Security, reliability and resilience from microgrids:

Techno-economic and regulatory challenges and opportunities

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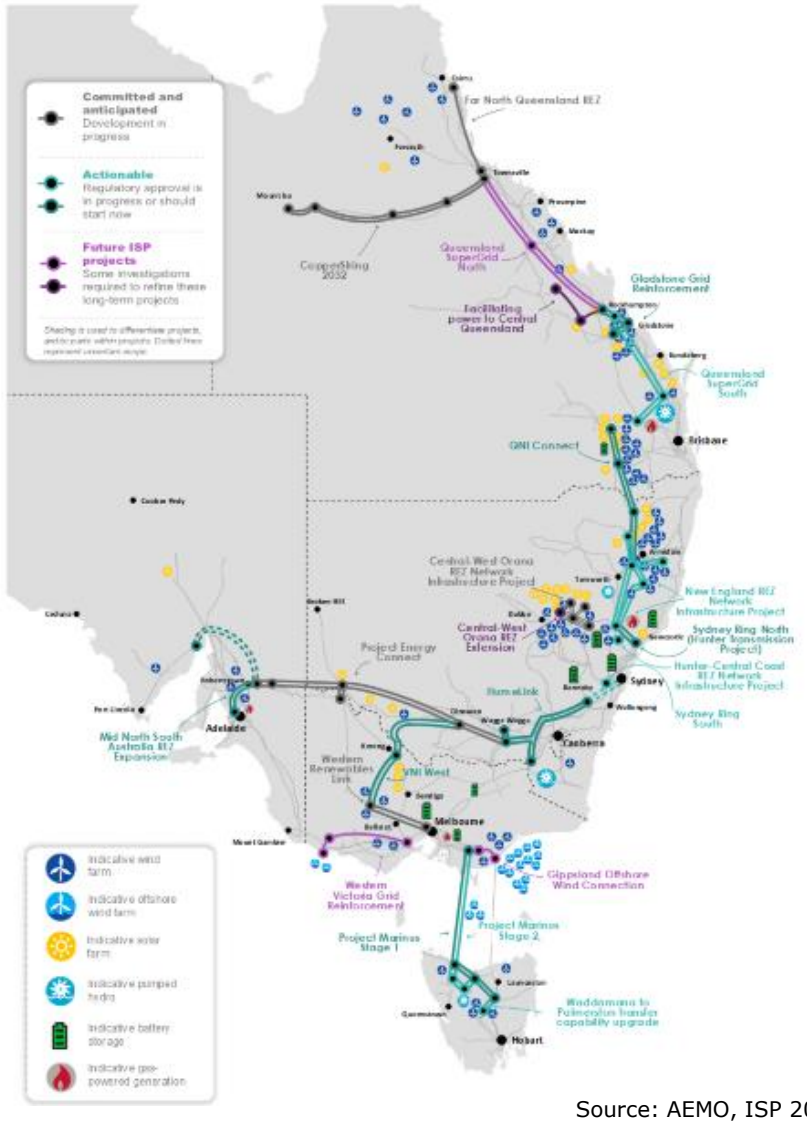
Shenzhen-Macao 2025 Symposium on Microgrids 2025

University of Macao

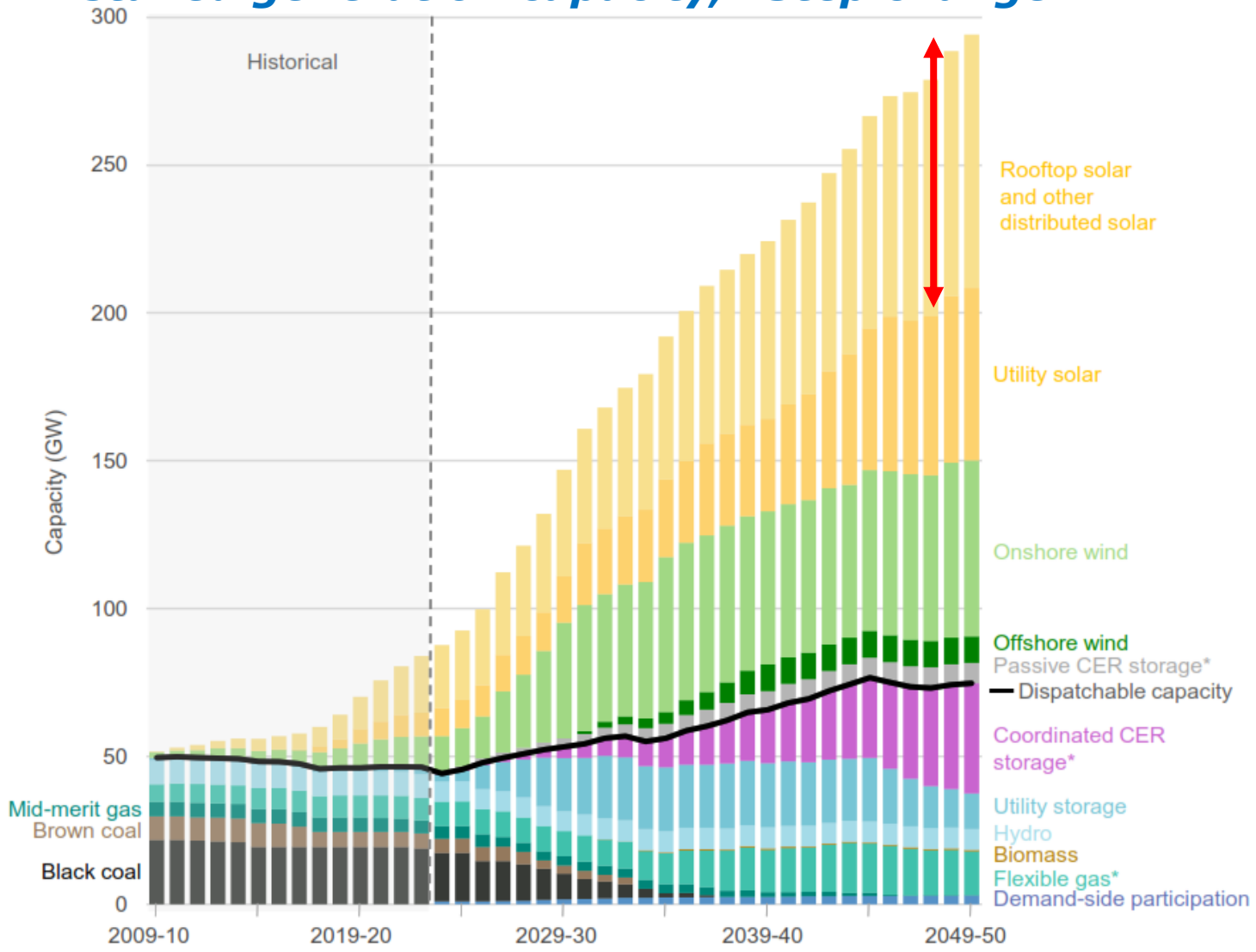
Macao, China, 12th November 2025

Transition or revolution?

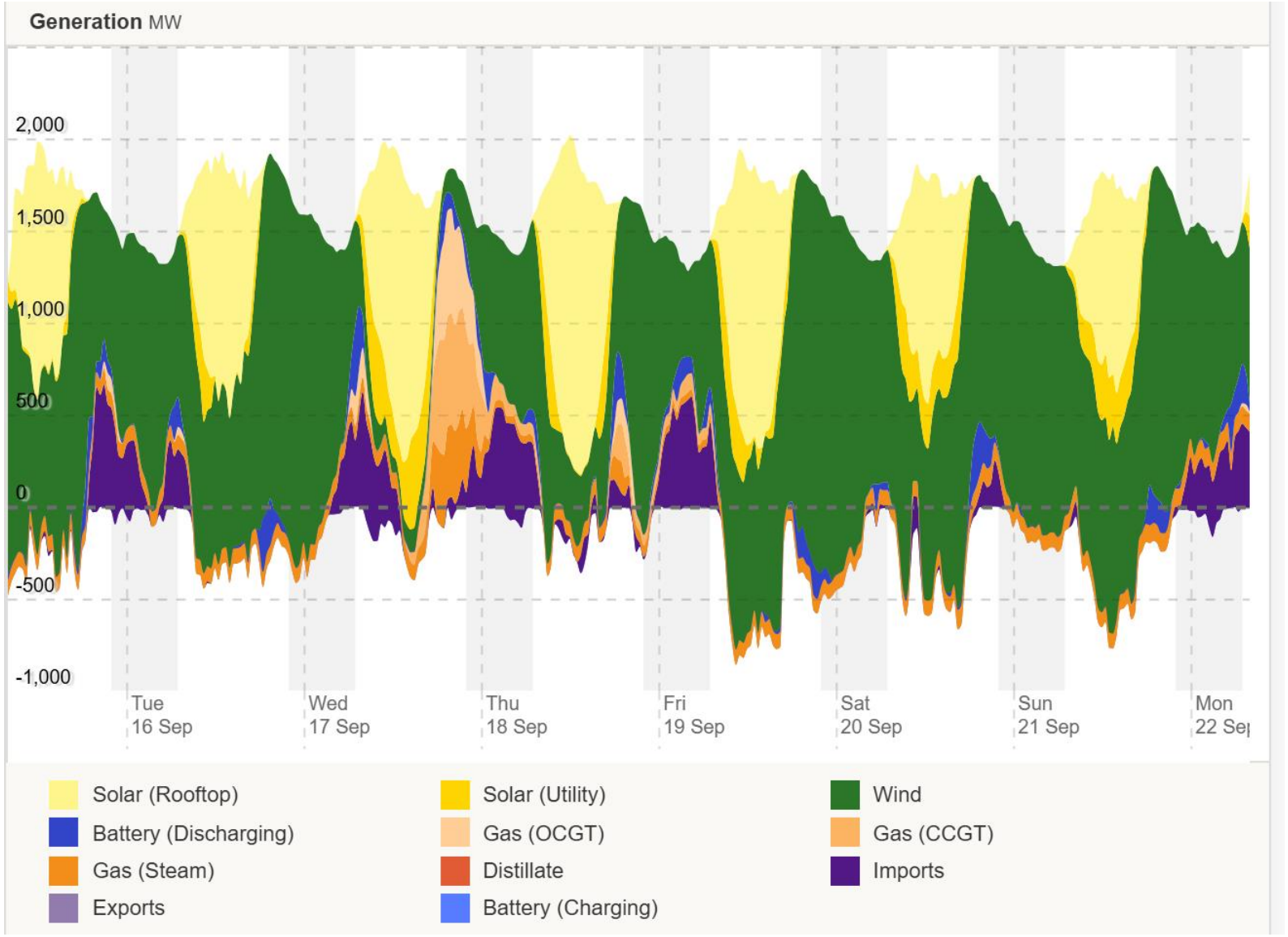


Source: AEMO, ISP 2024

Installed generation capacity, "Step change"



Fast-forward to the future!



Source: AEMO and OpenNEM

Issues with the old paradigm

Fit-and-forget is NOT fit-for-purpose!

Visible generators

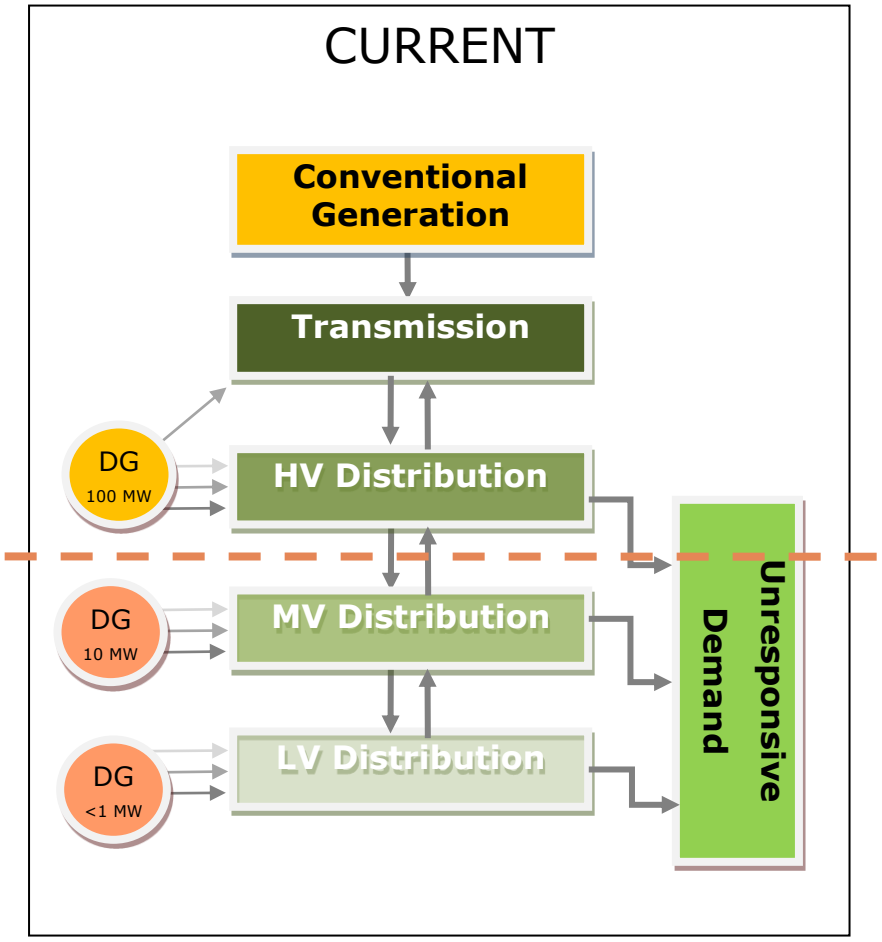
=

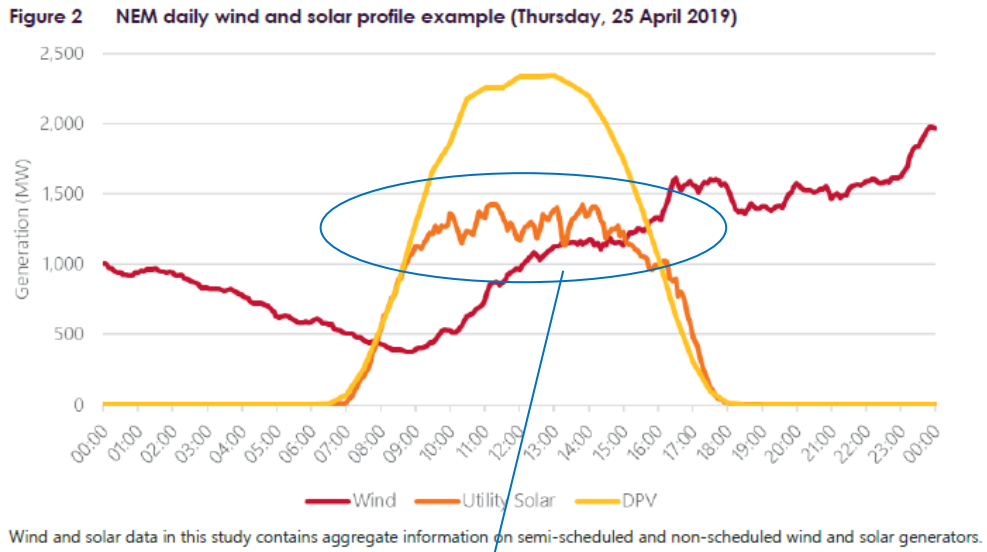
"dispatchable" and "controllable"

Invisible **DERs**

=

"non-dispatchable" and "non-controllable"



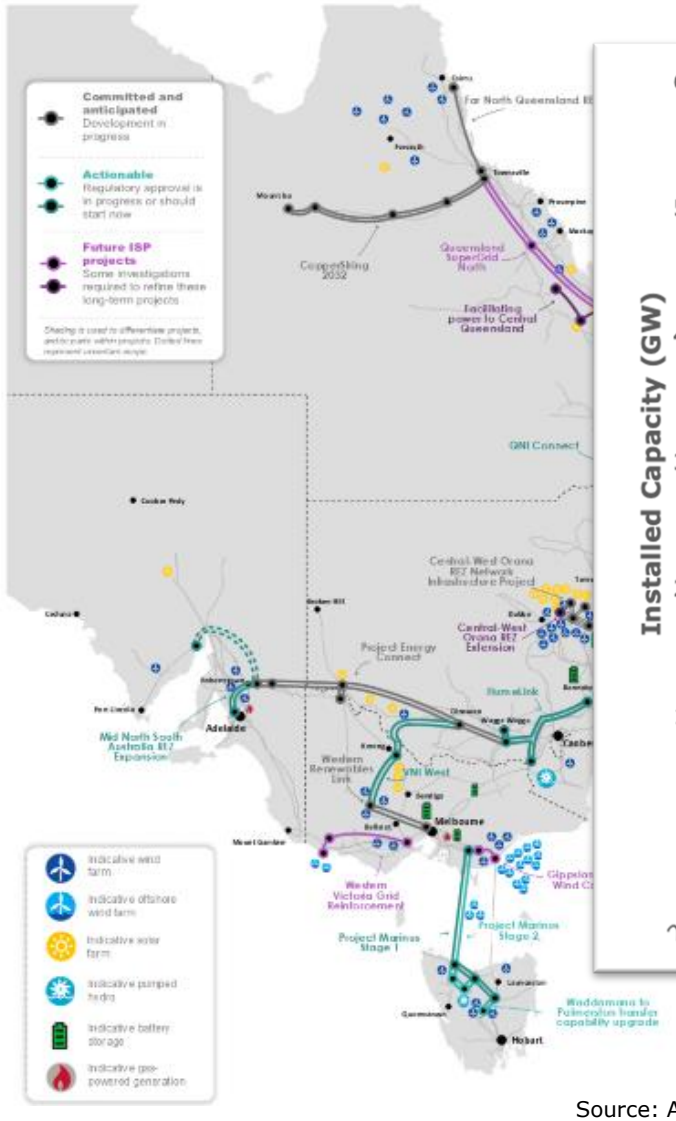


Source: AEMO

Economic self-curtailment and physical curtailment

Need for physical and market visibility and coordination!

Coordinated CER as key storage resources



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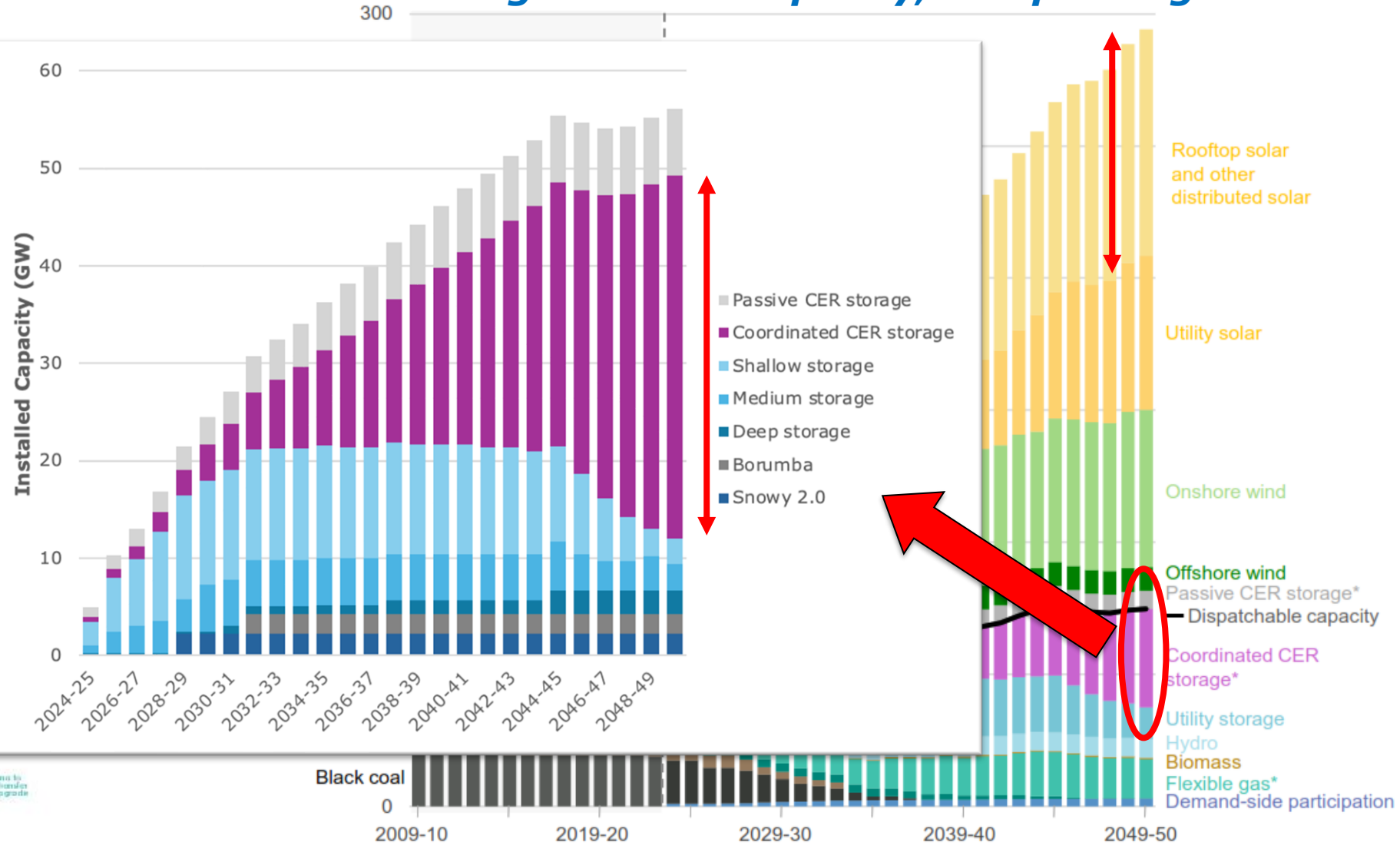
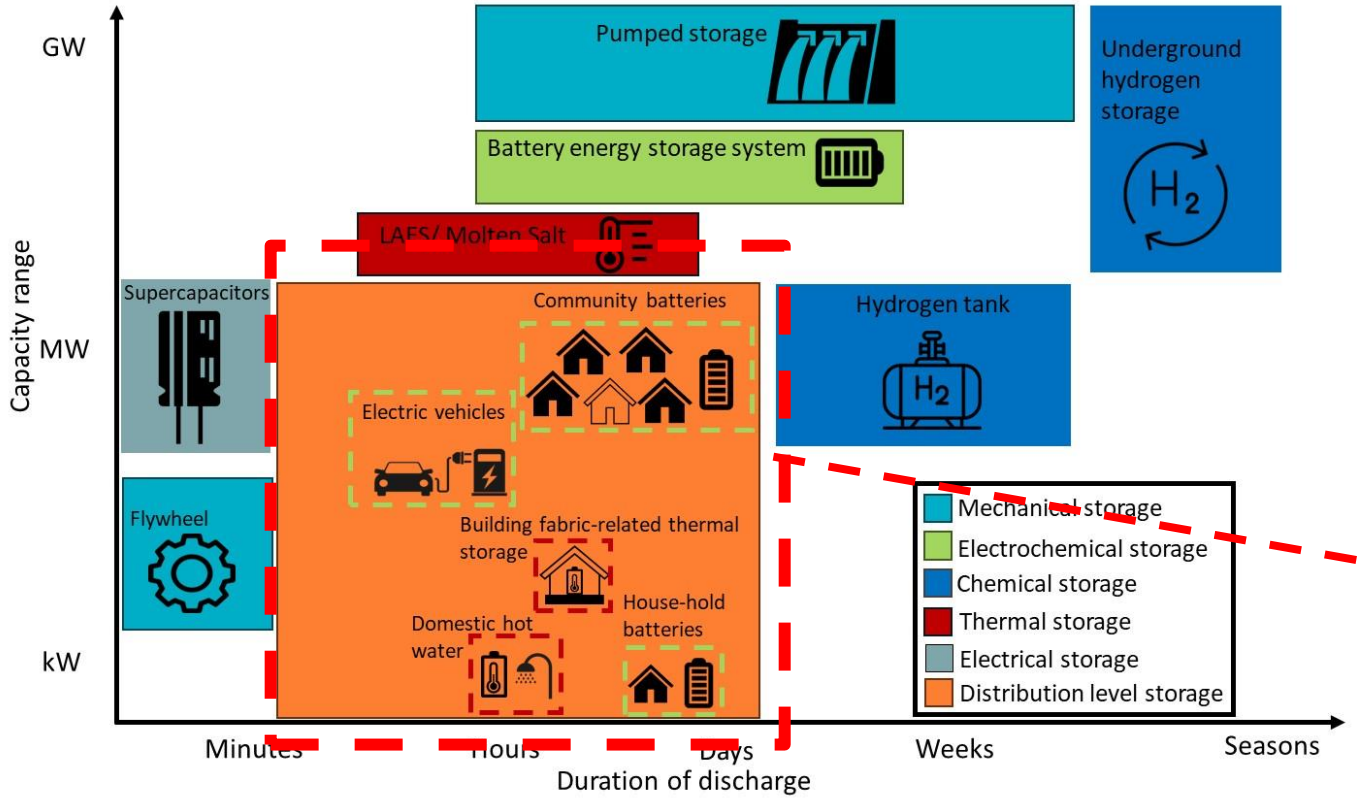
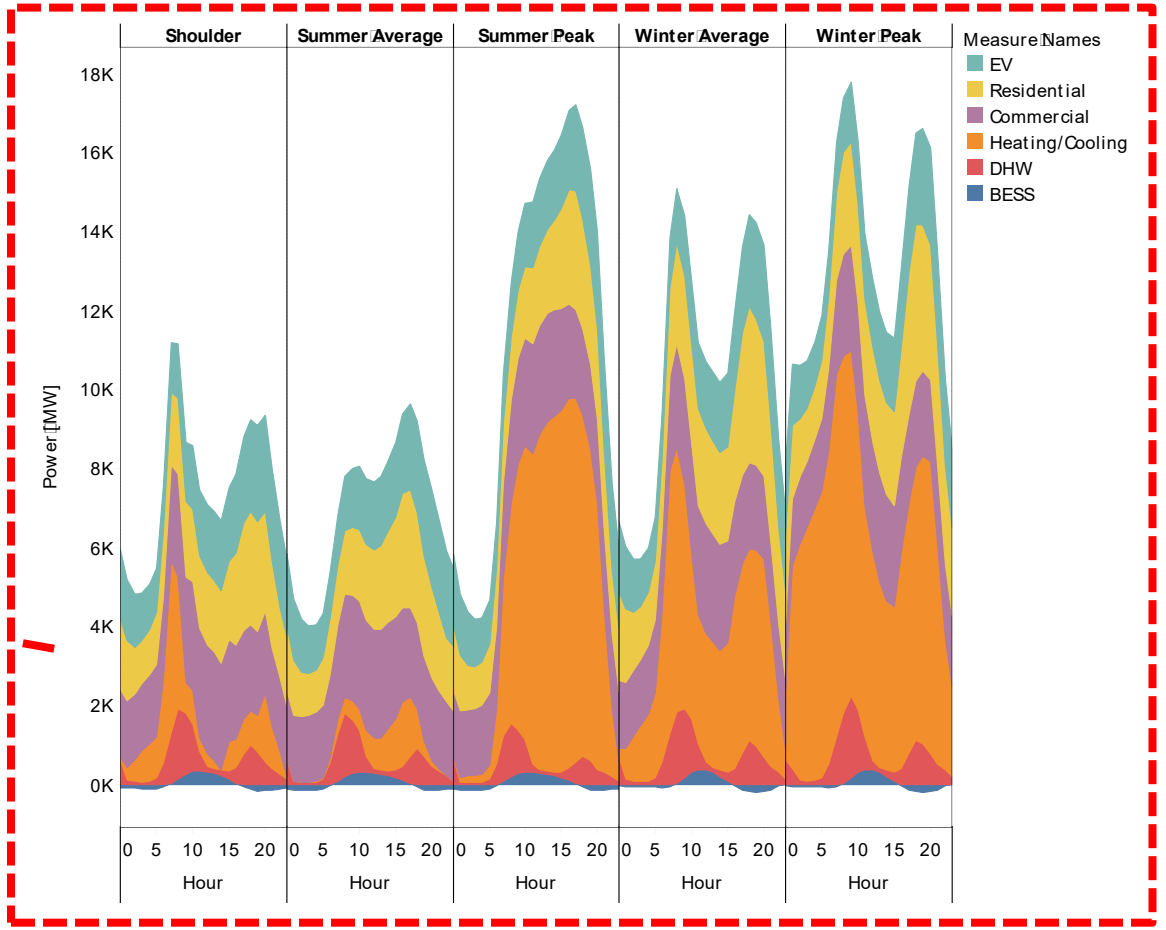


Source: AEMO, ISP 2024

Flexible demand as *"virtual storage"*

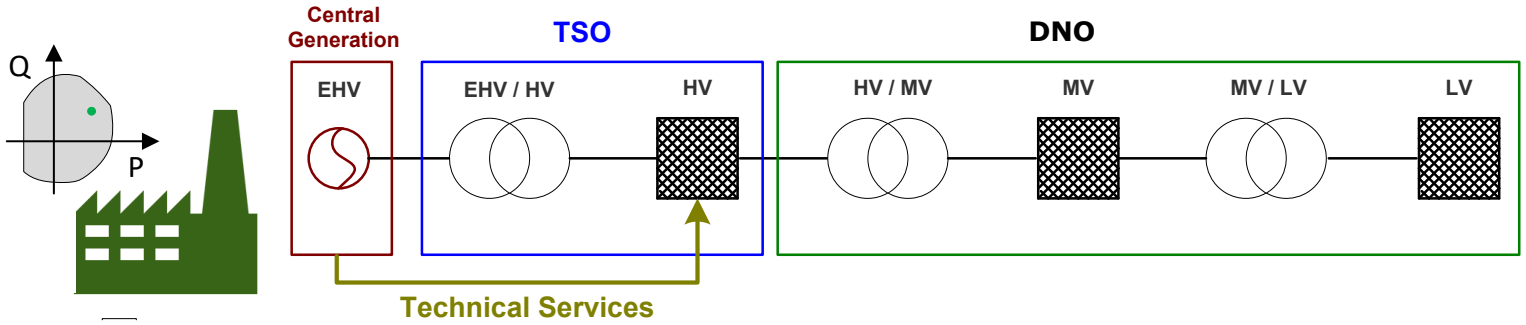


2050 Victorian electrified demand



J. Vorwerk, *et al.*, "Electrifying thermal loads vs. installing batteries: A case study on fast frequency resource potentials of the Victorian power system", *Electric Power Systems Research*, Volume 235, October 2024, 110622

Historical provision of flexibility, security and reliability



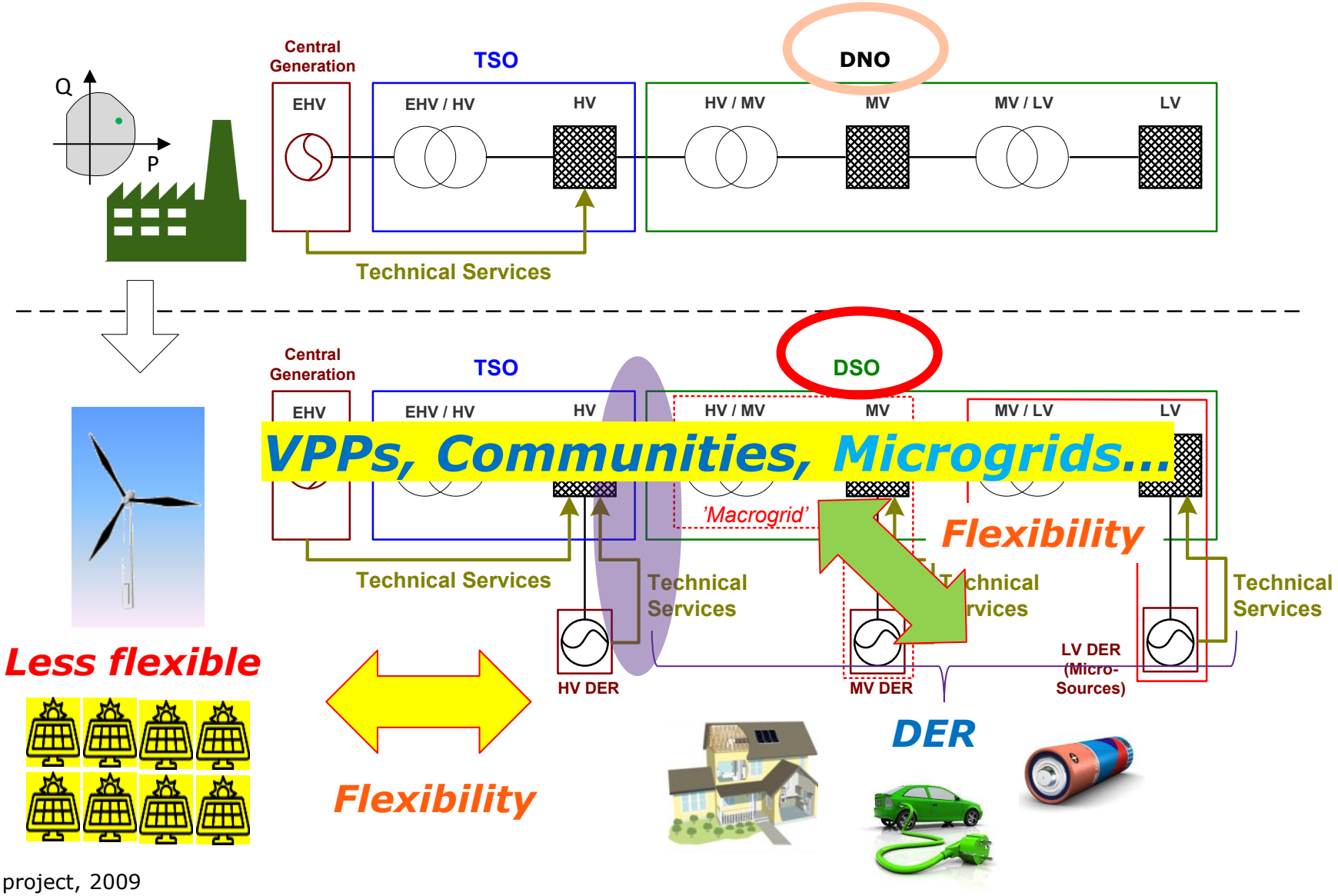
Inflexibility

Flexibility

Source: "More Microgrids" project, 2009

(Images sourced from the internet)

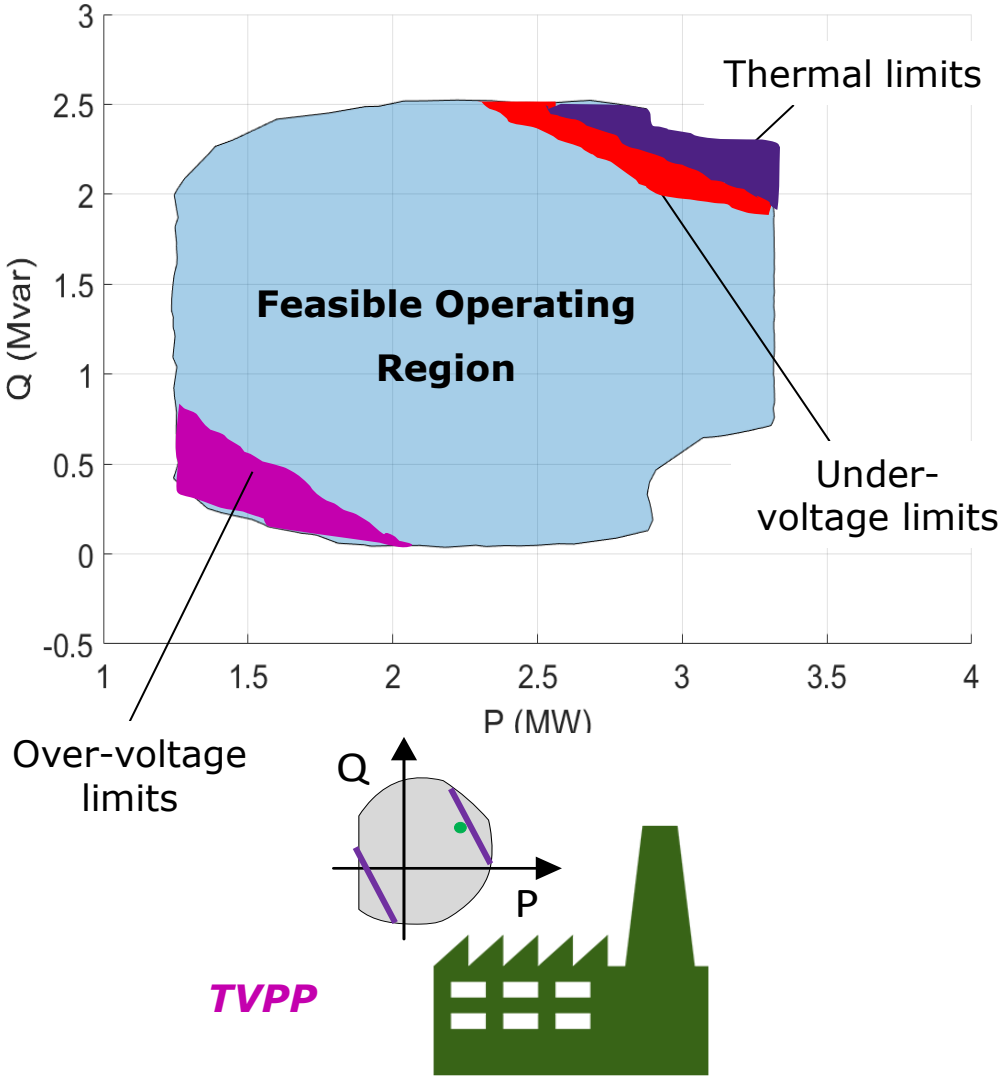
Future provision of flexibility, security and reliability

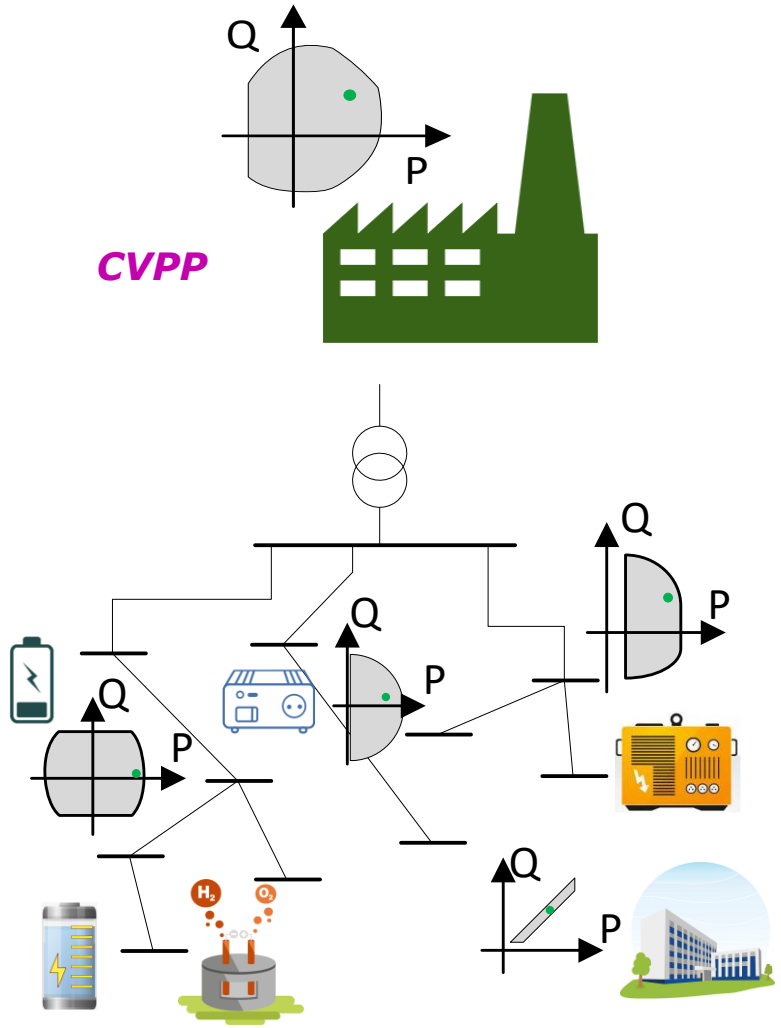


Source: "More Microgrids" project, 2009

(Images sourced from the internet)

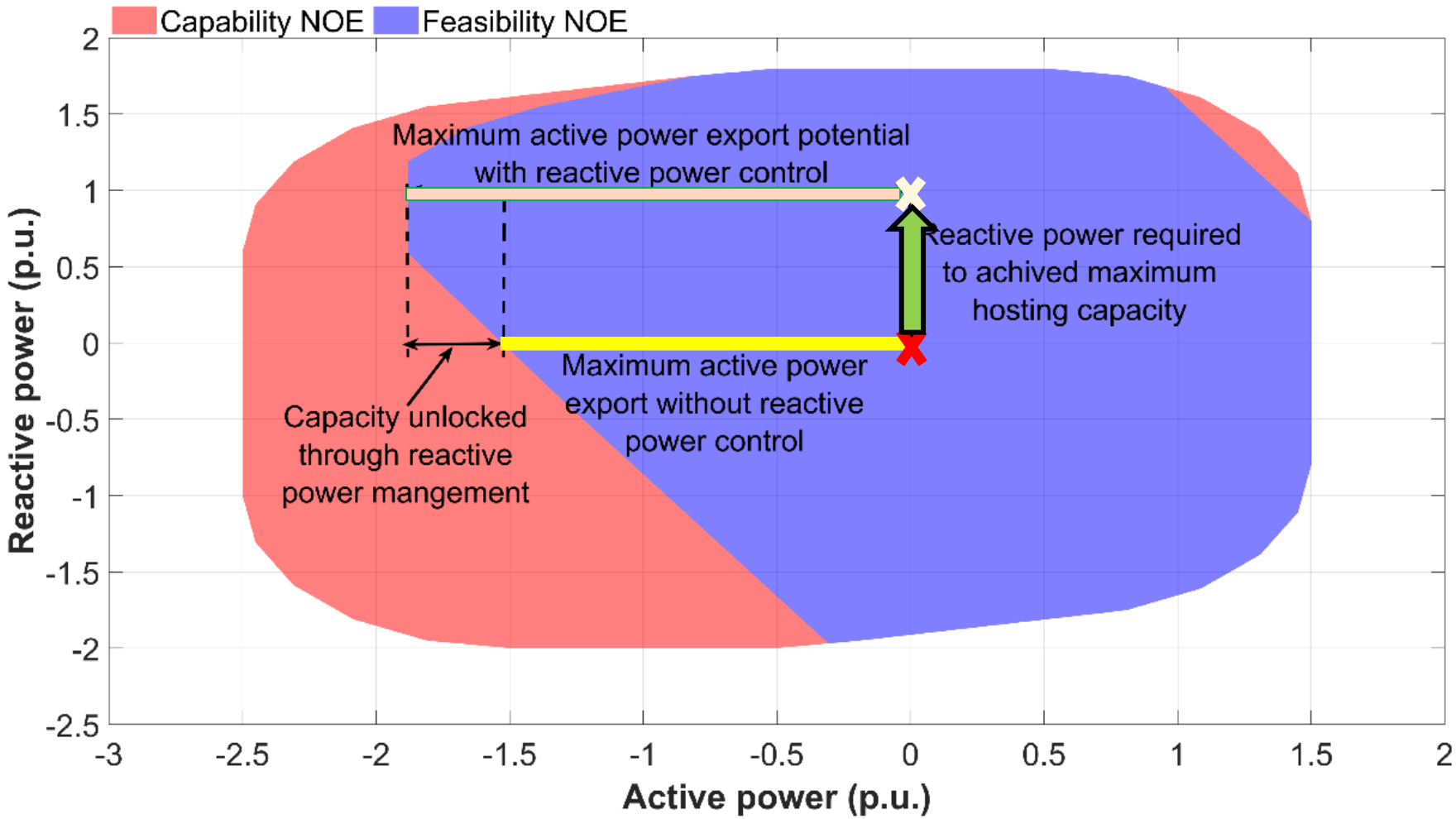
Role of and tools for DSO and microgrid management





S. Riaz *et al*, "Modelling and characterisation of flexibility from distributed energy resources", *IEEE Transactions on Power Systems*, July 2021

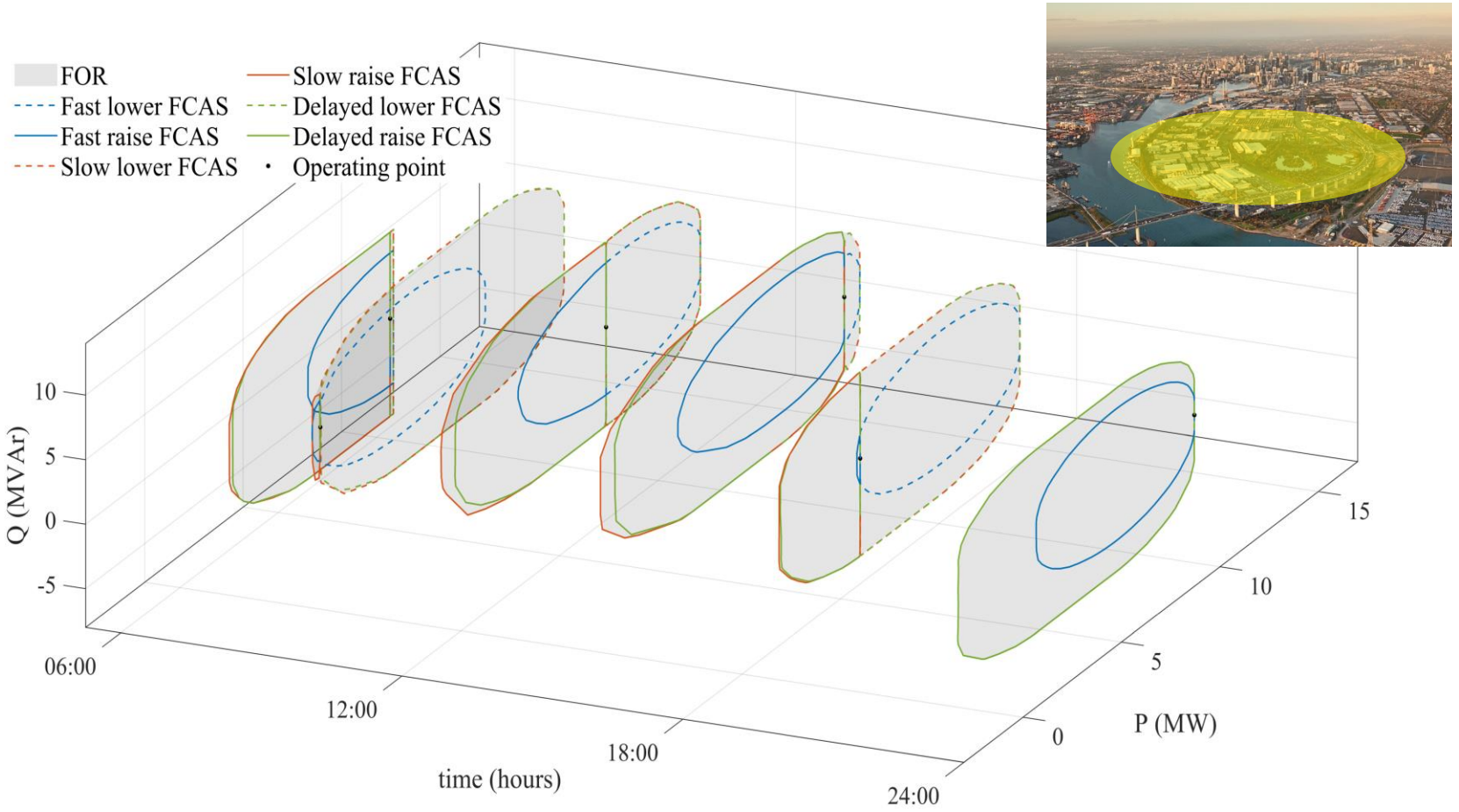
Microgrid nodal operating envelopes for system and local services



M. Liu *et al.*, "Grid and market services from the edge", *IEEE Power and Energy Magazine*, July/August 2021, *Invited Paper*

S. Riaz *et al*, "Modelling and characterisation of flexibility from distributed energy resources", *IEEE Transactions on Power Systems*, July 2021

Microgrids for whole-system and market services



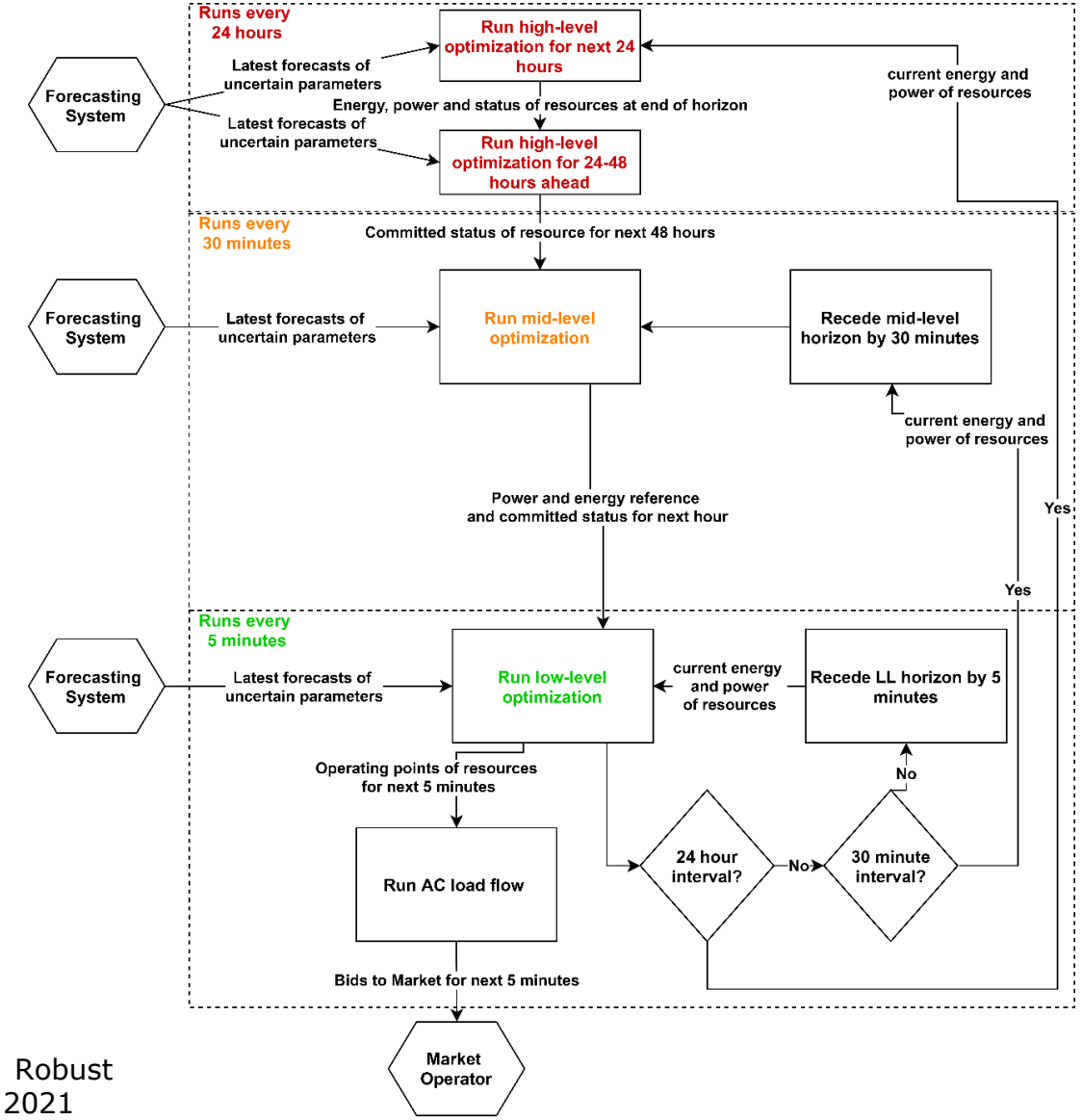
H. Wang, *et al*, "Integrated Techno-economic Modeling, Flexibility Analysis, and Business Case Assessment of an Urban Virtual Power Plant with Multi-market Co-optimization", *Applied Energy*, Volume 259, 1 February 2020, 114142

J. Naughton, et al., "Co-Optimizing Virtual Power Plant Services Under Uncertainty: A Robust Scheduling and Receding Horizon Dispatch Approach," in *IEEE Trans. on Power Syst.*, 36, 5, pp. 3960-3972, 2021

S. Riaz *et al*, "Modelling and characterisation of flexibility from distributed energy resources", *IEEE Transactions on Power Systems*, July 2021;

Network-aware, multi-service value stack under uncertainty

- High-level is run twice every 24 hours (24-48 hour schedule is preliminary)
- Mid-Level *recedes* every 30 minutes
- Low-Level *recedes* every 5 minutes
- AC load flow is run to ensure accuracy of the low-level bids



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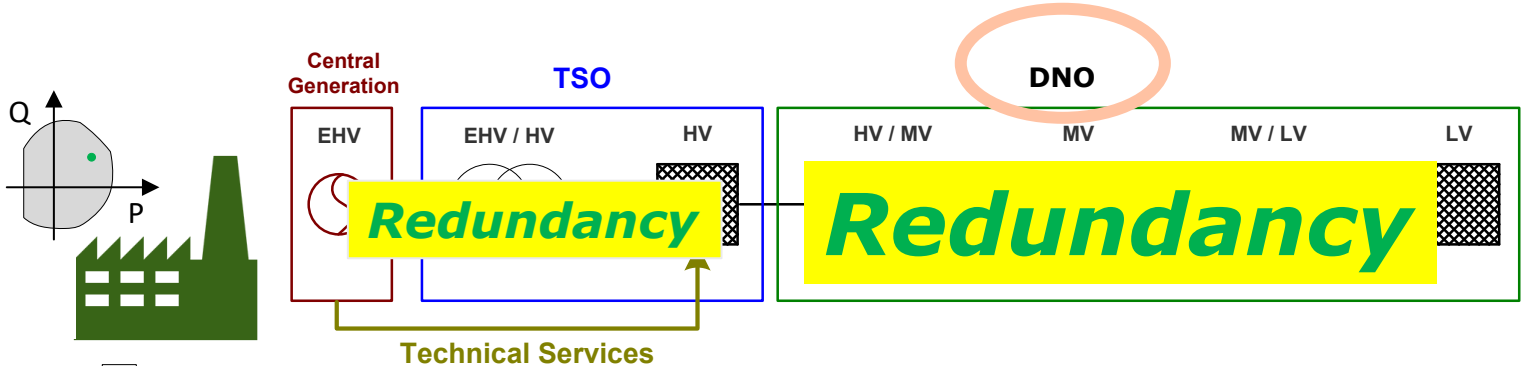
How much redundancy?



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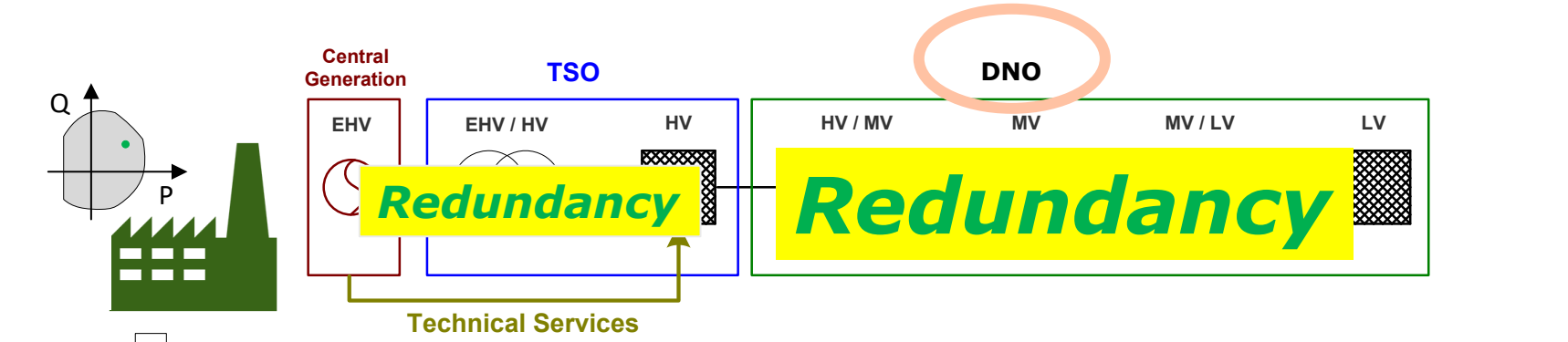
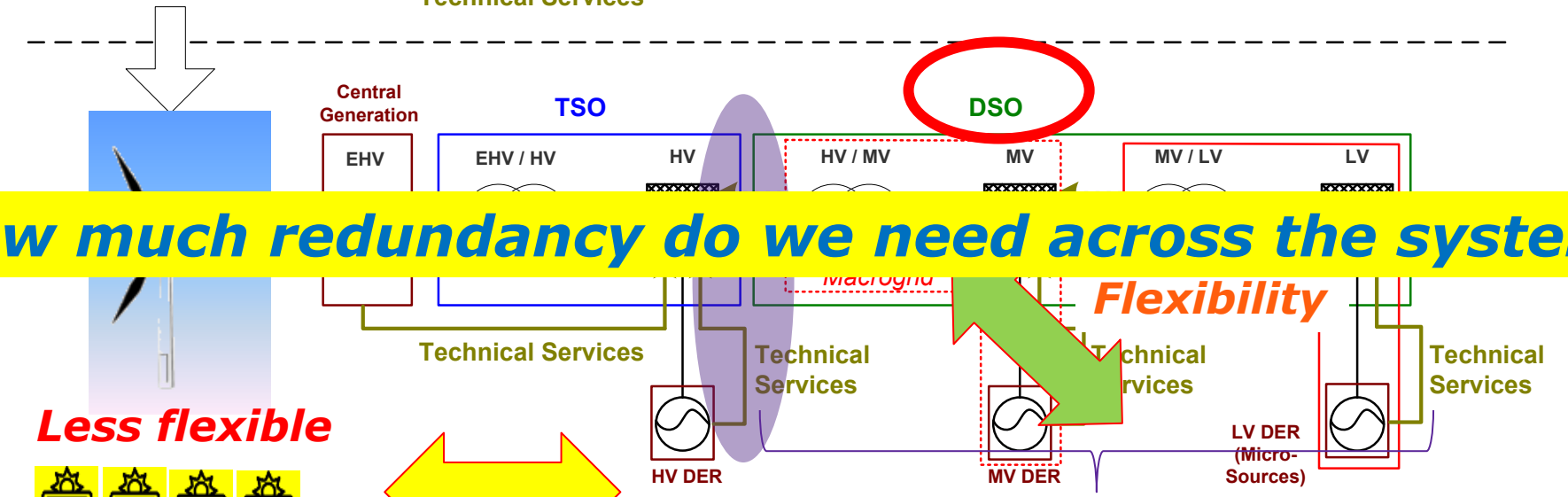




How much redundancy do we need across the system?

Source: "More Microgrids" project, 2009

(Images sourced from the internet)

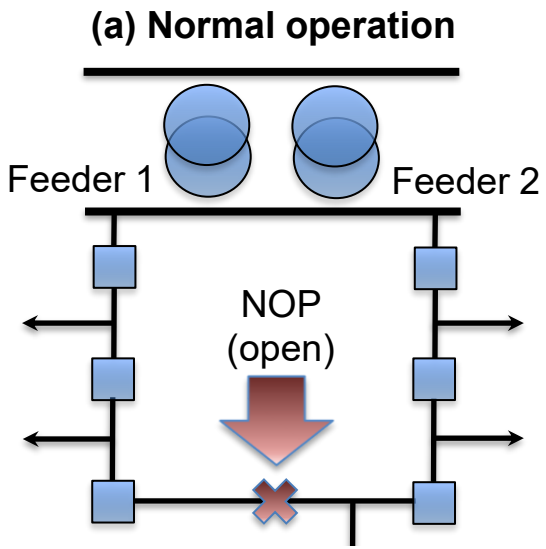
Network security and (premium) reliability services from the demand side

E. A. Martínez Ceseña, *et al.*, "Techno-economic and business case assessment of multi-energy microgrids with co-optimization of energy, reserve and reliability services," *Applied Energy*, 2018

A. L. Syrri and P. Mancarella, "Reliability and Risk Assessment of Post-Contingency Demand Response in Smart Distribution Networks", SEGAN, 7, 1-12, 2016

Network security and (premium) reliability services from the demand side

N-1 redundancy



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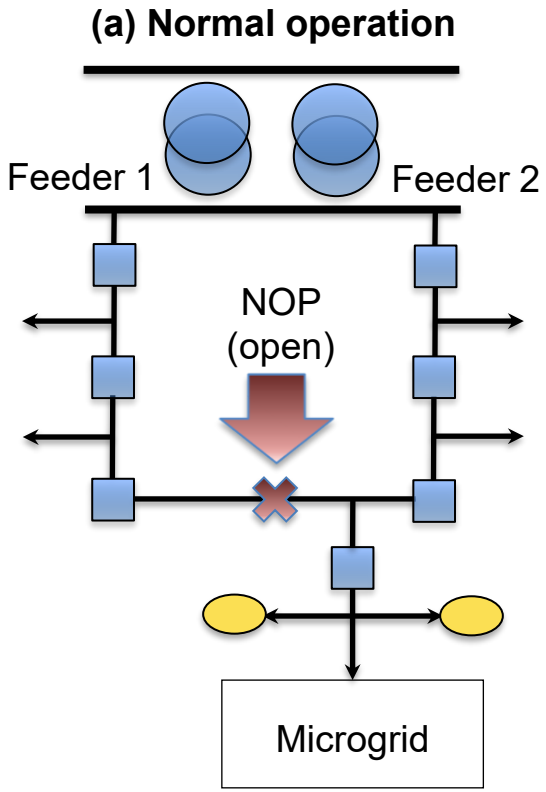

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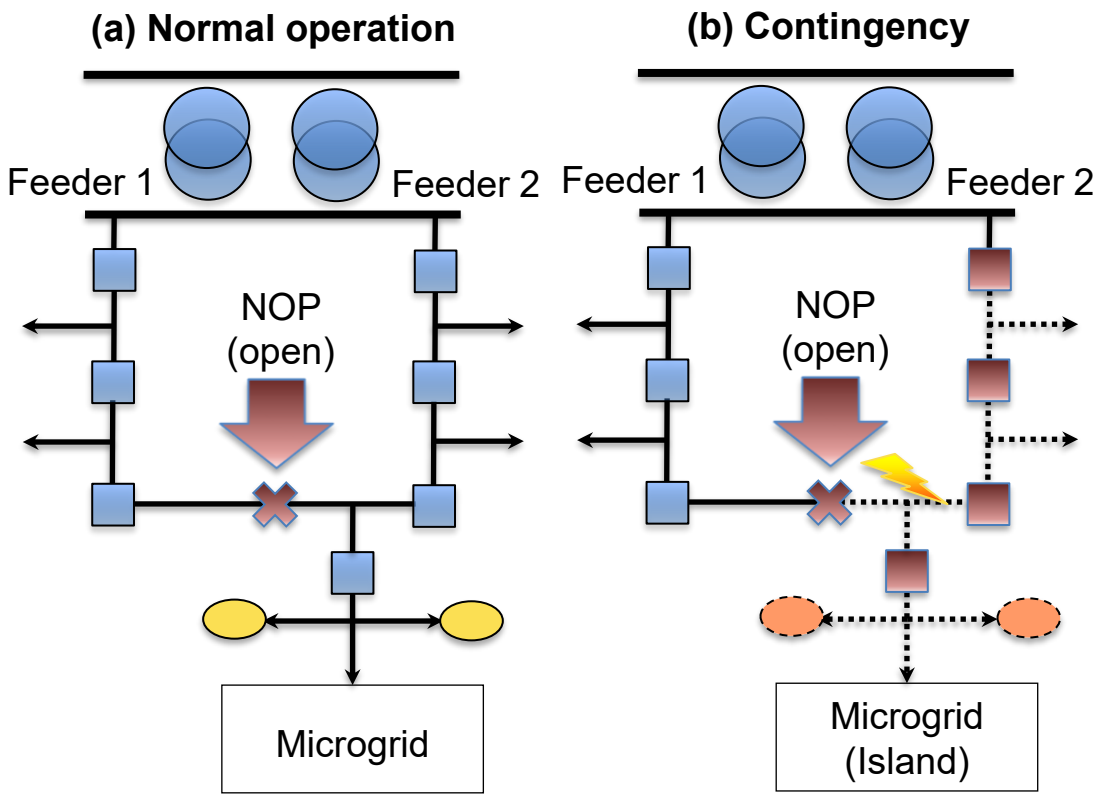

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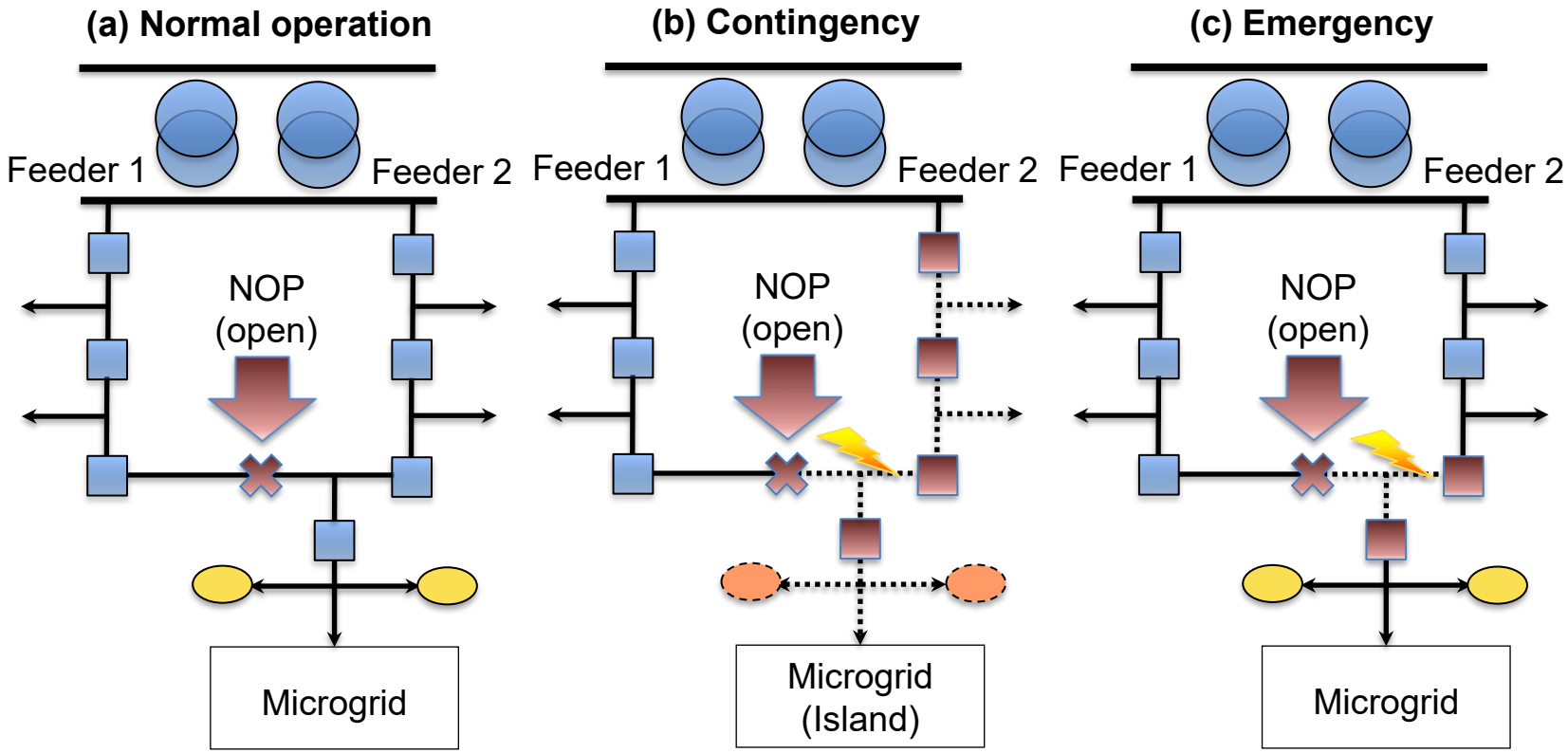
Network security and (premium) reliability services from the demand side

- With DER, ***no or less N-1 redundancy is needed***
- **Microgrids** could then also supply islanded customers during emergency conditions



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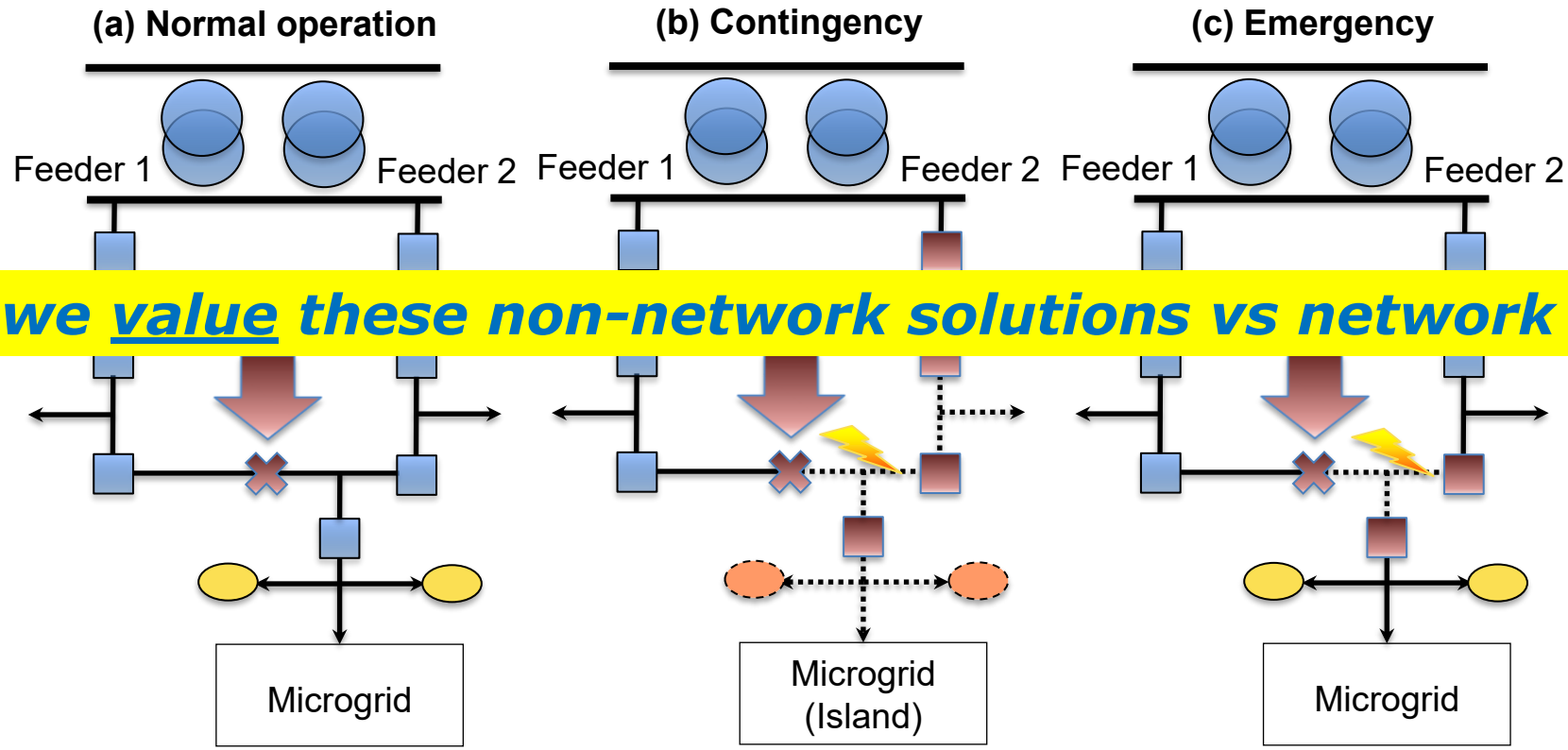
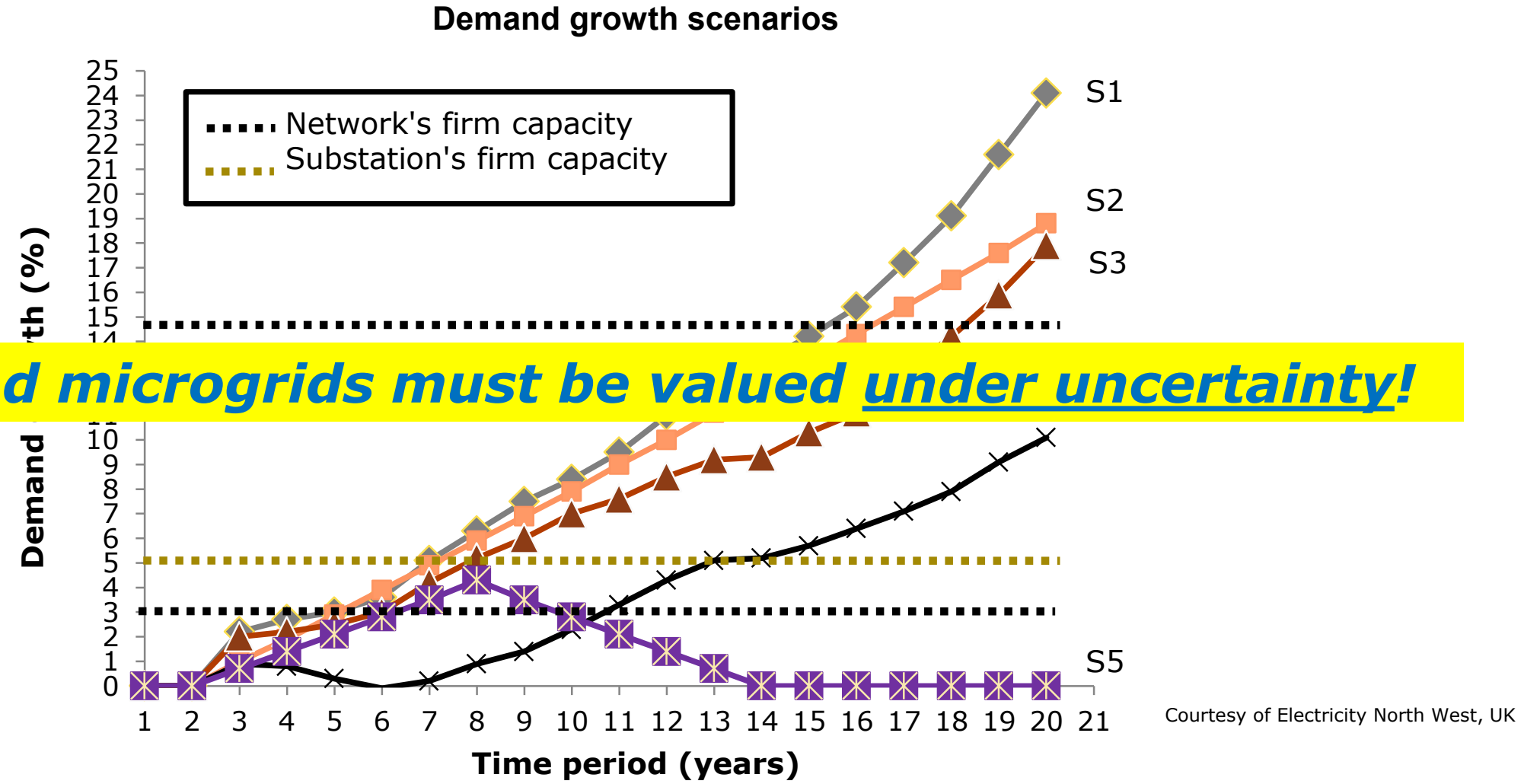


But how do we value these non-network solutions vs network solutions?

E. A. Martínez Ceseña, *et al.*, "Techno-economic and business case assessment of multi-energy microgrids with co-optimization of energy, reserve and reliability services," *Applied Energy*, 2018

A. L. Syrri and P. Mancarella, "Reliability and Risk Assessment of Post-Contingency Demand Response in Smart Distribution Networks", SEGAN, 7, 1-12, 2016

Business case for DER and microgrids: Do we really know the future?



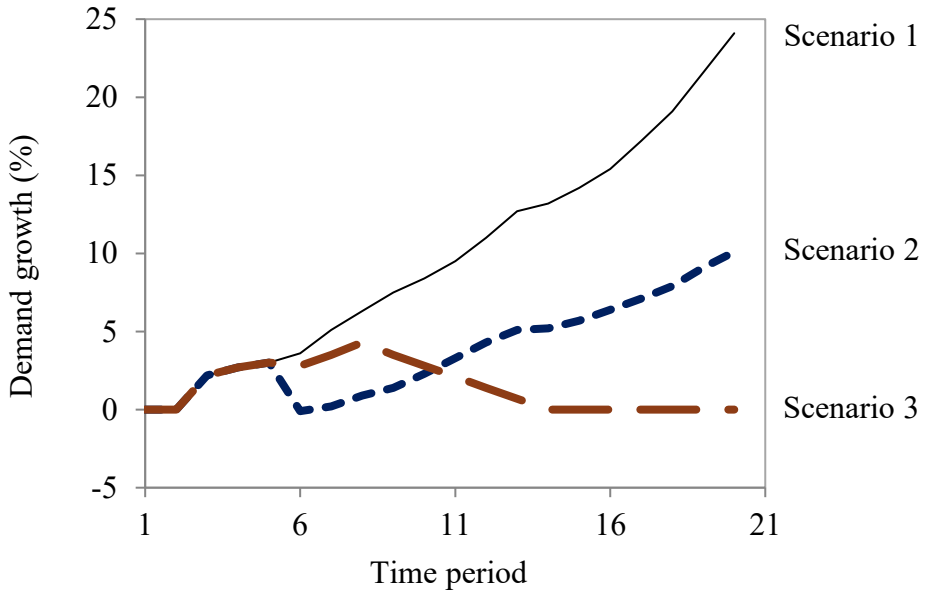
DER and microgrids must be valued under uncertainty!

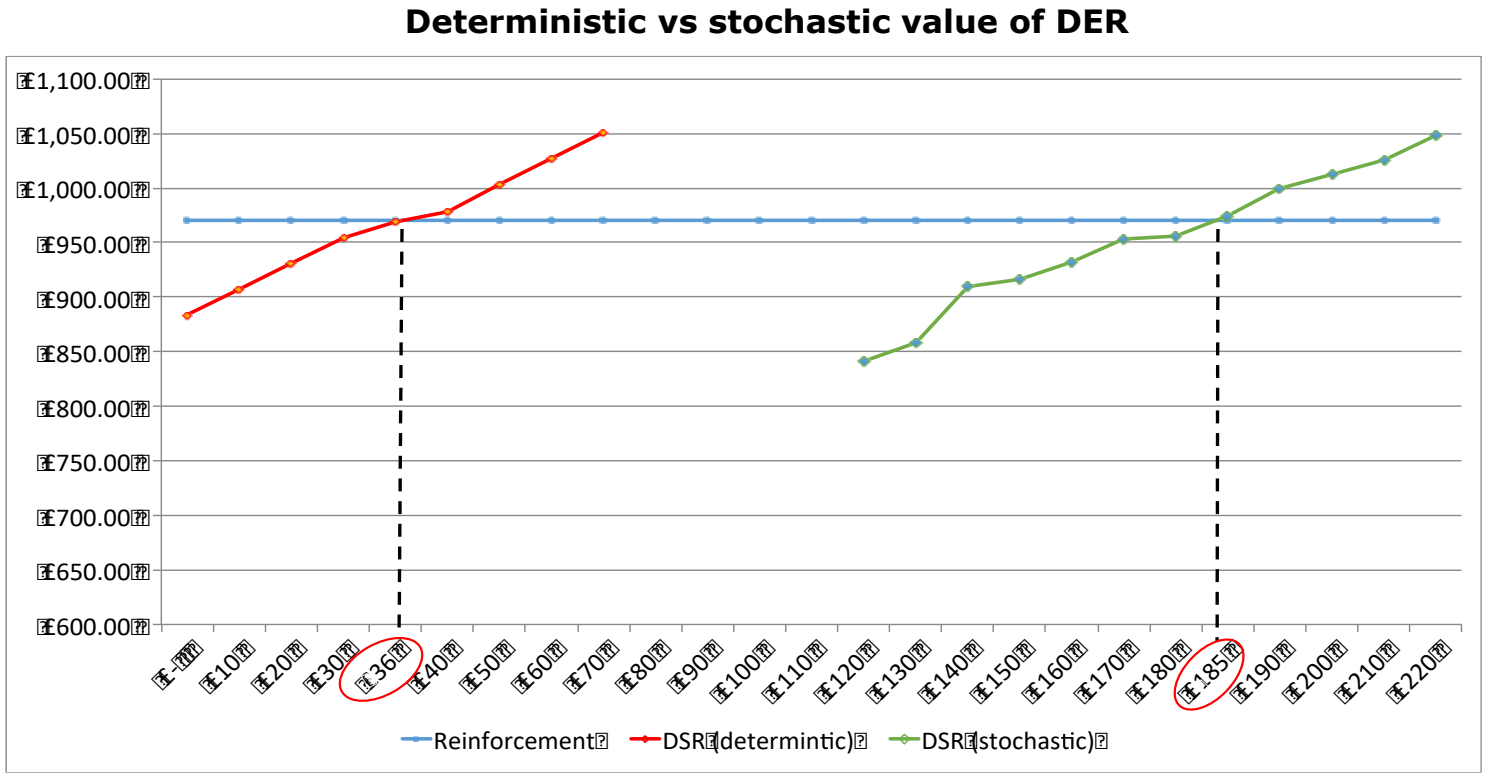
Courtesy of Electricity North West, UK

R. Moreno, A. Street, J.M. Arroyo, and P. Mancarella, "Planning Low-Carbon Electricity Systems under Uncertainty Considering Operational Flexibility and Smart Grid Technologies", *Philosophical Trans. Royal Society A*, June 2017

Option value of DER and microgrids

- **DER and microgrids** are key elements in future network design…
- … but we need a ***new regulatory framework*** too!





E. A. Martínez Ceseña and P. Mancarella, "Practical Recursive Algorithm and Flexible Open-Source Applications for Planning of Smart Distribution Networks with Demand Response," *SEGAN,* vol. 7, pp. 104 –116, 2016.

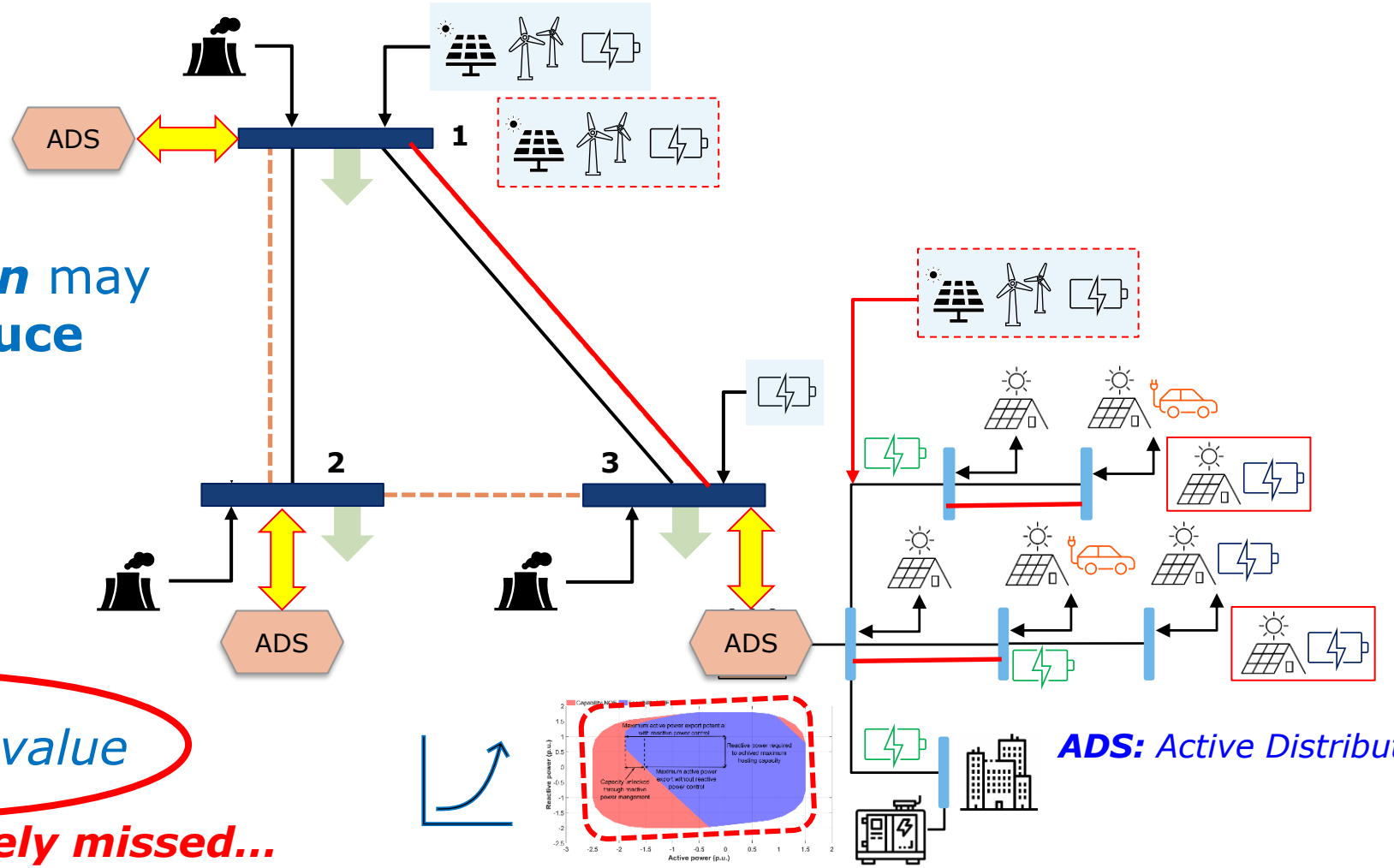
J. A. Schachter, *et al.*, Flexible investment under uncertainty in smart distribution networks with demand side response: Assessment framework and practical implementation. *Energy Policy,* 2016

Orchestrated DER:
Hidden benefits across the whole system

- ***DER orchestration*** may systematically **reduce** transmission:
  - **investment** requirements
  - **investment uncertainty**

→ *risk-hedge value*

currently completely missed…



ADS: *Active Distribution System*

P. Apablaza *et al.*, "Assessing the Impact of DER in the Expansion of Low-Carbon Power Systems Under Deep Uncertainty*", Electric Power System Research*, 2024

P. Apablaza, *et al.*, "Valuing Distributed Energy Resources Flexibility in an Uncertain and Risk-Aware Low-Carbon Power System Planning Context", *SEGAN*, July 2025

How to plan for extreme uncertainty, the *black swan*?

(Images sourced from the internet)

Will more *network redundancy* enhance resilience?

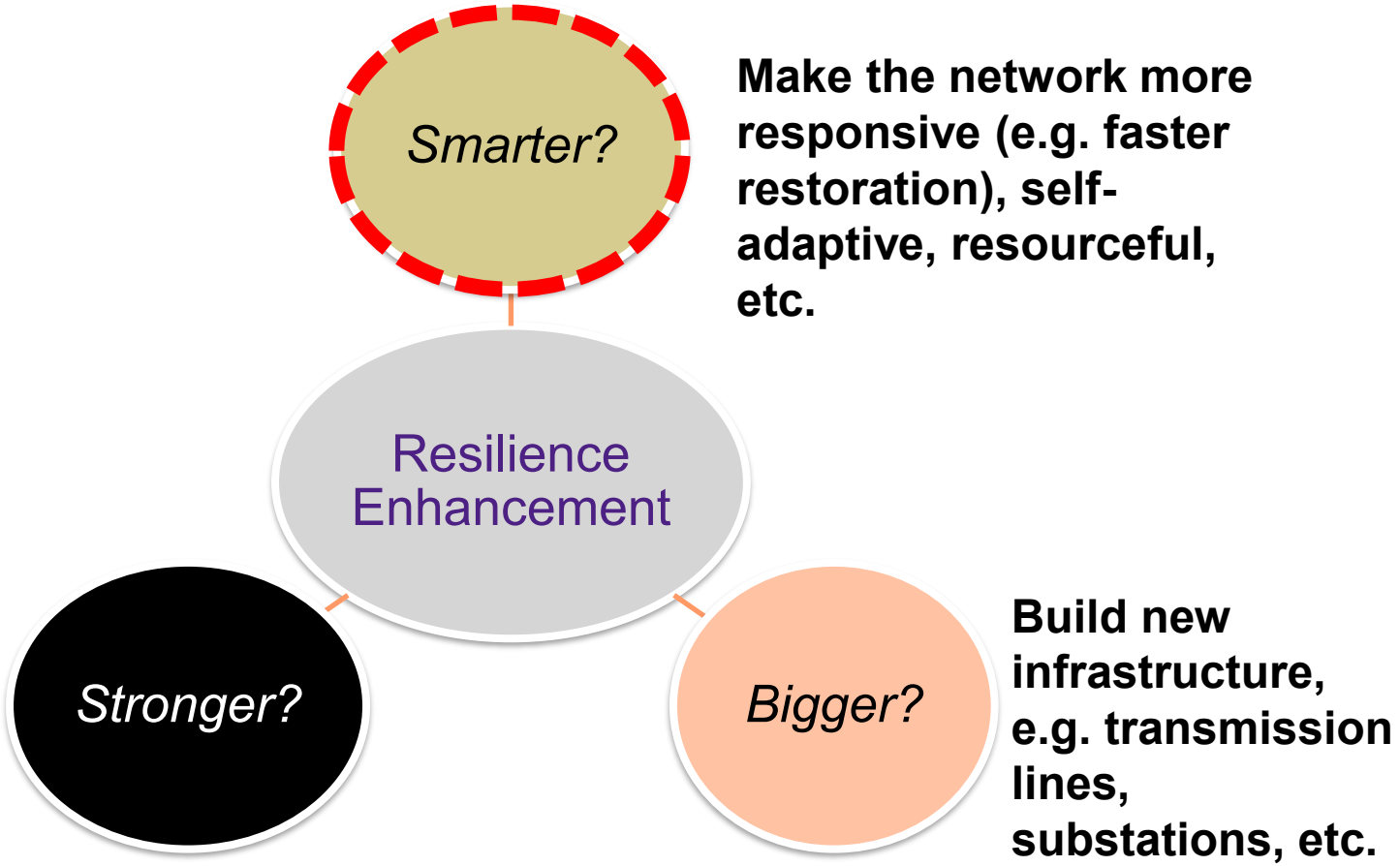
Why Investments Do Not Prevent Blackouts

The idea that increasing the capacity of the transmission network should improve the security of the system and reduce the probability of blackouts is intuitively appealing. However, this intuition does not withstand scrutiny.

Daniel Kirschen and Goran Strbac

D. Kirschen and G. Strbac, "Why investments do not prevent blackouts", *The Electricity Journal*, March 2004

Planning for the unknown extremes: The *resilience trilemma*



M. Panteli and P. Mancarella, The Grid: Stronger, Bigger, Smarter? Presenting a conceptual framework of power system resilience, *IEEE Power and Energy Magazine,* May/June 2015

R. Moreno, *et al.*, "From Reliability to Resilience: Planning the Grid Against the Extremes", *IEEE Power and Energy Magazine*, *July-August 2020*

M. Panteli, *et al.*, "Power Systems Resilience Assessment: Hardening and Smart Operational Enhancement Strategies," Proceedings of the IEEE, 105, 7, pp. 1202-1213, July 2017

Y. Zhou, *et al.*, "System-level assessment of reliability and resilience provision from microgrids", *Applied Energy*, Volume 230, 15 November 2018, Pages 374-392

Why don't we build microgrids?
Need for a new regulatory framework

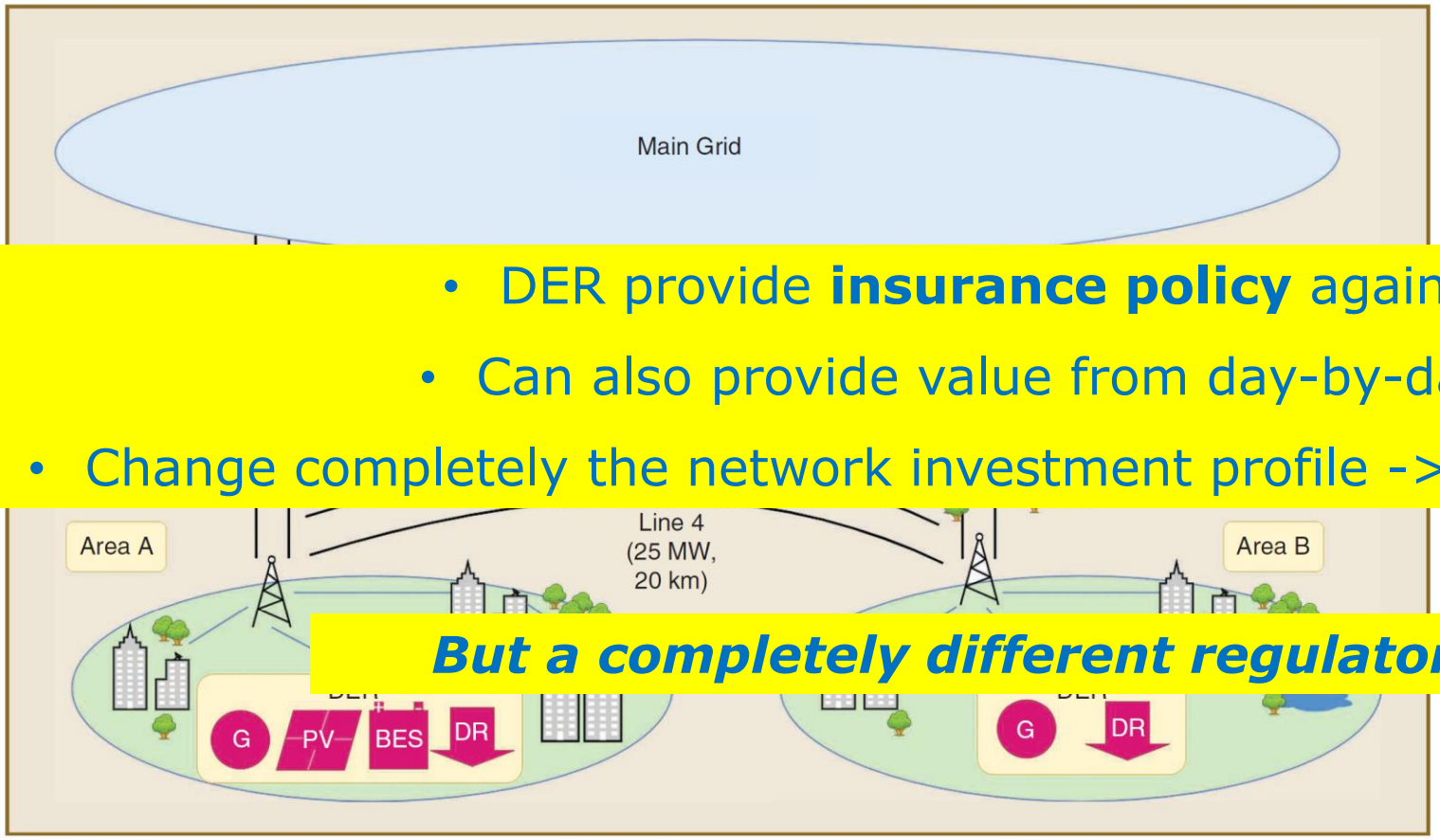


figure 8. The electricity network and DER candidates along with areas exposed to wildfires. BES: battery energy storage.

- DER provide **insurance policy** against extreme events!
- Can also provide value from day-by-day market operation
- Change completely the network investment profile -> **less redundancy, smarter grid!**

But a completely different regulatory set-up is needed!

table 2. Results with costs in thousand U.S. dollars (kUS$) per year.

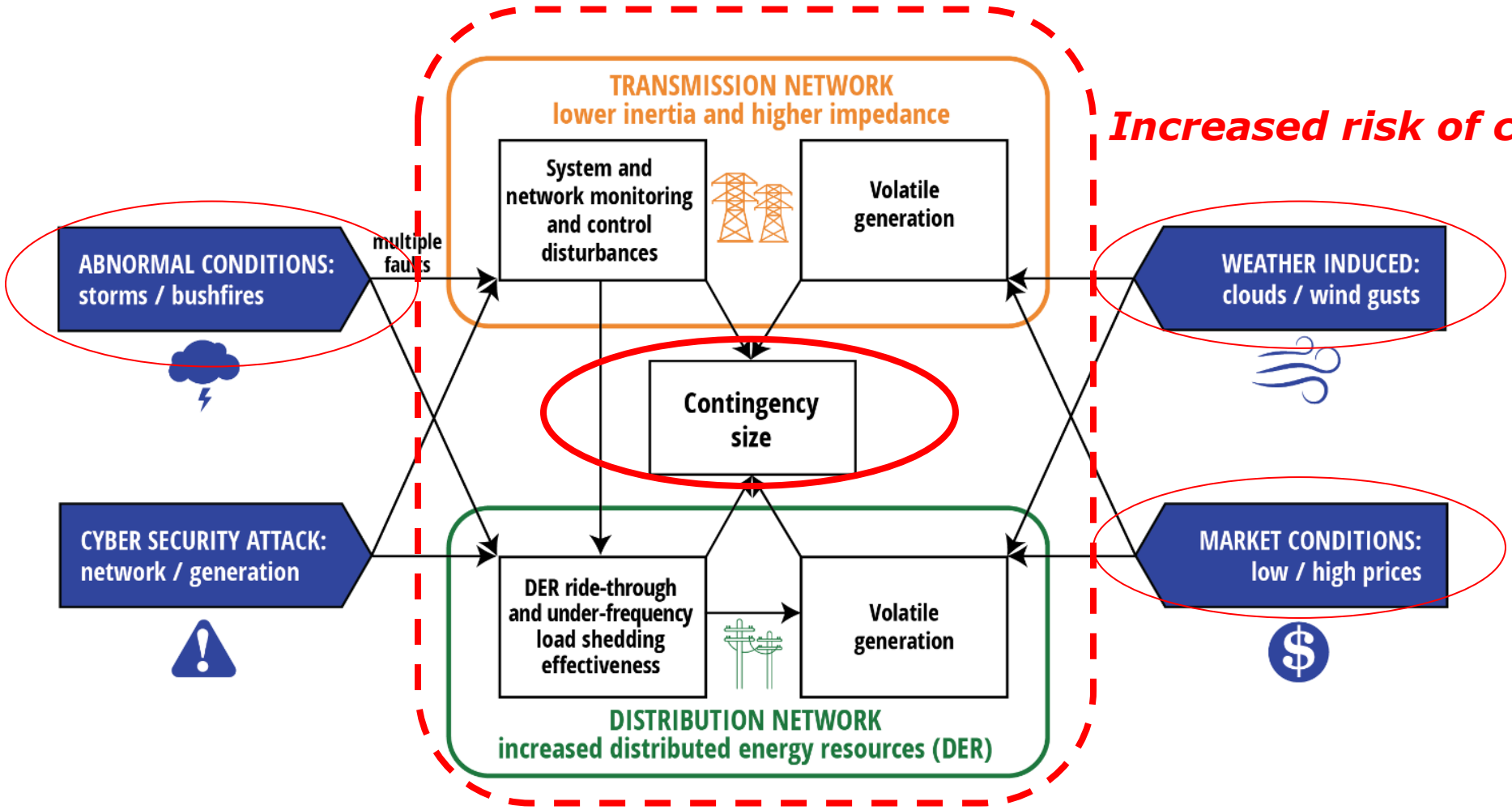
	Case A	Case A (Reevaluated)	Case B
Assets and measures	L1, L2, L5, L6, MG	L1, L2, L5, L6, MG, DR	L1, L2, L3, L4, L5, PV, BES
cost			
Operational cost	32,850	33,115	21,901
Lost-load cost	27	19,665	6
Total cost	32,990	52,893	33,558

L: line; MG: mobile generator.

R. Moreno, *et al.*, Microgrids Against Wildfires: Distributed Energy Resources Enhance System Resilience. *IEEE Power and Energy Magazine*, 20(1), 78-89, 2022

R. Moreno, *et al.*, "From Reliability to Resilience: Planning the Grid Against the Extremes", *IEEE Power and Energy Magazine, 2020*

"Blurring" of security and resilience



Increased risk of cascading

J. Eggleston, C. Zuur, P. Mancarella, "**From security to resilience**: technical and regulatory options to manage extreme events in low-carbon grids", *IEEE Power & Energy Magazine*, Sept/Oct 2021

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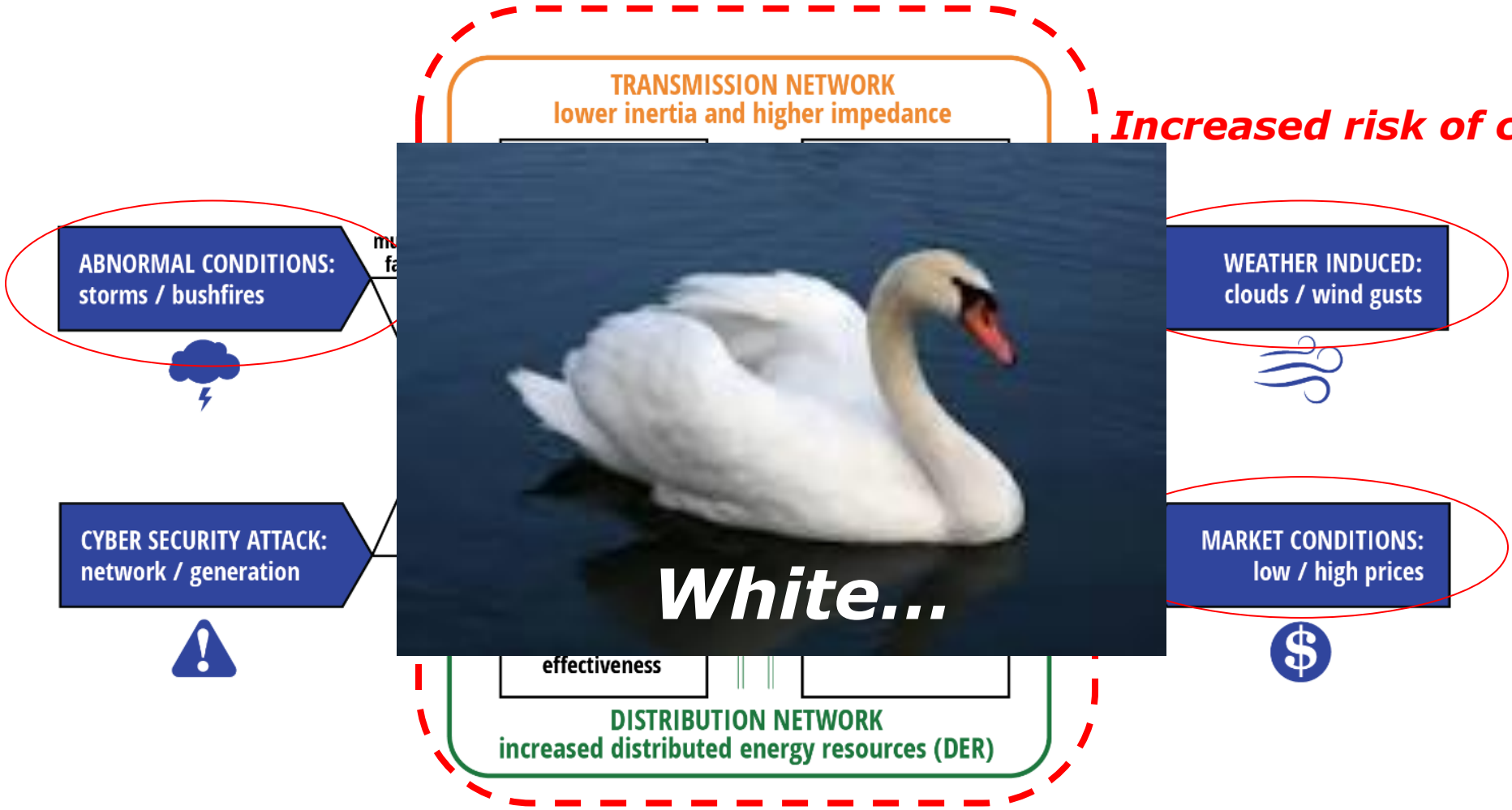

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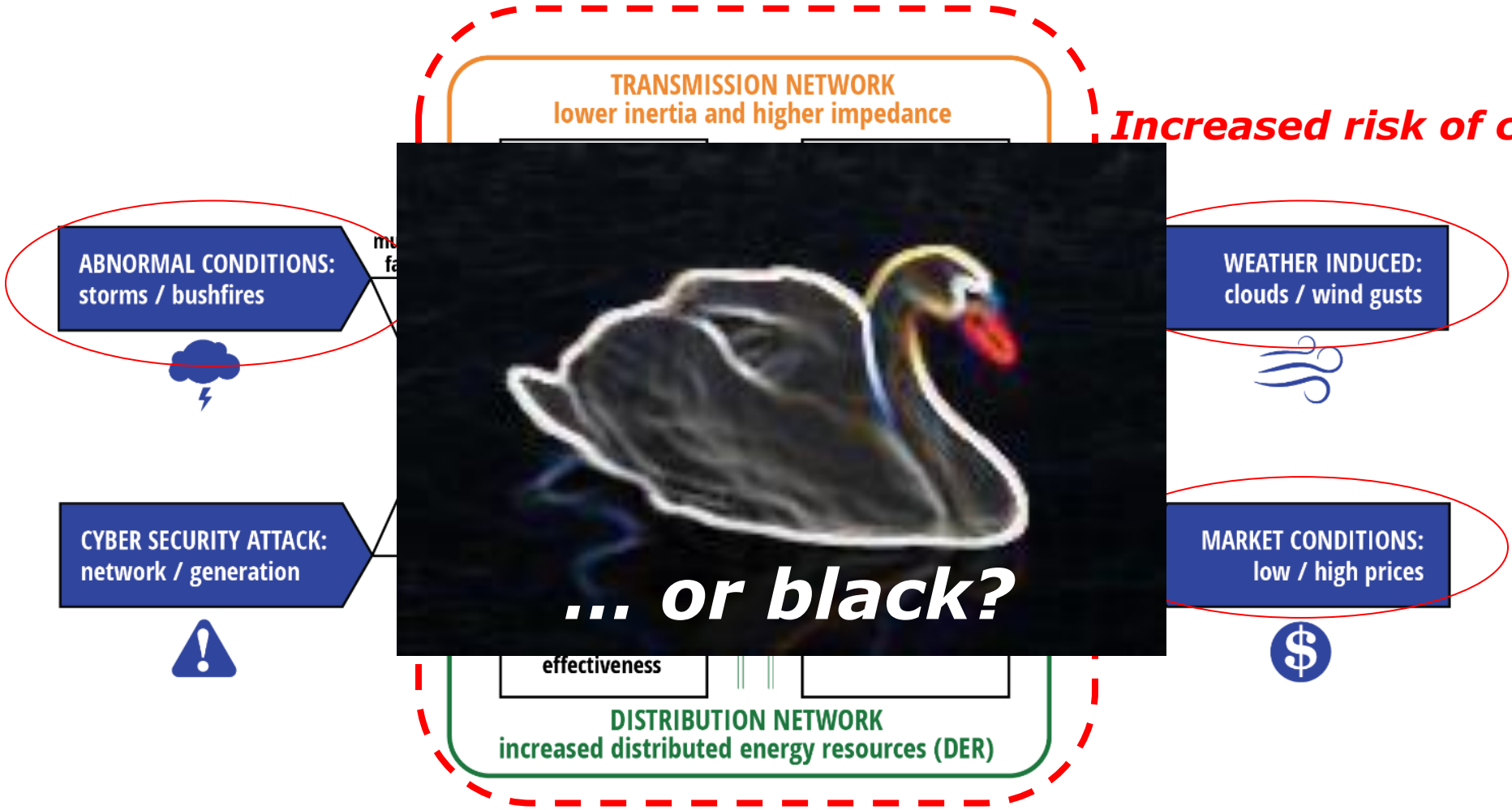

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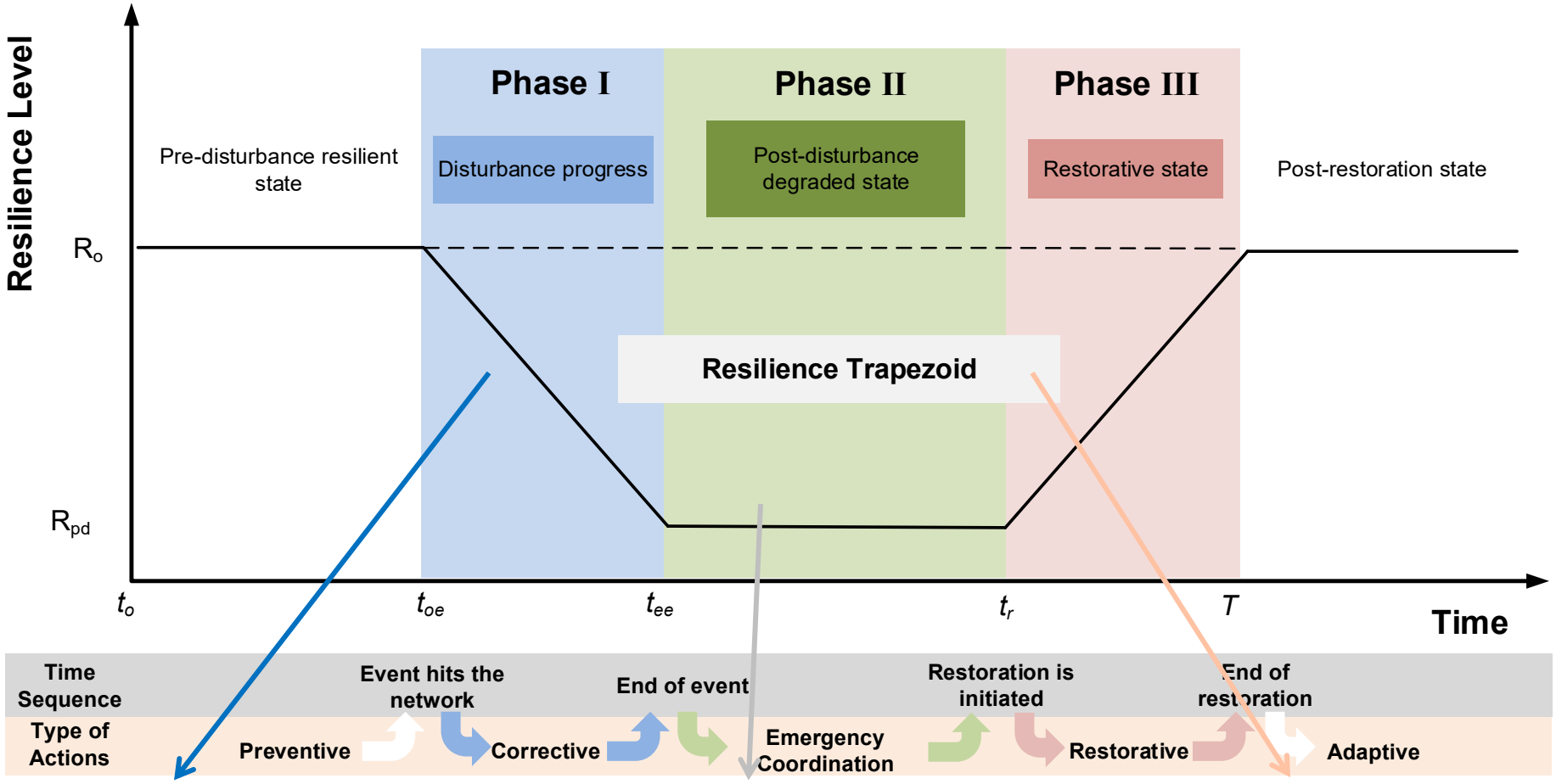
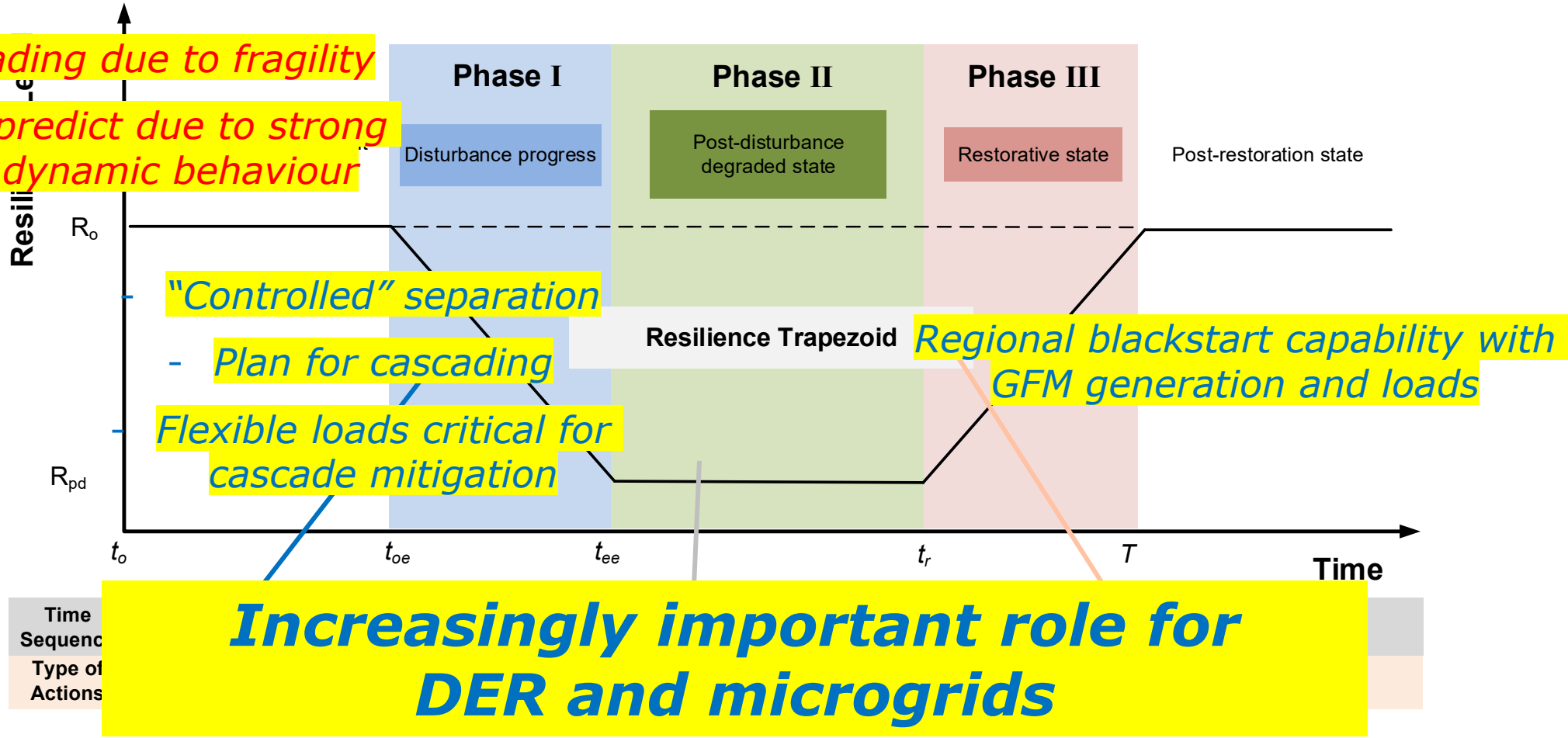
How to ensure resilience in IBR-dominated grids?



M. Panteli, P. Mancarella, D. N. Trakas, E. Kyriakides, and N. D. Hatziargyriou, "Metrics and Quantification of Operational and Infrastructure Resilience in Power Systems", IEEE Transactions on Power Systems, vol. 32, no. 6, November 2017

How to ensure resilience in IBR-dominated grids?

- *More cascading due to fragility*
- *Difficult to predict due to strong nonlinear dynamic behaviour*



- *"Controlled" separation*
- *Plan for cascading*
- *Flexible loads critical for cascade mitigation*
- *Regional blackstart capability with GFM generation and loads*

Increasingly important role for DER and microgrids

M. Panteli, *et al.*, "Boosting the Power Grid Resilience to Extreme Weather Events Using Defensive Islanding", *IEEE Transactions on Smart Grid,* 2016, vol. 7.

B.V. Venkatasubramanian, *et al.*, "Investment planning framework for mitigating cascading failures", *Electric Power Systems Research*, 234, Sept. 2024, 110807

M. Panteli, P. Mancarella, D. N. Trakas, E. Kyriakides, and N. D. Hatziargyriou, "Metrics and Quantification of Operational and Infrastructure Resilience in Power Systems", IEEE Transactions on Power Systems, vol. 32, no. 6, November 2017

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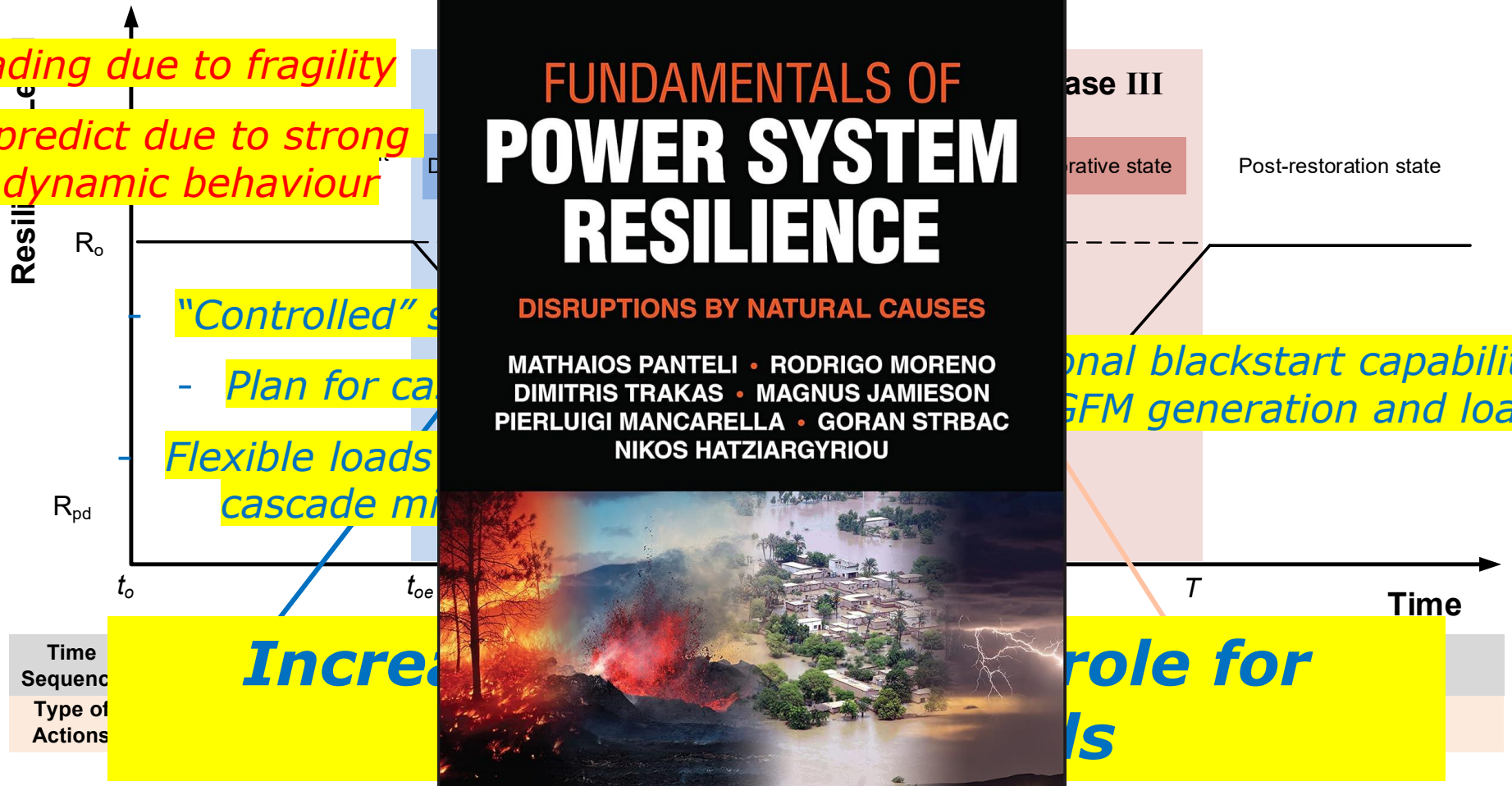

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Incre role for ls

M. Panteli, *et al.*, "Boosting the Power Grid Resilience to E , *et al.*, "Investment planning framework for mitigating Using Defensive Islanding", *IEEE Transactions on Smart Gr ic Power Systems Research*, 234, Sept. 2024, 110807

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Back to the future

Back to the future

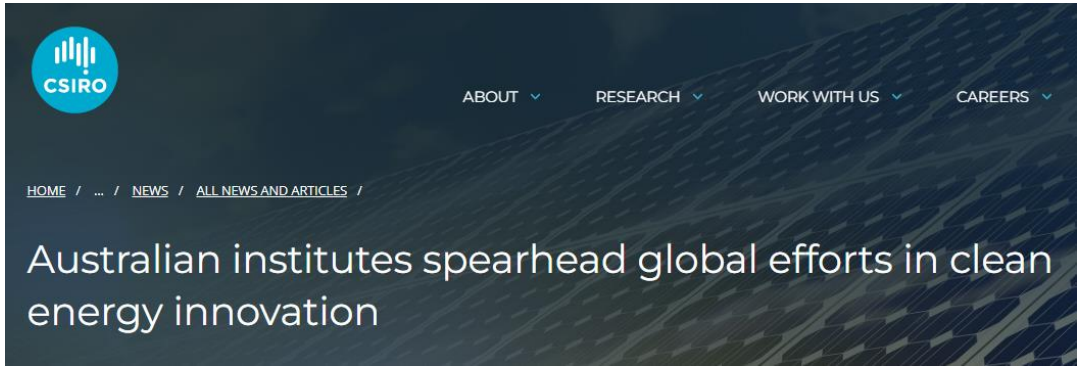
US-UK-Australia

Global Centre on Climate Change and Clean Energy

"Electric Power Innovation for a Carbon-free Society" (EPICS)

New Global Research Centre to provide EPIC clean energy boost

The new Electric Power Innovation for a Carbon-Free Society (EPICS) Centre will address challenges in clean energy production and storage.



GLOBAL PST CONSORTIUM

Interested in joining?

We welcome collaborations, visits, etc!

https://www.csiro.au/en/news/All/News/2023/September/Australian-institutes-spearhead-global-efforts-in-clean-energy-innovation

https://www.unimelb.edu.au/newsroom/news/2023/september/new-global-research-centre-to-provide-epic-clean-energy-boost

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Thank you!
Any question?

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Security, reliability and resilience from microgrids:

Techno-economic and regulatory challenges and opportunities

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Shenzhen-Macao 2025 Symposium on Microgrids 2025

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