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Capacity Credit of Renewables and Storage in Low-Carbon Power Systems

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"Tendencias actuales para el reconocimiento de potencia en sistemas eléctricos con bajas emisiones de CO_2"

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Outline

- Context:
  - Variable Renewable Energy (VRE) sources
  - Supply adequacy
- "Capacity Credit" of VRE (and storage):
  - Definitions
- Approaches to capacity credit assessment
- Case study examples
- Concluding remarks

What is meant by intermittent/variable generation?

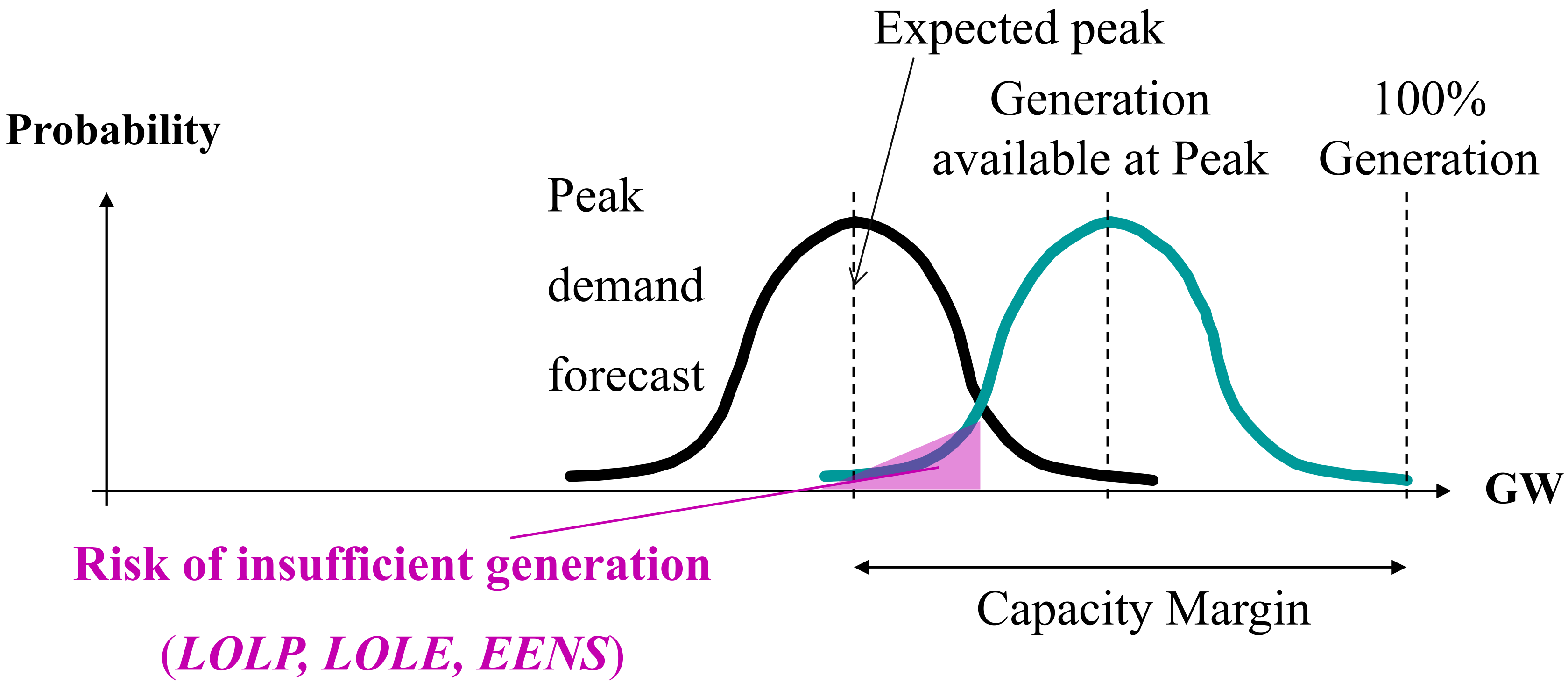
- Generation whose output varies with environmental conditions and for which the operator has no control upon the "available fuel"
- Many renewables (such as wind, solar, etc.) are classified as being intermittent/variable
  - **Variable Renewable Energy (VRE)**
- Can VRE provide *reliable supply*?

- *How intermittent/variable is conventional thermal generation?*

Long-term reliability: generation (or more generally "supply") adequacy

- **Generation adequacy**:
  - Capability to meet demand with a certain level of reliability of supply
- Various reliability indicators to measure adequacy
  - ***LOLP*** (Loss of Load Probability)
  - ***LOLE*** (Loss of Load Expectation)
    - Probability of (peak) demand exceeding available generation
  - ***EENS*** (Expected Energy Not Supplied)

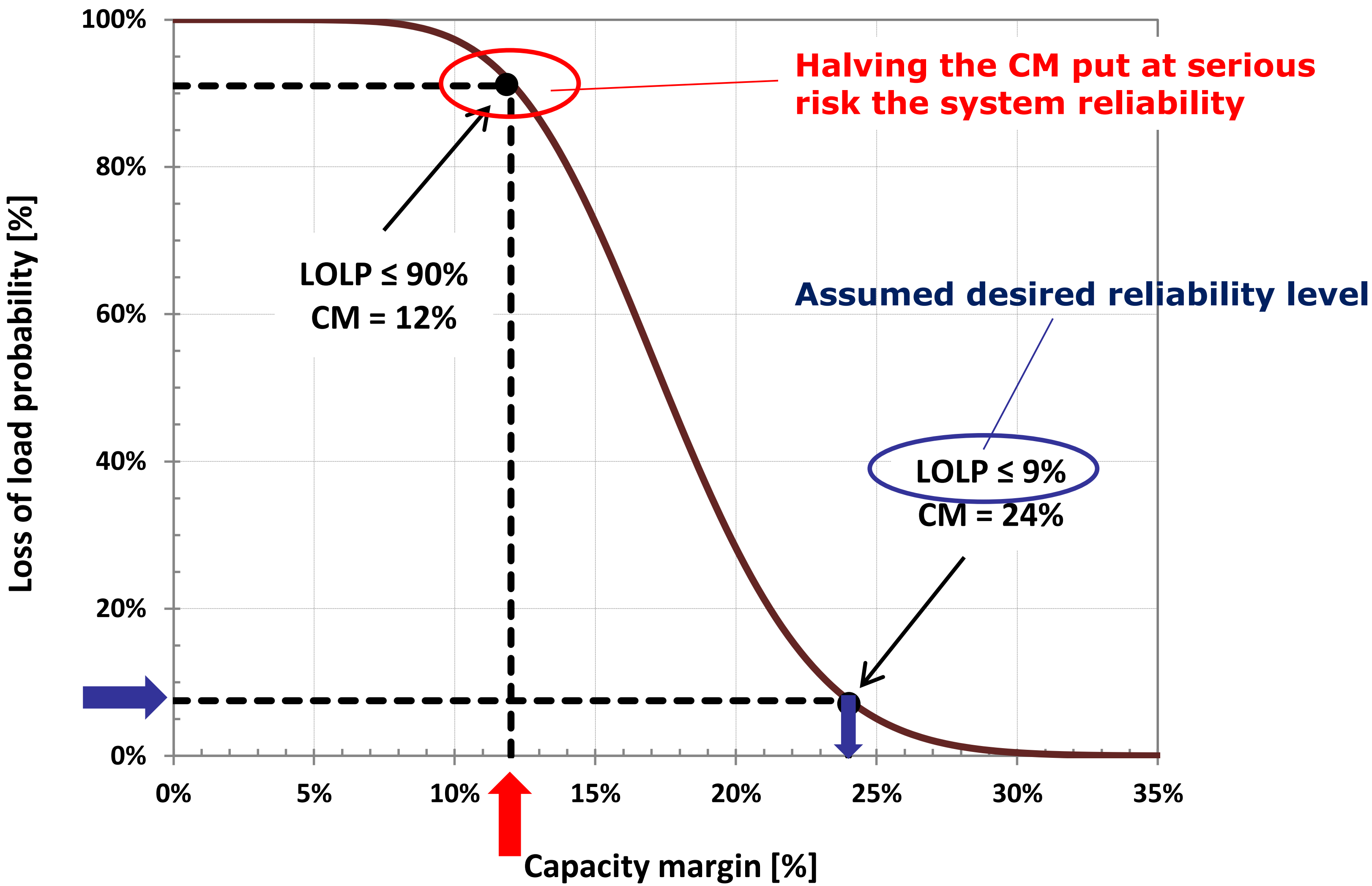
Classical approach to determining generation adequacy and plant margin



- The higher the planned *capacity margin*, the lower the *LOLP* (or other reliability indicator)
- Generation capacity is considered “adequate” if the system meets minimum levels required for *LOLP, EENS*, etc.

“The Book”: R. Billinton and R.N. Allan, *Reliability evaluation of power systems*, Springer, 1996

Example: Generation adequacy and capacity margin



Capacity measures for variable generation

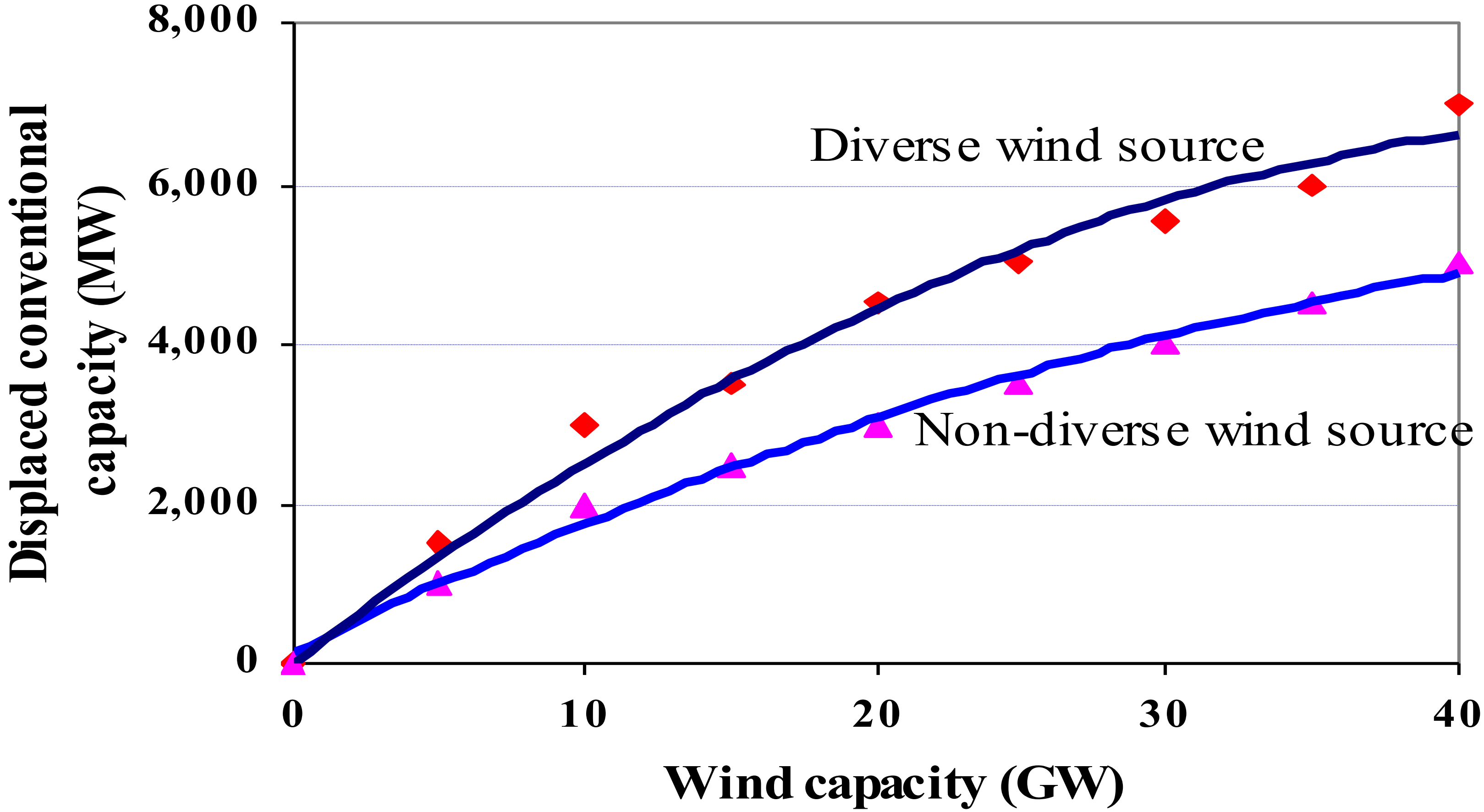
- **Capacity credit** (or *capacity value*) of VRE sources is a measure of the amount of load that can be served on an electricity system by variable plant with no decrease in the reliability level (e.g., no increase in the LOLP)
  - It is often expressed in terms of *conventional thermal capacity that variable generation capacity can replace*
- **Capacity factor** is the energy produced by a generator relative to the maximum possible energy output (100% of max output at all times)
  - Capacity factor for base load thermal generators can be around 85%
  - Wind achieves capacity factors of 20% - 50%

Capacity Credit = Capacity Value ≠ Capacity Factor

Determinants of capacity credit

- The degree of ***correlation*** between *demand peaks and variable output*
- The ***average level*** of output
  - A higher level of average output over peak periods will tend to increase capacity credit
- The range of variable outputs (***diversity***)
  - For example, having different types of variable plant on a system decreases variance and increases overall renewables capacity credit

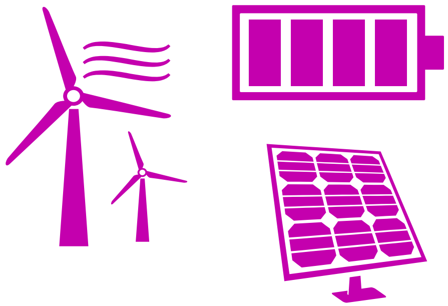
Displaced conventional capacity by wind generation – a simple UK example



Note: calculations assume 40% wind capacity factor

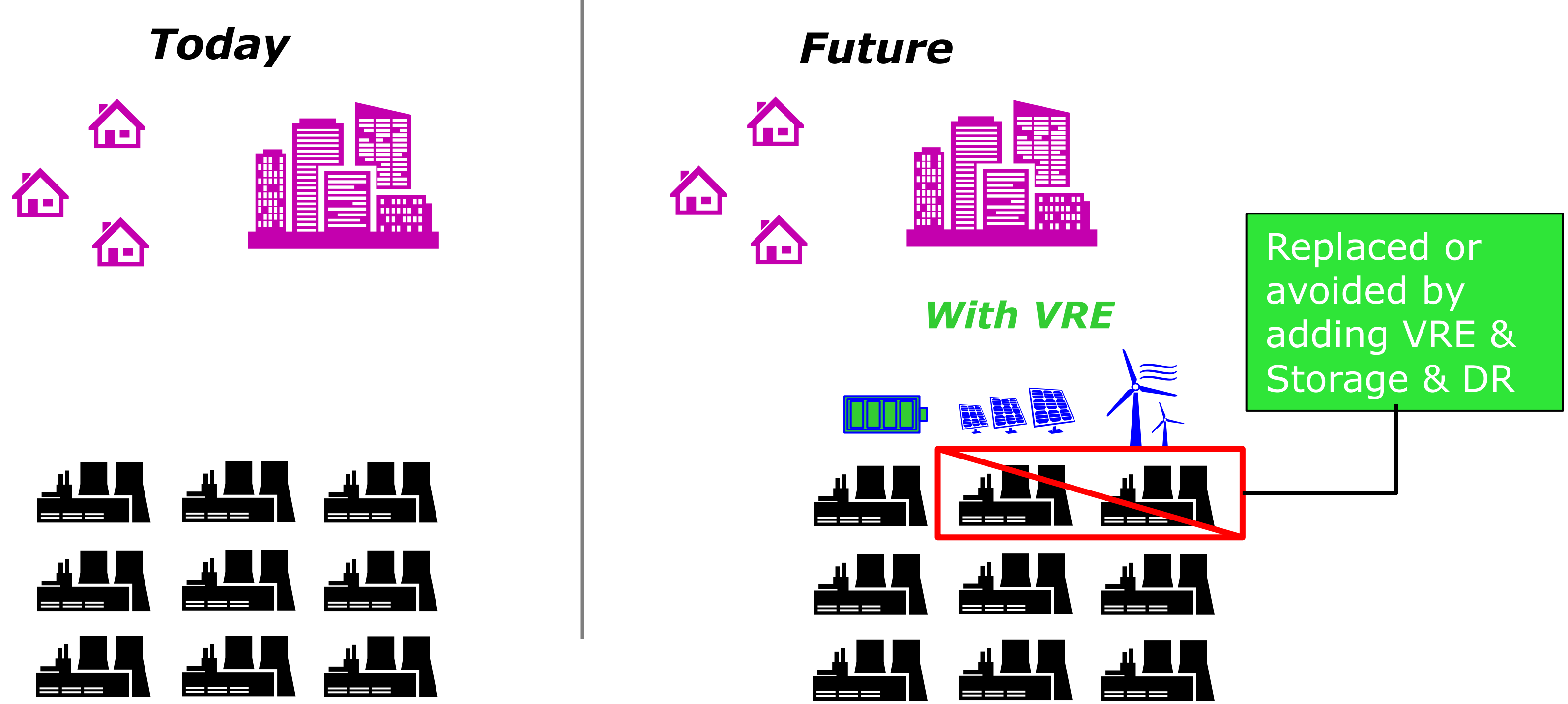
Capacity Credit in Low-carbon Power Systems: a more general definition

- Capacity Credit of generation, storage, or flexible load resources:
  - **Contribution of the resource to supply adequacy**
- The amount of <u>conventional power generation</u> that can be <u>replaced or avoided</u> by adding **VRE, Storage, Demand Response** (DR) to the system without reducing the system reliability level



Key questions pertinent to capacity credit

- How much can we rely on VRE to provide security of supply?
  - System adequacy
  - "Firm capacity" of VRE?
- How can storage (and DR) help firm up the capacity of VRE?
- How should VRE capacity be valued in markets



How to Calculate Capacity Credit: Methods

Methods based on approximations and proxies

- Capacity Factor Approximation Method
- Loss-of-Load Probability-Weighted Capacity Approximation
- Garver-Method, Z-Method

- Pros: Low computational burden
- Cons: Not accurate (variance can be up to 100%)

  - especially with different VRE types, penetration levels

  - basically not trustable *at all* with storage, complex system and market operation, etc.

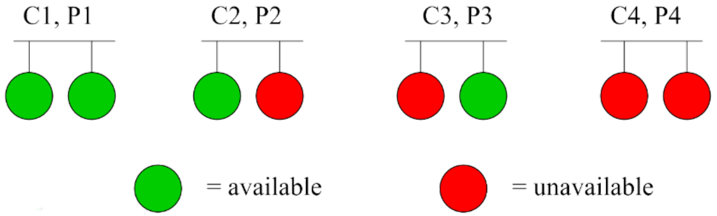
Simple formulas?

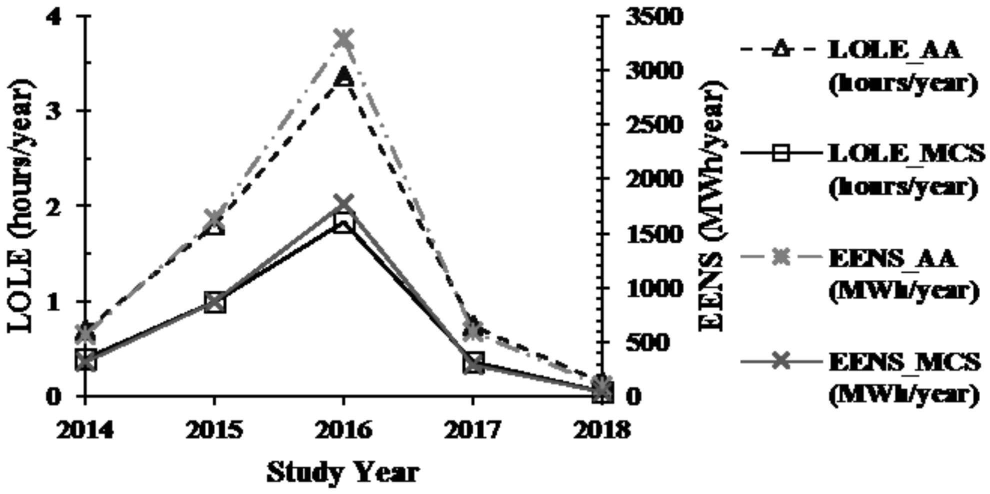
Forget-about-it!

How to Calculate Capacity Credit: Methods

Reliability-based methods

- ***Analytical methods***
  - Example: Capacity Outage Probability Table (COPT)
- Pros: Simple
- Cons:
  - Not accurate
  - Time-independent: the temporal correlation between demand and wind/solar or storage/DR cannot be considered





An example of UK wind-rich system[2]

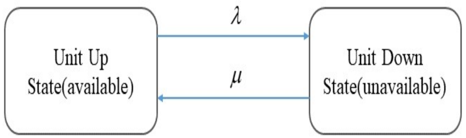
- Risk of supply inadequacy is overestimated using analytical method
- The Capacity Credit of wind may be grossly underestimated, as a result

How to Calculate Capacity Credit: Methods

Reliability-based methods

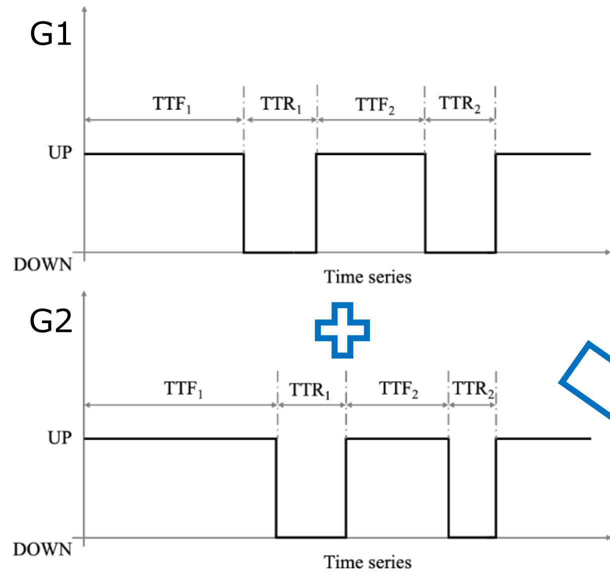
- ***Monte-Carlo Simulation (MCS)***
  - Pros:
    - Accurate, as can model system operation in any detail
  - Cons:
    - Computationally (very) heavy
      - However, fortunately the state of the art is rich in acceleration and fast sampling techniques
- Methodology:
  - Calculate the **net load profiles** (load not covered by VRE, storage or DR) from:
    - Time series of wind/solar (from different climatic years)
    - Production models
  - Calculate conventional generators' available capacity profile
  - Assess reliability indicators (*LOLE, EENS,* etc.)

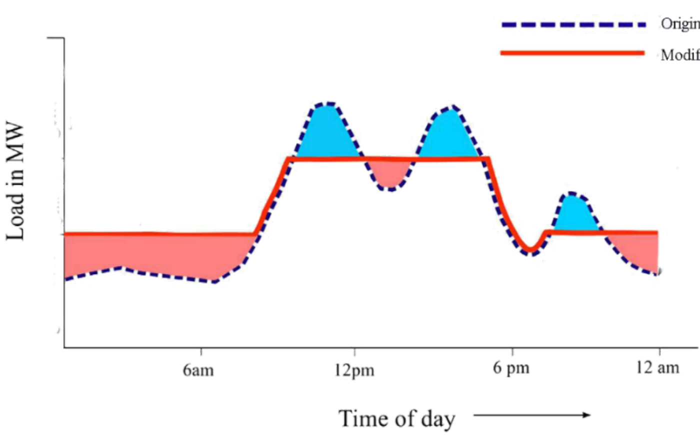
How to Calculate Capacity Credit: *Monte-Carlo Simulation (MCS)*



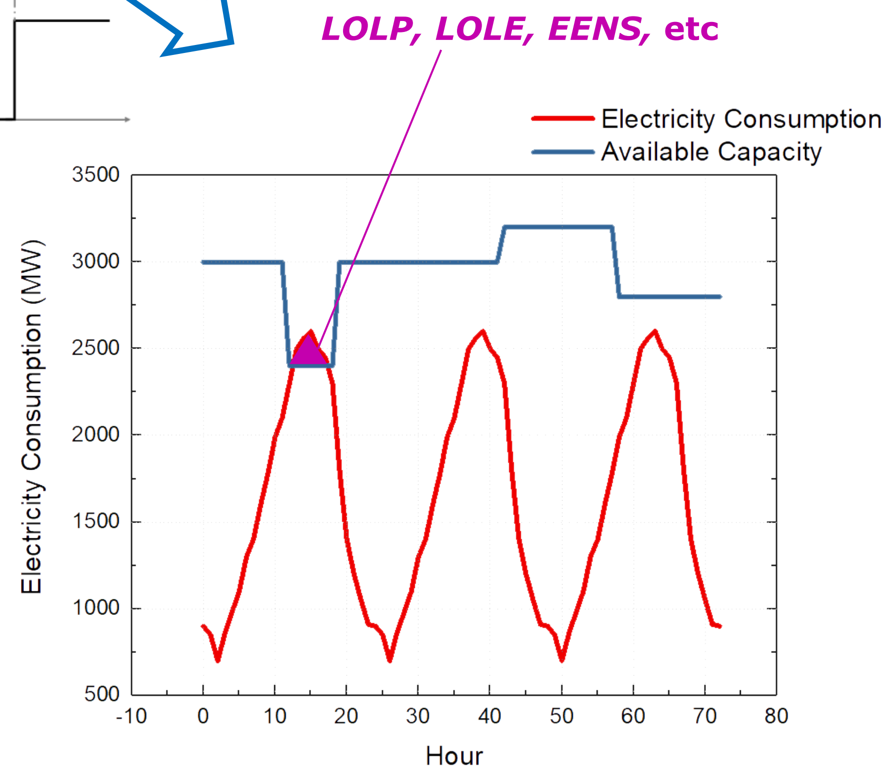
$$TTF = -\frac{1}{\lambda}\ln(k)$$

$$TTR = -\frac{1}{\mu}\ln(k')$$



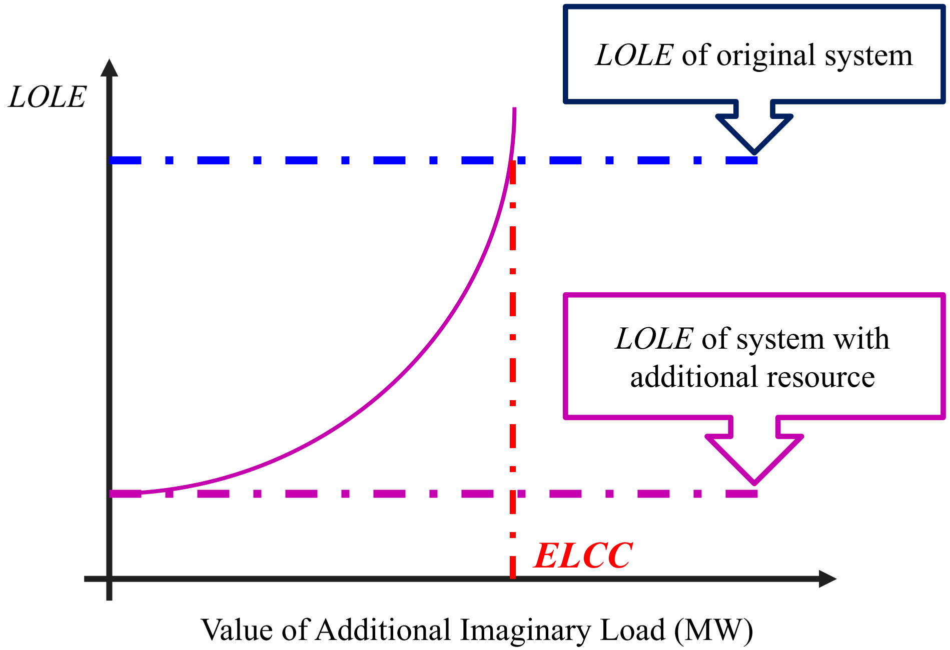


Example: net load profile after storage integration



How to calculate the Capacity Credit of a resource: Metrics

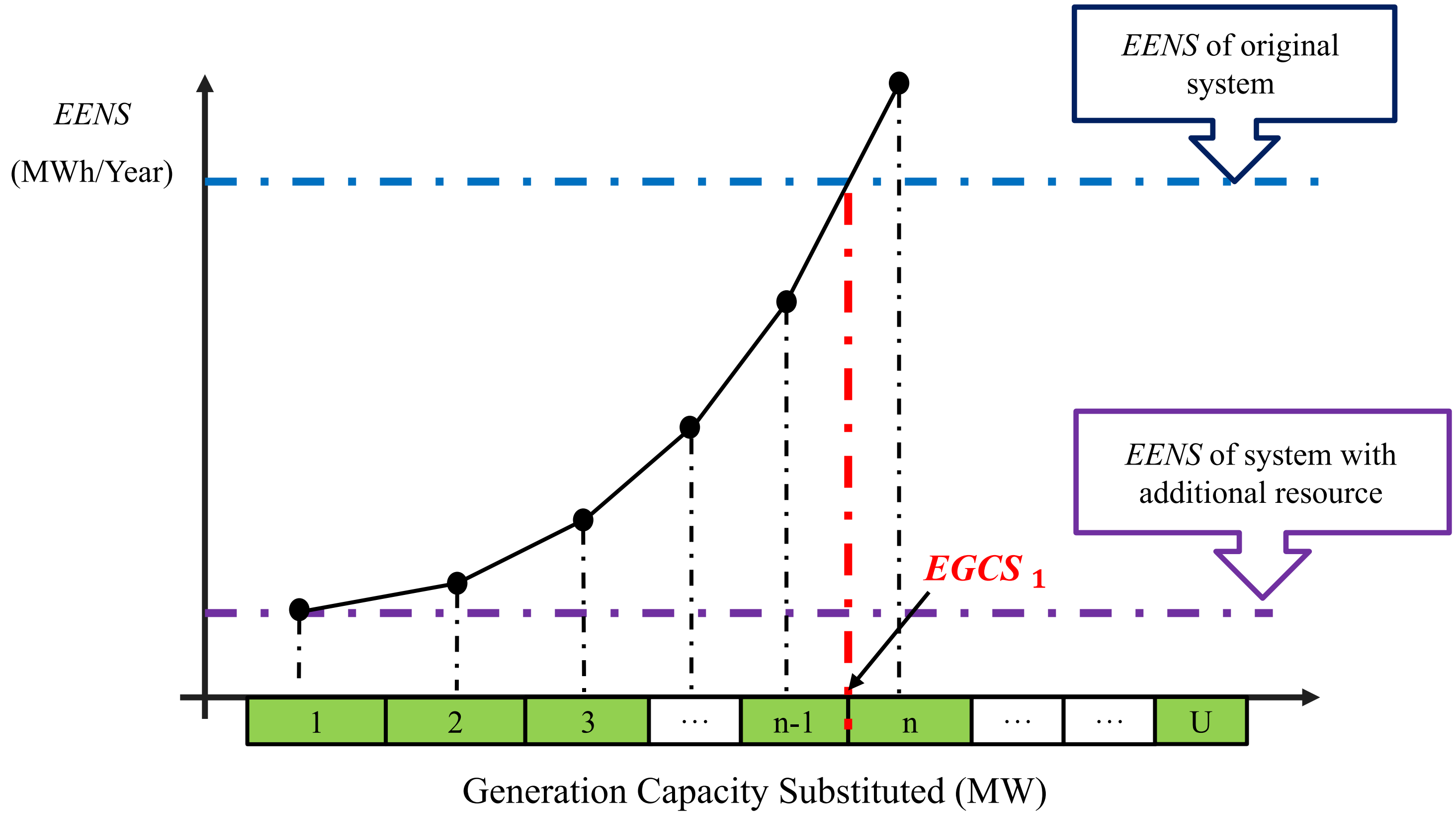
- **Effective Load Carrying Capability (*ELCC*)**
  - The amount by which the system's load can increase (when a resource is added to the system) while maintaining the same system reliability (as measured by *LOLP, LOLE,* etc.)



* Figure adapted from [1], general methodology discussed in [3] and [4]

How to calculate the Capacity Credit of a resource: Metrics

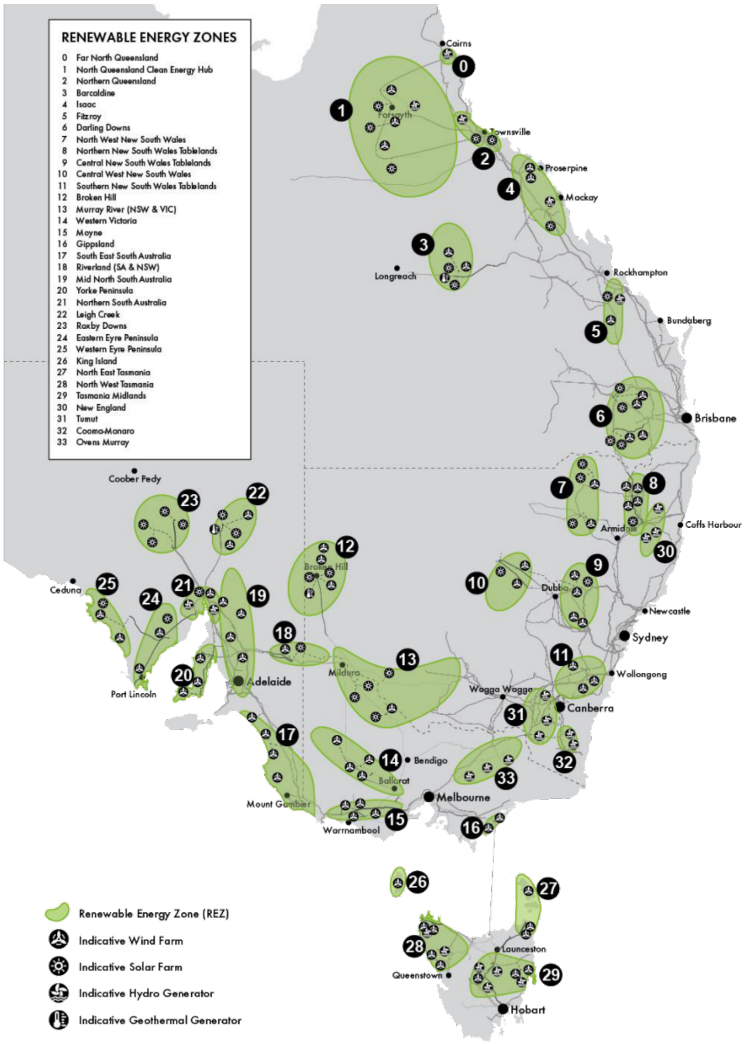
- **Equivalent Generation Capacity Substitution (*EGCS*)**:
  – The amount of *conventional generation* that could be *displaced (retired)* by adding a new resource while preserving the level of system adequacy



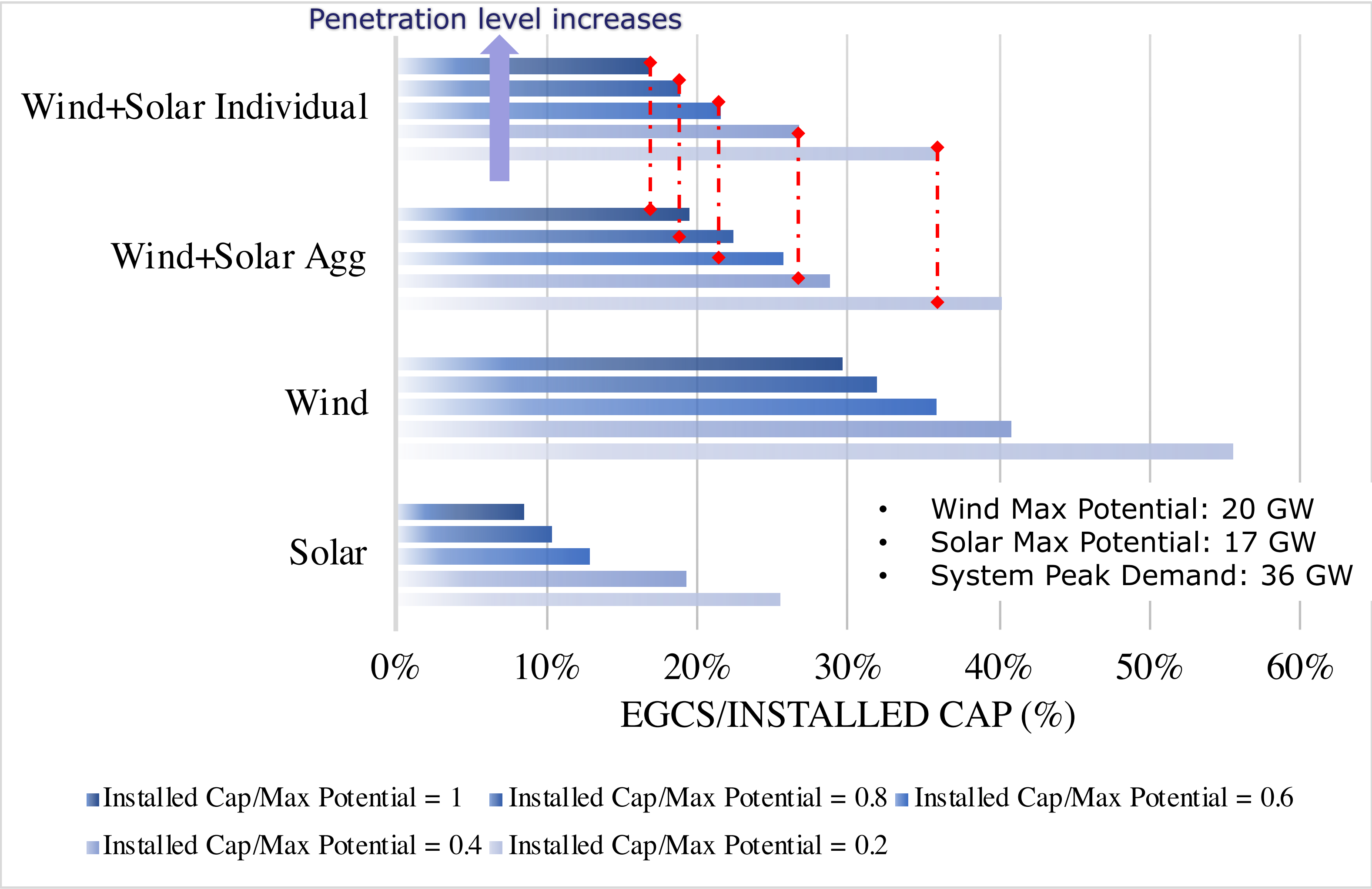
* Adapted from [1], [3] and [4]

Example: Australian National Electricity Market (NEM) grid

- Wind Potential: 20 GW
- Solar Potential: 17 GW
- System Peak Demand: 36 GW
- Proposed Pumped-Hydro Storage Plant (PHSP):
  - 15 Utility Scale PHSP Projects
  - total = 2.9 GW * 17 h ≈ 50 GWh

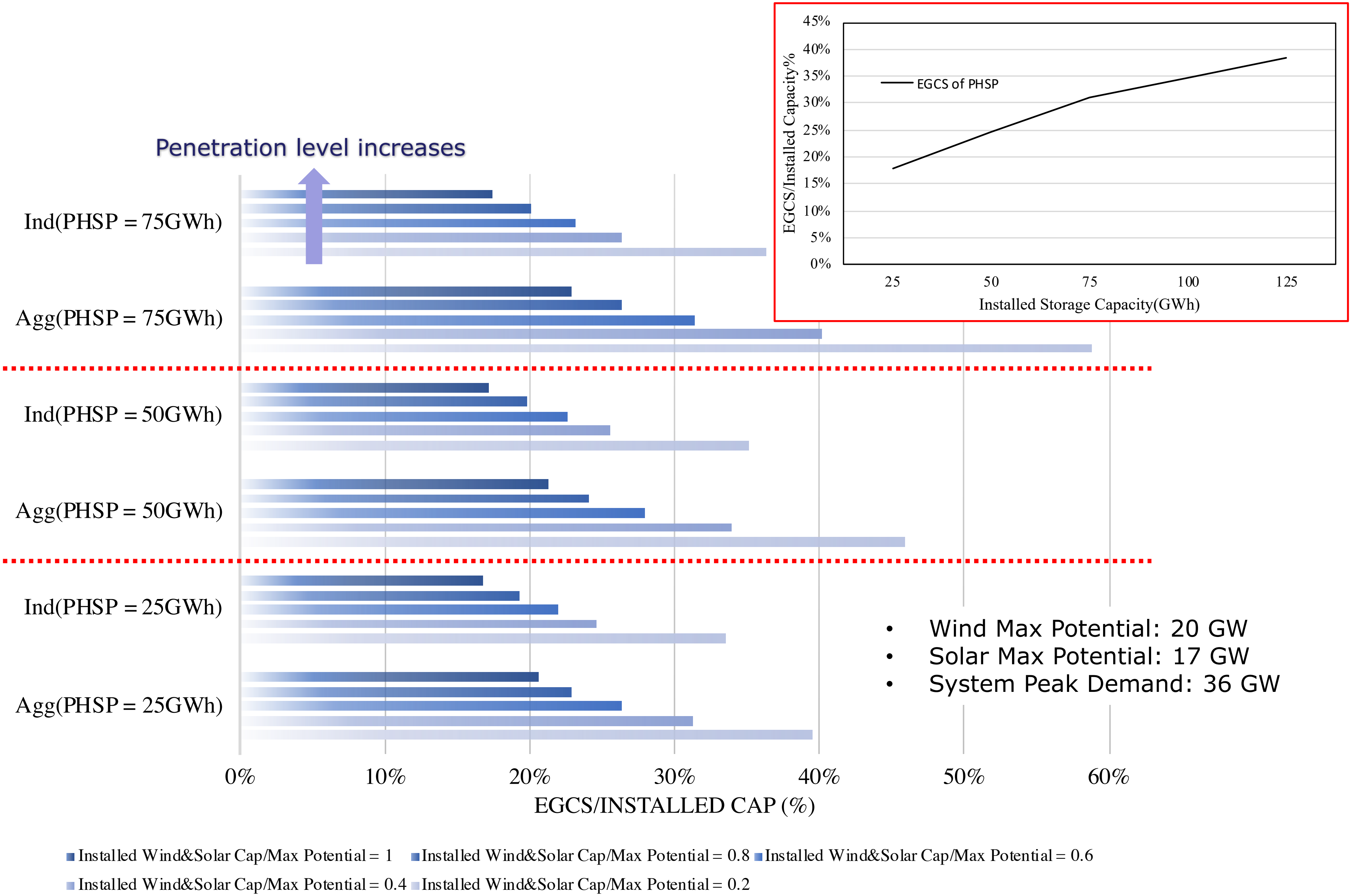


EGCS of Wind and Solar in NEM



- Individual: The sum of EGCS values of wind & solar when operated independently
- Aggregate: The EGCS value of wind & solar when they are both in the system

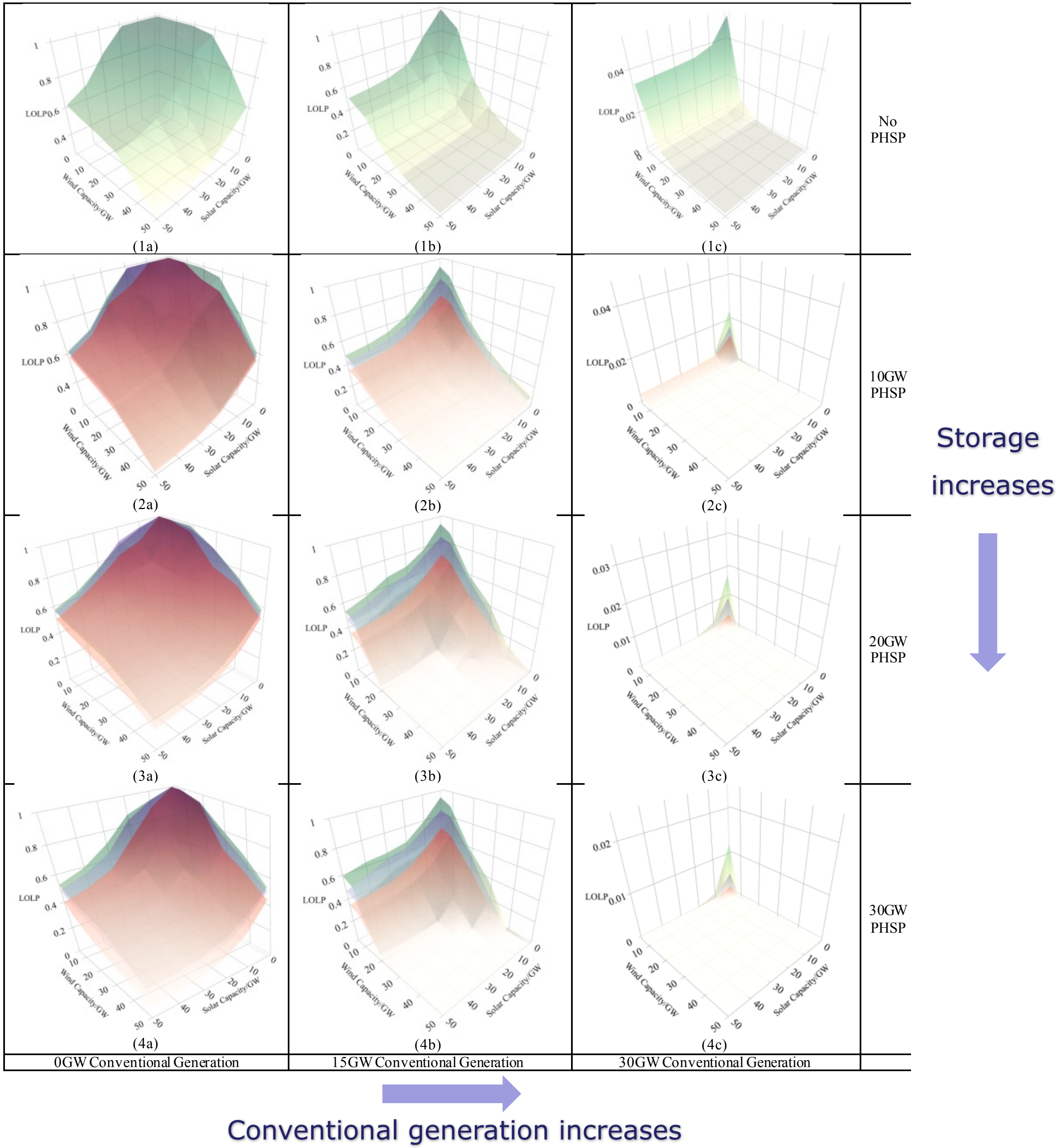
EGCS of Wind, Solar and PHSP



- Wind Max Potential: 20 GW
- Solar Max Potential: 17 GW
- System Peak Demand: 36 GW

Adequacy of a VRE-based NEM

How much storage do we need?



PHSP maximum charging and discharging power:

- 6h (green)
- 12h (blue)
- 24h (red)

Results from [5]

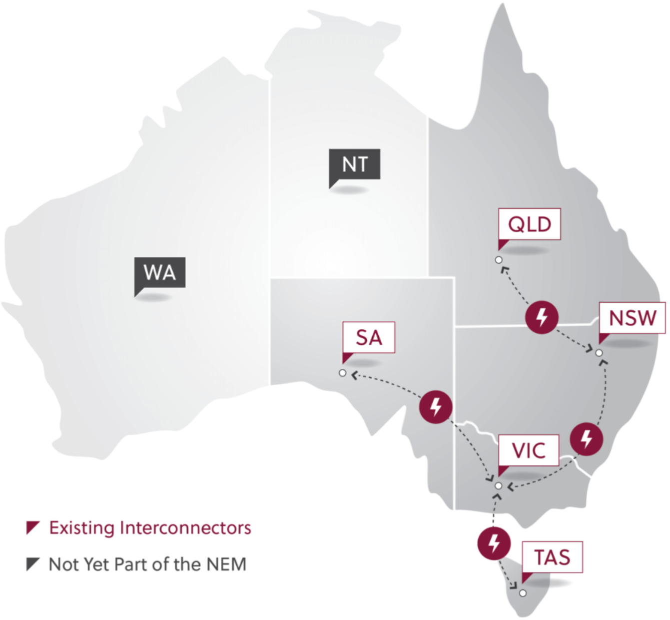
Role and impact of network

- Illustration of capacity credit evaluation in multi-area system[6]

- Capacity credit can be grossly over-estimated without considering network constraints

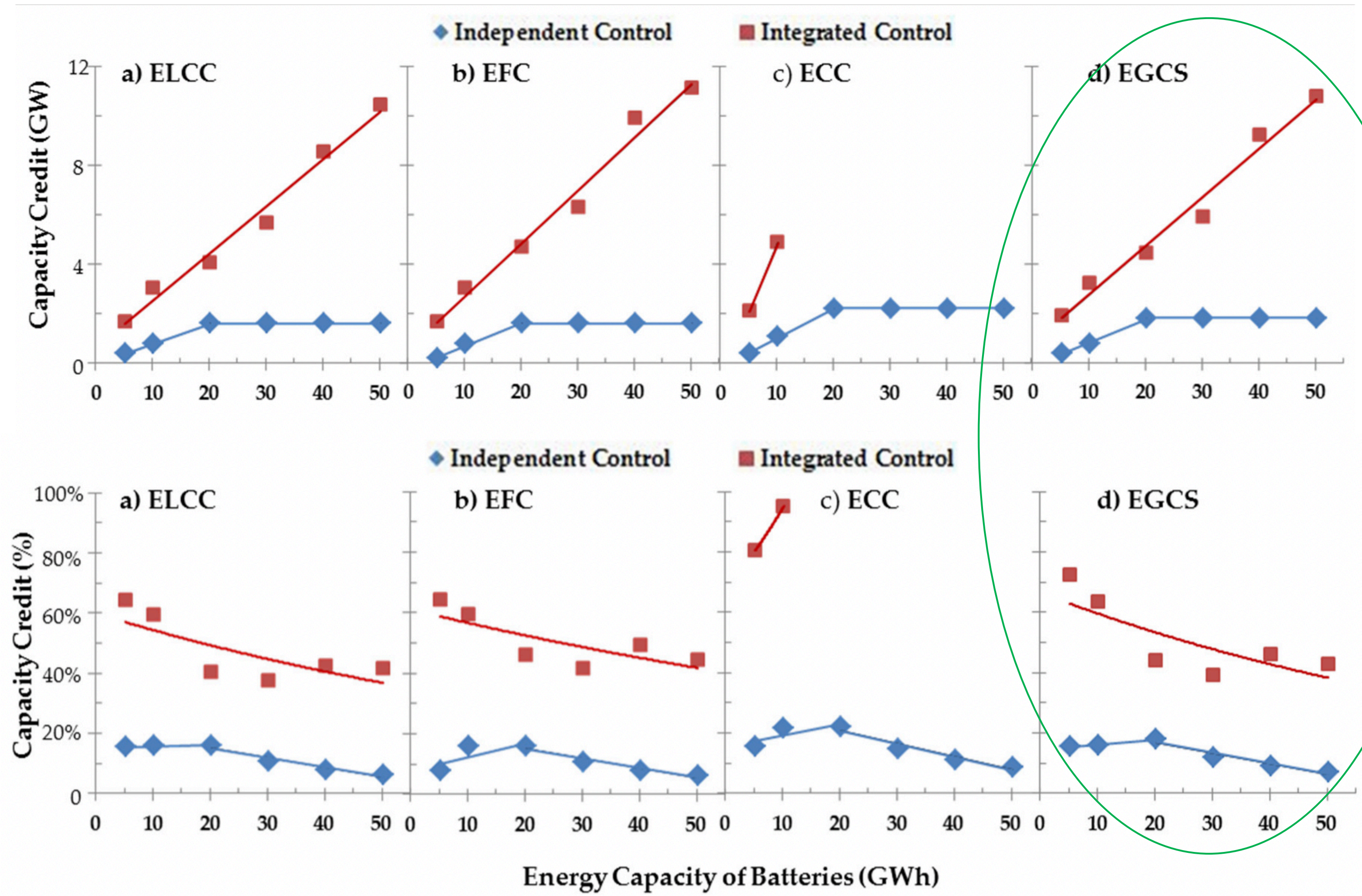
- Network constraints have impact on system scheduling and generation adequacy

- Meshing the system and a stronger interconnection to an area with large storage (TAS) or high capacity margin (QLD) can unlock more CC



See [6] for details

Capacity Credit of Distributed Energy Storage: UK case study example



- The energy/power ratio of batteries is assumed to be equal to 2

See [1] for details

Key concluding remarks

- **Capacity Credit (CC)** is a key technical concept for **system planning and market design** in the presence of renewables and other enabling technologies such as storage
- Given the complexity of system and market operation with renewables and storage, **simple formulas do not work**!
- Reliability-based **Monte Carlo Simulations** assessment is the state-of-the-art and most suitable methodology
- **Different metrics** for capacity credit may be adopted (e.g., *EGCS, ELCC*) with different reliability indicators (e.g., *LOLE*)
- *Renewables can provide significant capacity value, especially if "firmed up" by storage, but the assessment is case specific and requires suitable modelling*
- **Networks** can be both enabling and constraining system CC
- **Distributed storage** can provide (substantial) CC but requires suitable market signals over-riding self-consumption incentives

References

[1] L. Zhang, Y. Zhou, D. Flynn, J. Mutale and P. Mancarella, "System-Level Operational and Adequacy Impact Assessment of Photovoltaic and Distributed Energy Storage, with Consideration of Inertial Constraints, Dynamic Reserve and Interconnection Flexibility", *Energies*, vol. 10, no. 7, p. 989, 2017

[2] Y. Zhou, P. Mancarella and J. Mutale, "Generation adequacy in wind rich power systems: Comparison of analytical and simulation approaches," *2014 International Conference on Probabilistic Methods Applied to Power Systems (PMAPS),* Durham, 2014, pp. 1-6

[3] Y. Zhou, P. Mancarella and J. Mutale, " A framework for capacity credit assessment of electrical energy storage and demand response", *IET Generation, Transmission & Distribution*, vol. 10, no. 9, pp. 2267-2276, 2016

[4] Y. Zhou, P. Mancarella and J. Mutale, "Modelling and assessment of the contribution of Demand Response and Electrical Energy Storage to Adequacy of Supply", *Sustainable Energy, Grid And Networks (SEGAN)*, vol. 3, pp. 12–23, September 2015

[5] G. Liu and P. Mancarella, "Adequacy Assessment of Renewables-Dominated Power Systems with Large-Scale Energy Storage," 2019 29th Australasian Universities Power Engineering Conference (AUPEC), Nadi, Fiji, 2019, pp. 1-6, doi: 10.1109/AUPEC48547.2019.211877

[6] G. Liu, M. Vrakopoulou and P. Mancarella, "Assessment of the capacity credit of renewables and storage in multi-area power systems", *IEEE Trans. of Power Systems, submitted, under second review*

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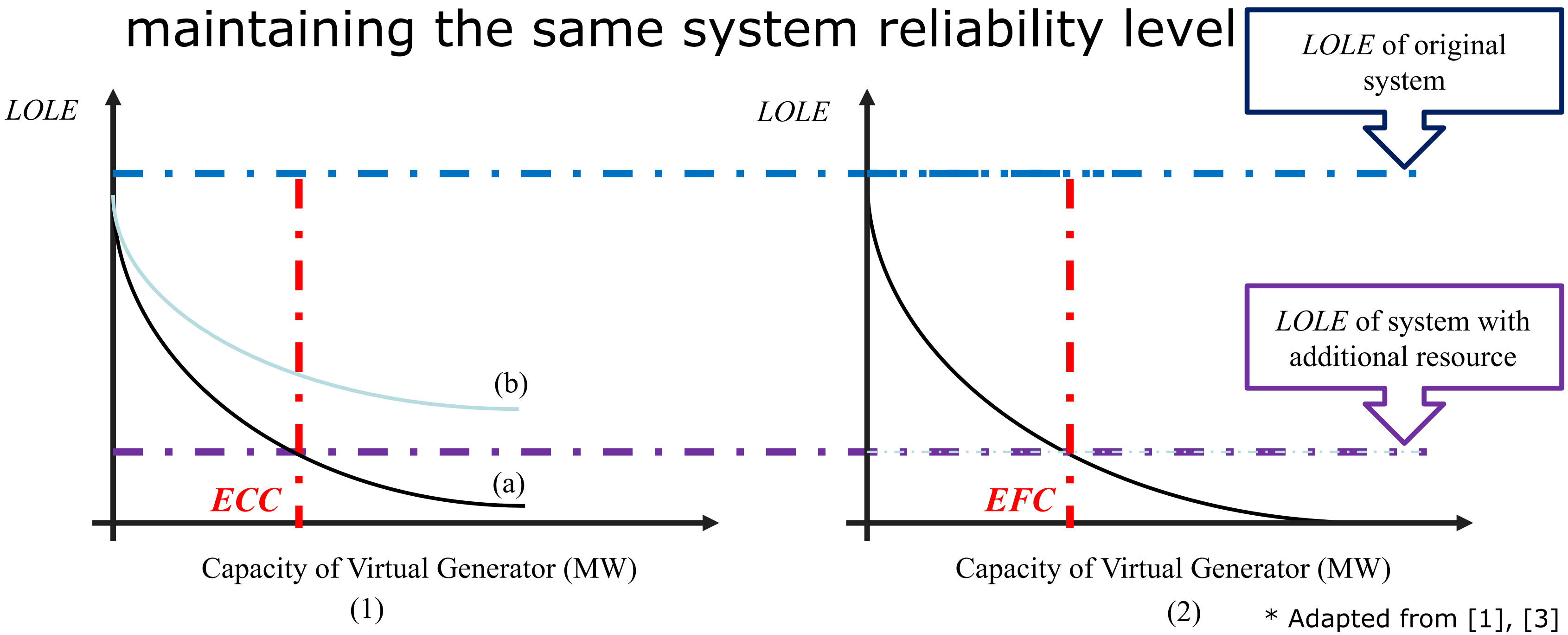
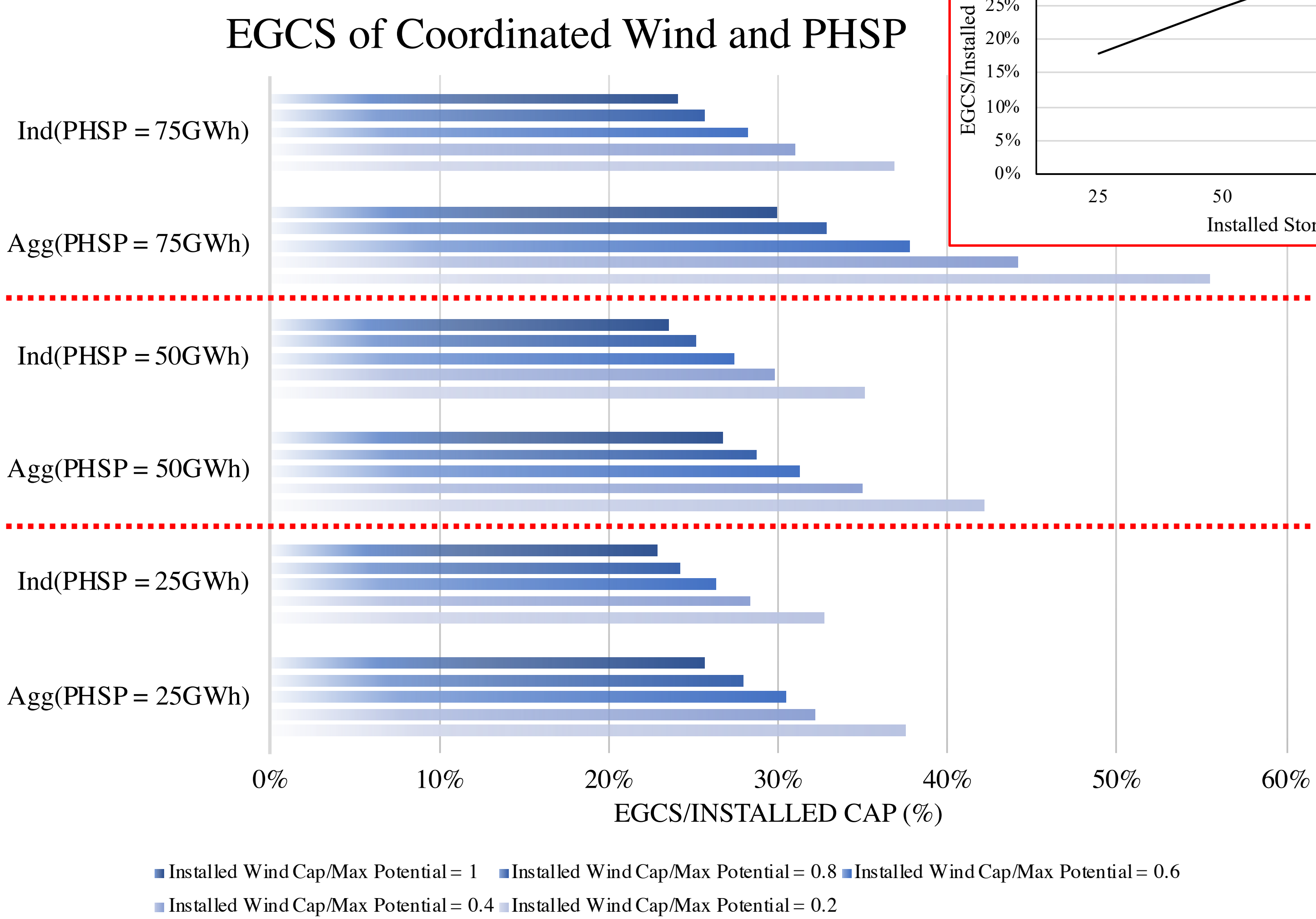
How to calculate the Capacity Credit of a resource: Metrics

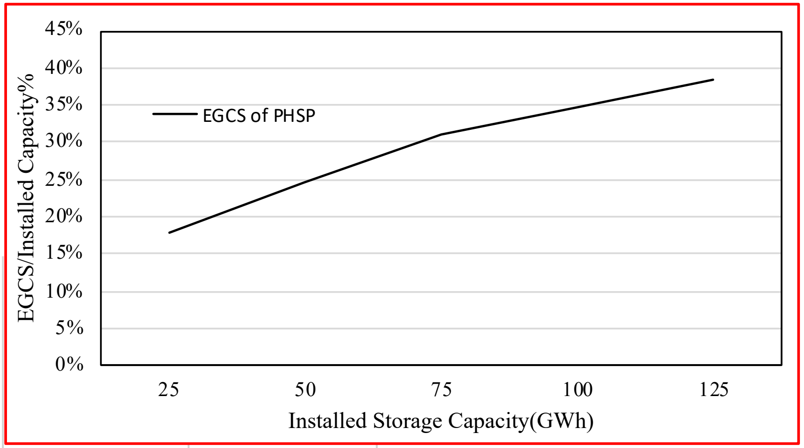
- **Equivalent Conventional Capacity (*ECC*)**:
  - The capacity of a virtual conventional generator that can replace the new resource while maintaining the same system reliability level
- **Equivalent Firm Capacity (*EFC*)**:
  - The capacity of a virtual, fully reliable conventional generator that can replace the new resource while maintaining the same system reliability level



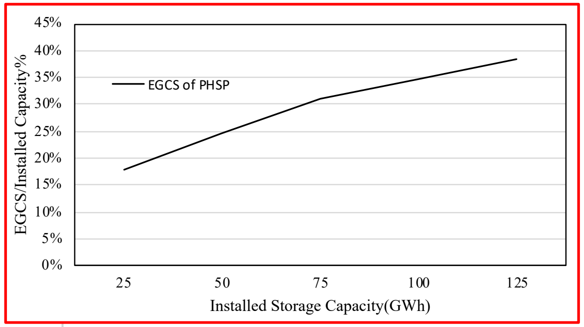
* Adapted from [1], [3] and [4]

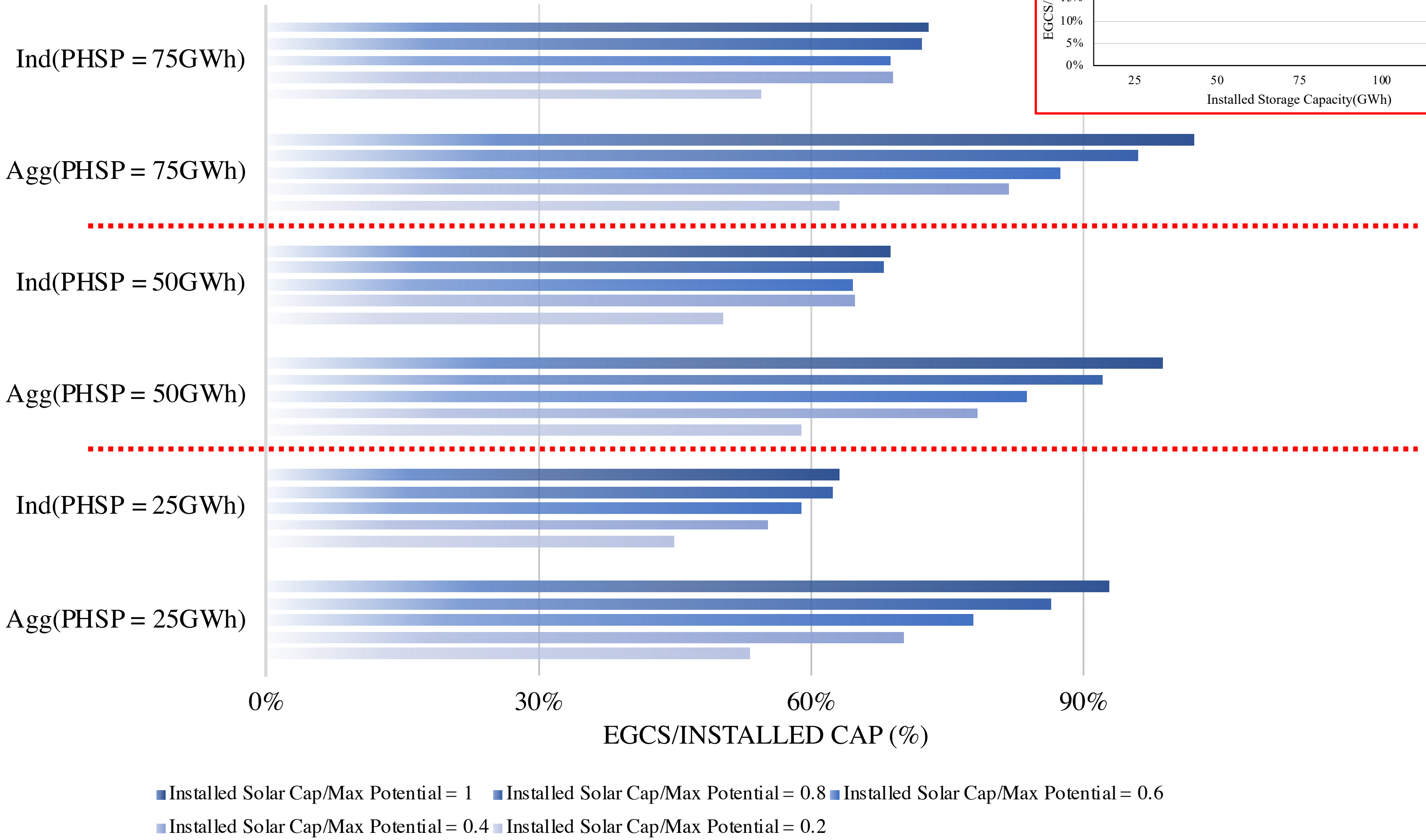
EGCS of Wind and PHSP





EGCS of Solar and PHSP



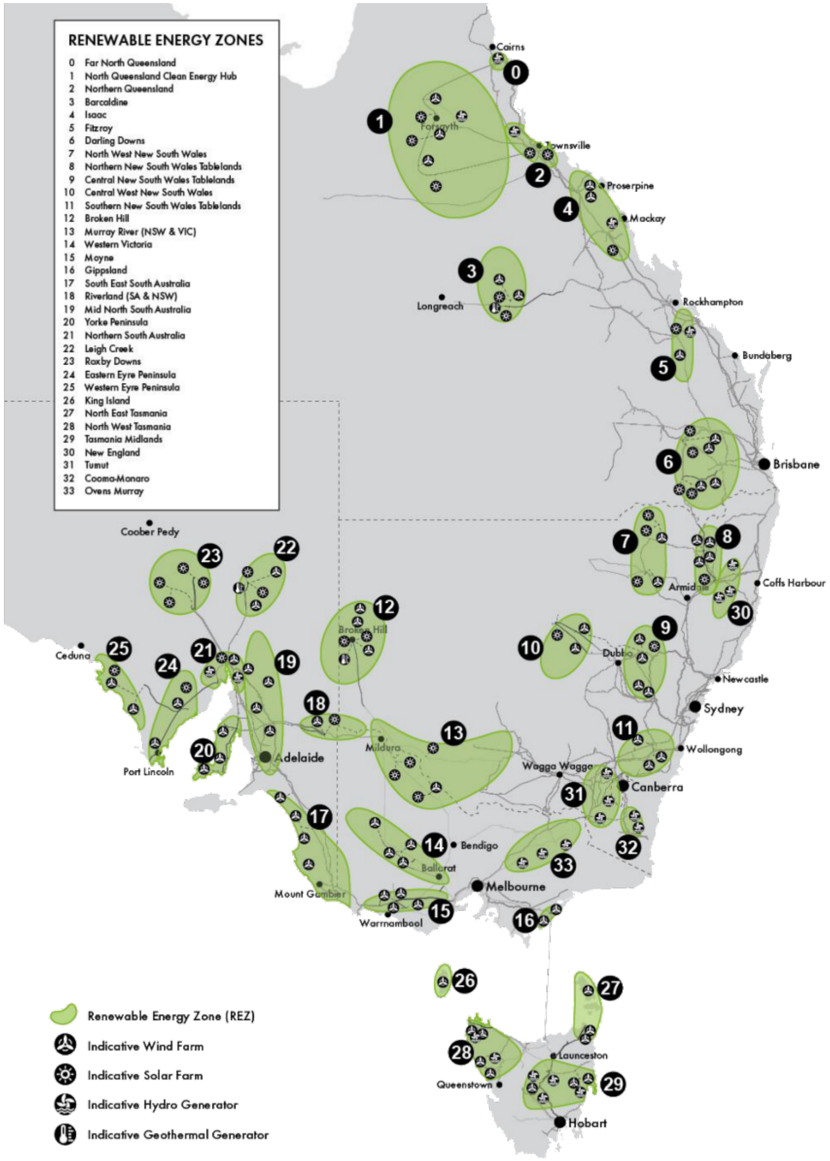


Capacity credit assessment in multi-area systems

	Wind Potential	Solar Potential	PHSP Projects	Peak Demand
QLD	3.89GW	4GW	0.31GW*5h	8.9GW
NSW	7GW	7GW	$\boxed{\text{1GW*14h}}$	15.1GW
VIC	5.21GW	4.9GW	0.03GW*6h	10GW
SA	2GW	0.98GW	0.36GW*13h	2.52GW
TAS	0.9GW	0	$\boxed{\text{1.2GW*24h}}$	1.5GW
Total	19GW	16.88GW	2.9GW*17h	36GW

	Conventional Generation Capacity	Conventional Generation Capacity Margin
QLD	13.63GW	$\boxed{\text{4.73GW}}$
NSW	15.32GW	0.22GW
VIC	10.67GW	$\boxed{\text{0.67GW}}$
SA	2.43GW	-0.09GW
TAS	2.46GW	0.96GW
Total	44.51GW	6.39GW

Interconnector	From/To	To/From	Capacity/MW
Terranora	QLD	NSW	210
QNI	QLD	NSW	1078
VIC1-NSW1	VIC	NSW	1600
Basslink	TAS	VIC	594
Heywood	VIC	SA	600
Murraylink	VIC	SA	220



See [6] for details

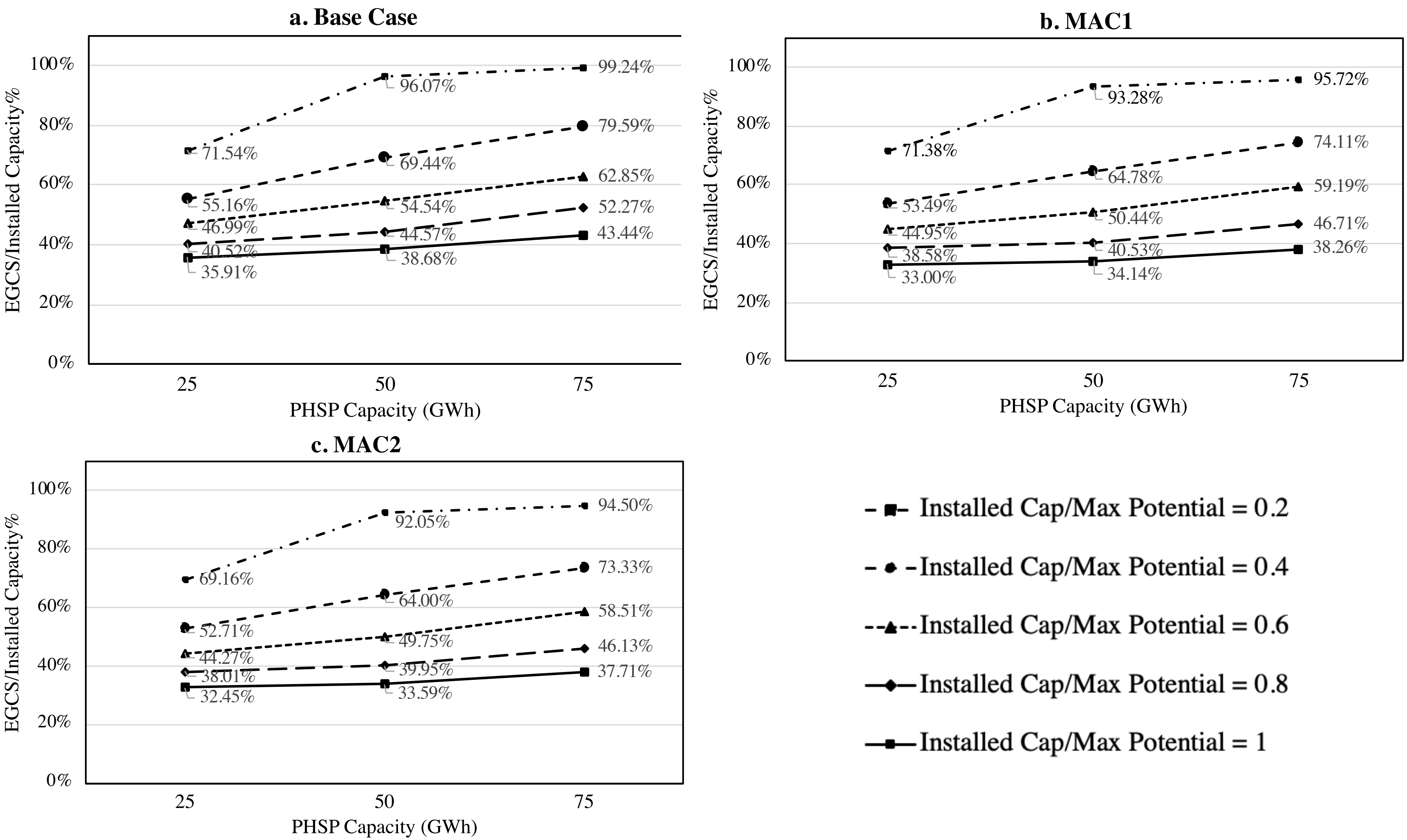
Case studies for multi-area system

- NEM – Wind +Solar +Storage Aggregation System
- Three cases are studied:
  - **Base Case (BA)**:
    - the system is treated as a single area system
  - **Multi-area Case 1 (MAC1)**:
    - network constraints are considered
    - all interconnectors are assumed to be fully reliable and with nominal capacity
  - **Multi-area Case 2 (MAC2)**:
    - both network constraints and interconnectors' unavailability are considered

See [6] for details

Results and analysis for multi-area systems

- NEM: Wind + Solar + Storage System



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