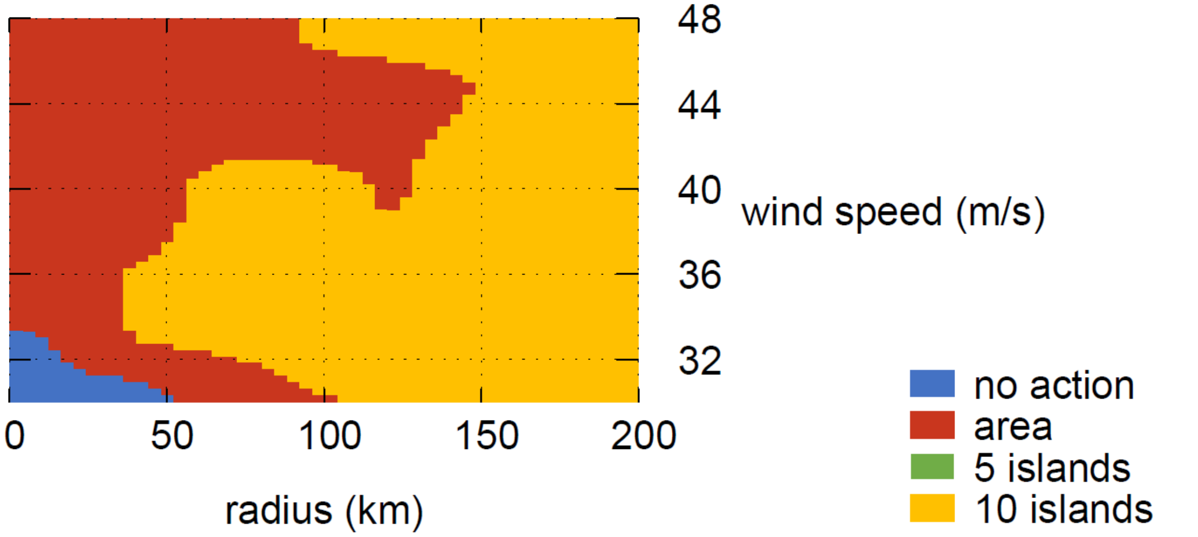
Resilience from Distributed Generation: Case of Wildfires

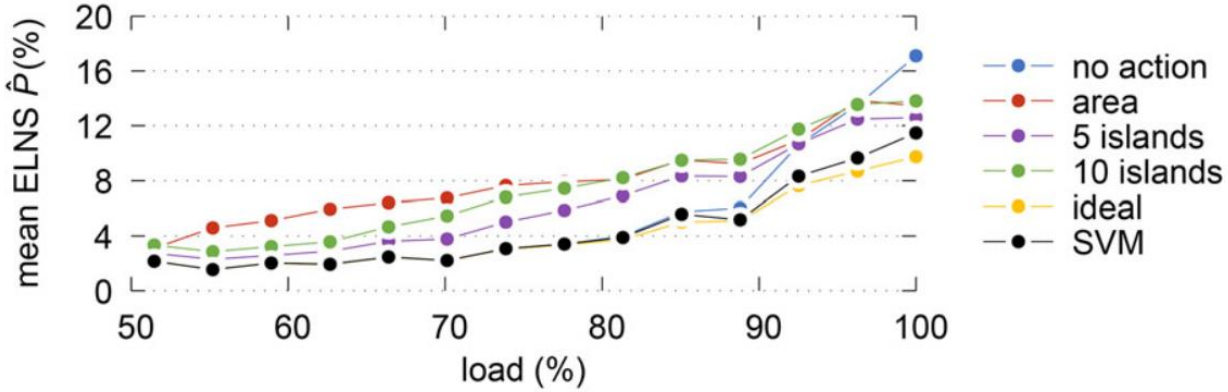
	Case A	Case A (OoS)	Case B
Assets and measures	L1, L2, L5, L6, MG, DR	L1, L2, L5, L6, MG, DR	L1, L2, L3, L4, L5, PV, BES, MG, DR
PV+BESS investment cost	-	-	11,500,000
Line investment cost	112,500	112,500	150,000
Operational cost	32,850,347	33,115,453	21,901,265
Lost load cost	26,682	19,665,051	6,416
Total cost	32,989,529	52,893,004	33,557,680

- **Case A:** the risk of wildfires in the neighboring area of lines 5 and 6 is neglected
- **Case A (OoS)**: features the same infrastructure as the previous Case A, where the costs of operation and unserved energy have been re-evaluated, including the risk of wildfires
- **Case B:** corresponds to the optimal design when the risk of wildfires is appropriately considered

Machine-Learning Driven Operational Decision-Making







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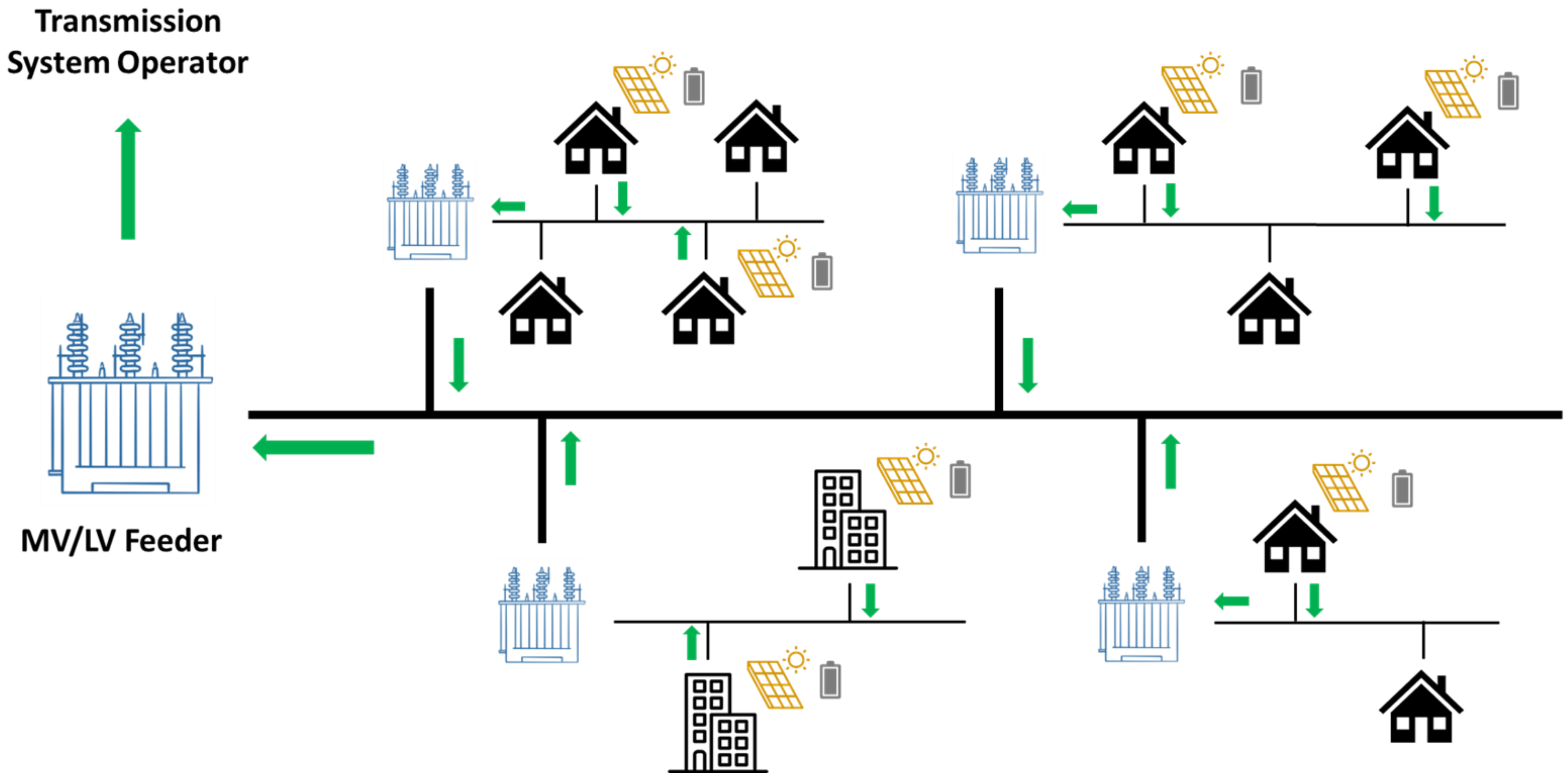
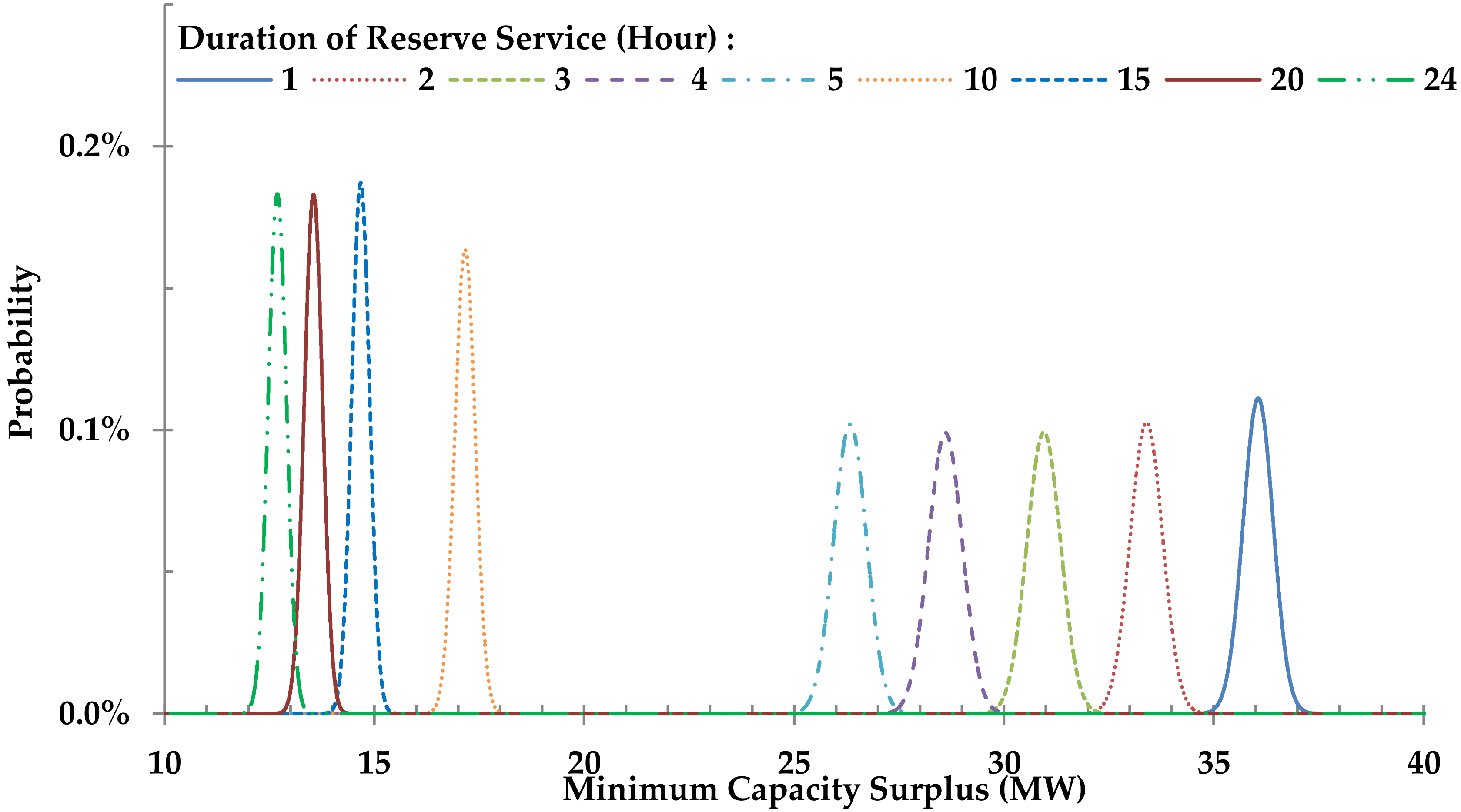
4TO FORO XM
Una mirada integral a la transición del sector eléctrico.

XM
Sumando energías

Aggregated Resilience and Reliability Services by DERs

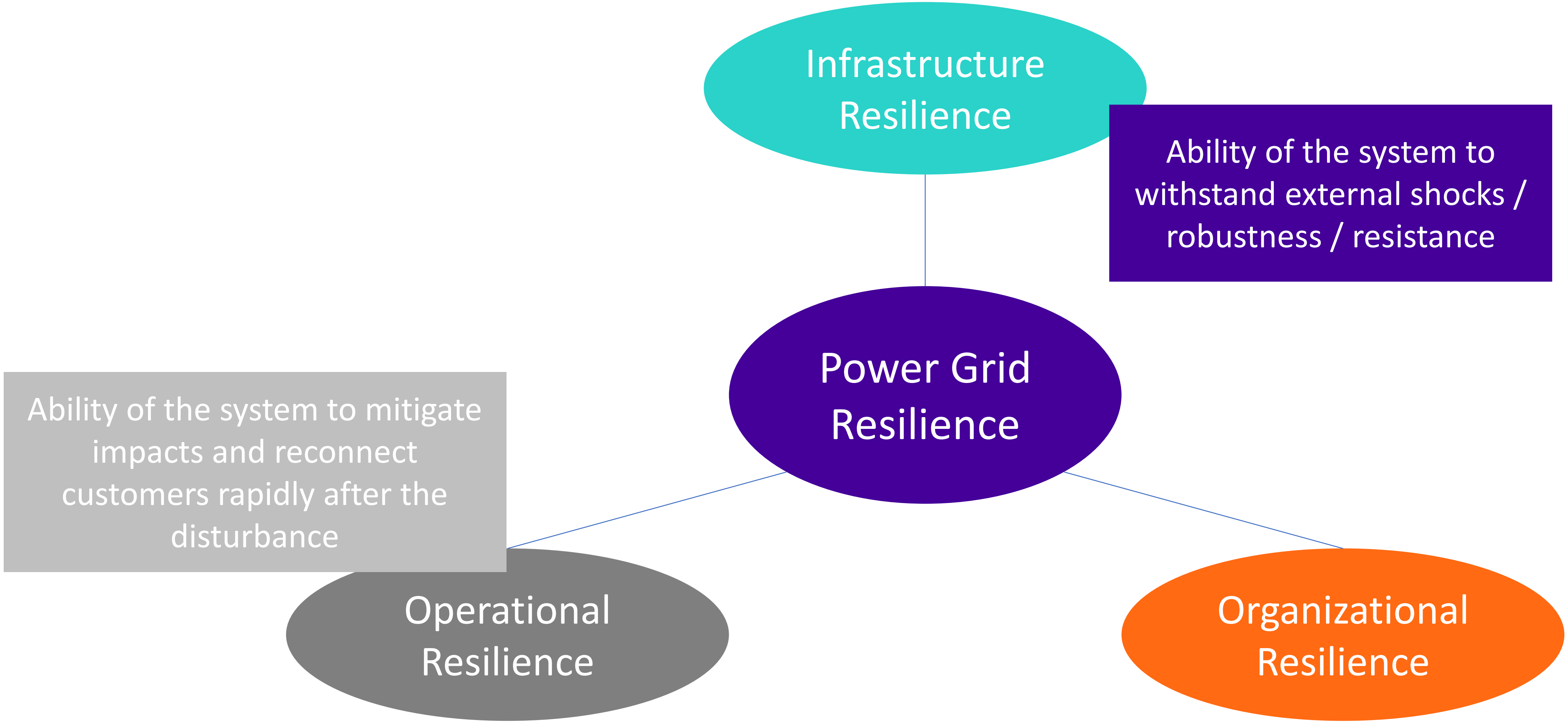


Aggregated Resilience and Reliability Services by DERs



Y. Zhou, M. Panteli, R. Moreno and P. Mancarella, "System-Level Assessment of Reliability and Resilience Provision from Microgrids", Applied Energy, Vol. 230, November 2018

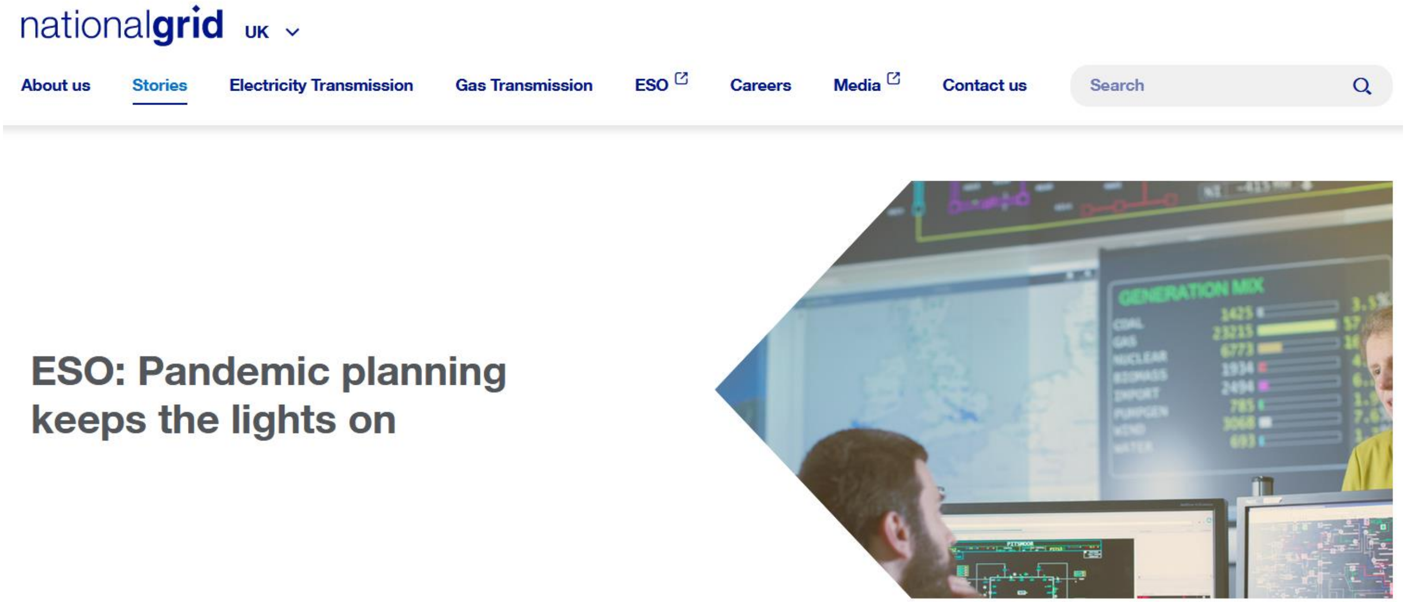
Is infrastructure and operational resilience enough?



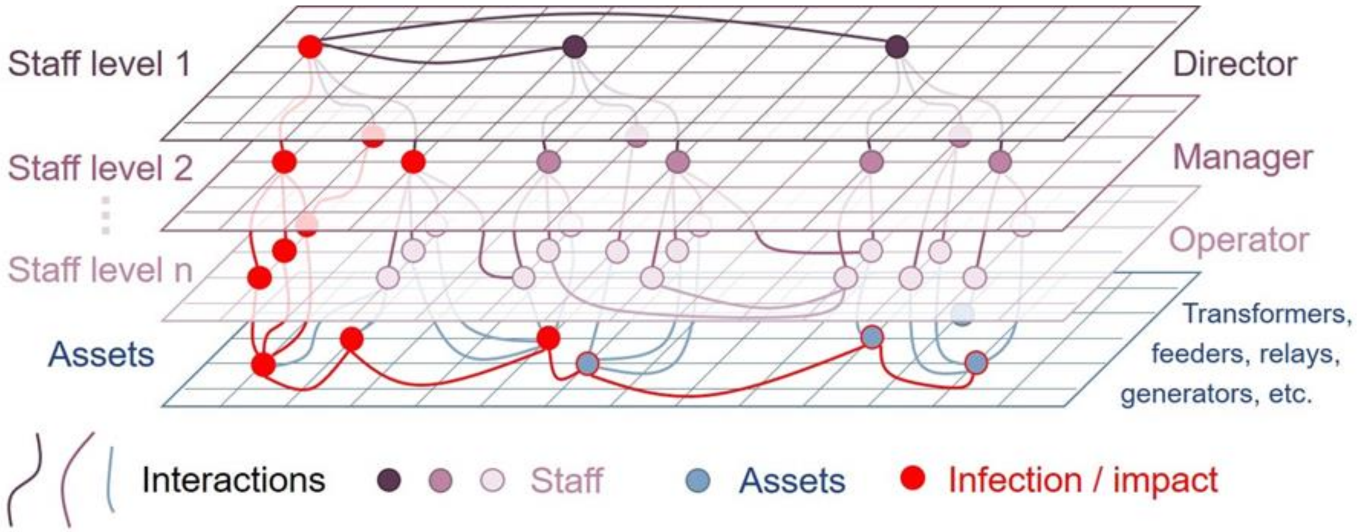
Organizational Resilience

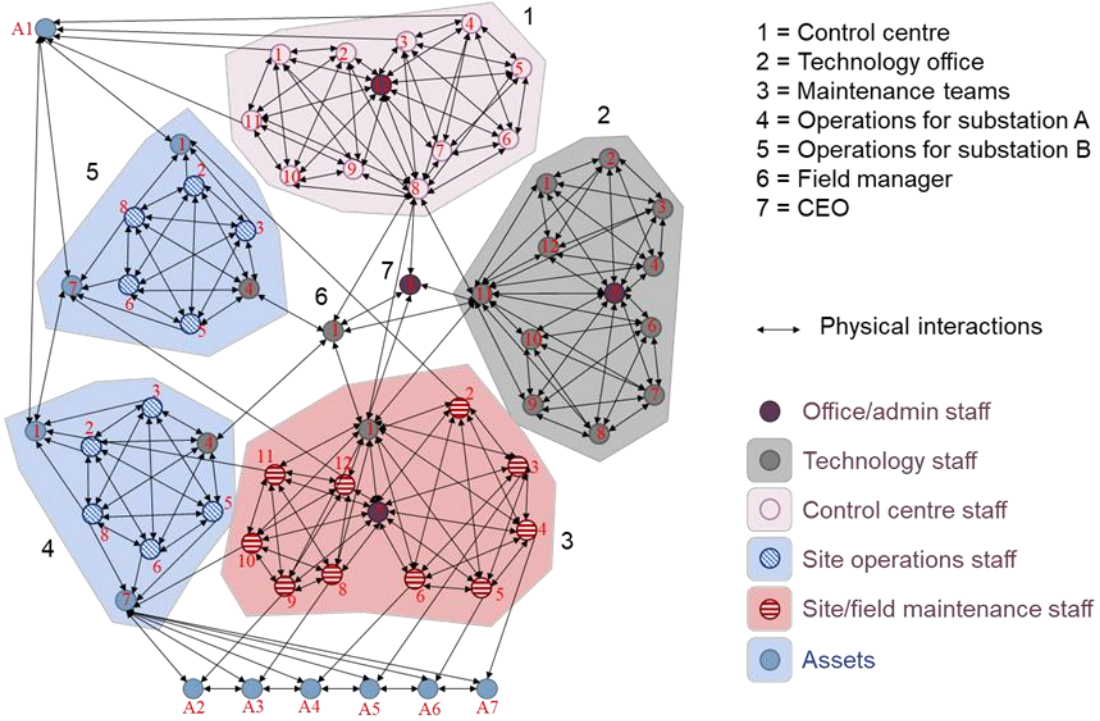
- Organizational resilience: refers to the underlying mechanisms and strategies keeping the infrastructure together, is a fundamental step towards achieving the three essential capabilities of a resilient system, namely *absorptive, adaptive and restorative capacities.*

- Essential in having key staff available, and in swiftly mobilising measures to support, protect and empower this staff to sustain rapid response and recovery and limit exposure to the virus.
- Such provision is imperative to ensure the smooth, safe and secure execution of operations, maintenance and construction activities to ensure electricity provision.



Organizational Structure and Interlinkages



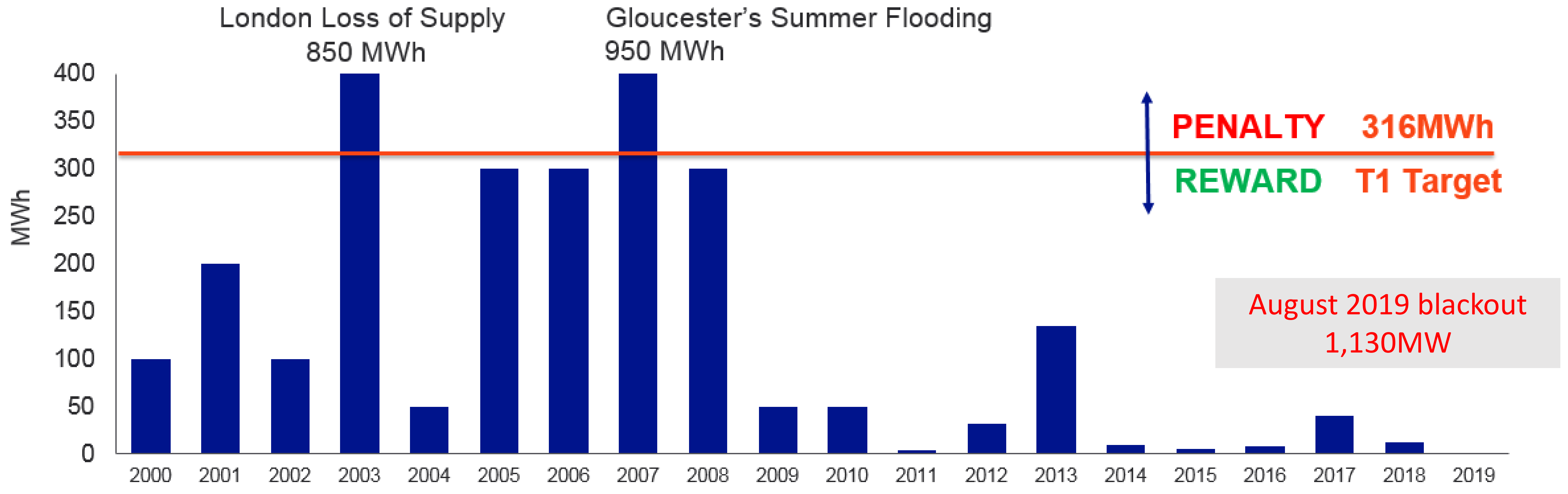


S. Skarvelis-Kazakos, M. Van Harte, M. Panteli, E. Ciapessoni, D. Cirio, A. Pitto, R. Moreno, C. Kumar, C. Mak, I. Dobson, C. Challen, M. Papic, C. Rieger, “Resilience of electric utilities during the COVID-19 pandemic in the framework of the CIGRE definition of Power System Resilience”, International Journal of Electrical Power & Energy Systems, Volume 136, 2022

Limitations in Regulatory Standards

Ofgem – RIIO-2 Final Determination

- The performance target for NGET is **147MWh** (average ENS).
- This is significantly lower than the RIIO-1 target of **316MWh**



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Regulatory and Market Matters

Operational Matters

- How can an extreme event be recognised (if there is time to do so, for example, in the case of weather fronts) when developing in real-time?
- How can regulation facilitate a close-to-real-time decision making framework for relevant stakeholders (e.g., system operator to respond to a sudden HILP event)?
- What is in the “power” of system operators and other stakeholders under extreme events? What are they allowed to do by the prevailing electricity rules?
- How can market transparency be ensured in the presence of extreme events, assuming a “nuanced” definition of extreme event?

The above points are also all particularly related to the fundamental question of *responsibilities* and most suitable *governance* for efficient decision making (which is key) as well as accounting/reporting in the presence of extreme events, especially when, operationally, some stakeholder’s interventions (e.g., by the system operator) may have avoided precipitation into say a blackout but at some cost of other stakeholders (example, pre-curtailment of renewable generation or load blocks to avoid system cascading).

Acknowledgement: Prof Pierluigi Mancarella, University of Melbourne

Regulatory and Market Matters

Planning Matters

- How should regulation discriminate “reliability from “resilience” events in the context of planning, and, again, should they be measured *coherently*, and *how*?
- What is the best approach to incorporate resilience into planning and what is its relationship with reliability-based planning based on “expected” events?
- Should a “database” of HILP event use cases and relevant information and data be developed and become part of the tests in planning new asset?
- Can existing cost-benefit analysis (CBA) methodologies used for reliability-based network planning be extended to incorporating resilience too, or a completely different approach such as based on risk aversion would be needed?
- What is the importance of regulation in addressing and facilitating the development of non-network, flexible solutions?
- To what extent should resilient decisions and planning strategies be pro-active, or somehow be able to adapt, time by time, to “new” extreme events (“adaptation” feature of resilience)?
- How should critical interdependencies be accounted for when planning an electricity asset in the context of resilience?

Further Reading

- R. Moreno, D. N. Trakas, M. Jamieson, M. Panteli, P. Mancarella, G. Strbac, C. Marnay, and N. Hatziargyriou, “Microgrids against Wildfires: Distributed Energy Resources Enhancing System Resilience”, IEEE Power and Energy Magazine, 2022 January/February issue
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