Project EDGE

Demonstrations Insights Forum | 16 August 2022

Agenda

Item	Lead	Timing
Welcome, Acknowledgement of Country	Ryan Batchelor (Nous)	5 min
Quick project status update	Nick Regan (AEMO)	5 min
Results from market suspension tests	Nick Regan (AEMO)	20 min
Objective function	James Naughton (UoM)	45 min
Close and next steps	Ryan Batchelor (Nous)	5 min

Acknowledgment of Country

We acknowledge the Traditional Owners of country throughout Australia and recognise their continuing connection to land, waters and culture.

We pay our respects to their Elders past, present and emerging.

Project EDGE update

Current position

- Finalising stakeholder feedback into final CBA methodology
- Two new aggregators being onboarded for participation from September
- Ongoing customer acquisition (including additional) C&I customers
- Providing update on DOE Objective Functions study

Key upcoming activities

- Publication of the final CBA Methodology
- Further consultation on data exchange problem statements and use cases
- Wider sharing of results from Market Suspension tests
- Ongoing results analysis and input into reform

Results from market suspension tests

EDGE Market Suspension field tests

To operate the system AEMO needs:
1. Visibility: Telemetry in real time
2. **Predictability**: Generator forecasts
3. Controllability: Dispatch instructions
4. **Measurement**: Telemetry (settlement)

The AEMO, AusNet and Mondo team reacted quickly to establish a test plan to learn from this rare event

Why specific Market Suspension tests?

In Market Suspension AEMO was directing large scale generators.
What should this look like in a high DER future (via VPPs)?

Hypothesis 1:
AEMO Dispatch Instructions that give a 'target' are more reliable than DOEs which give 'permissible limits'.

Hypothesis 2:
These two signals together will conflict at times and this needs to be understood to be managed in future operations.

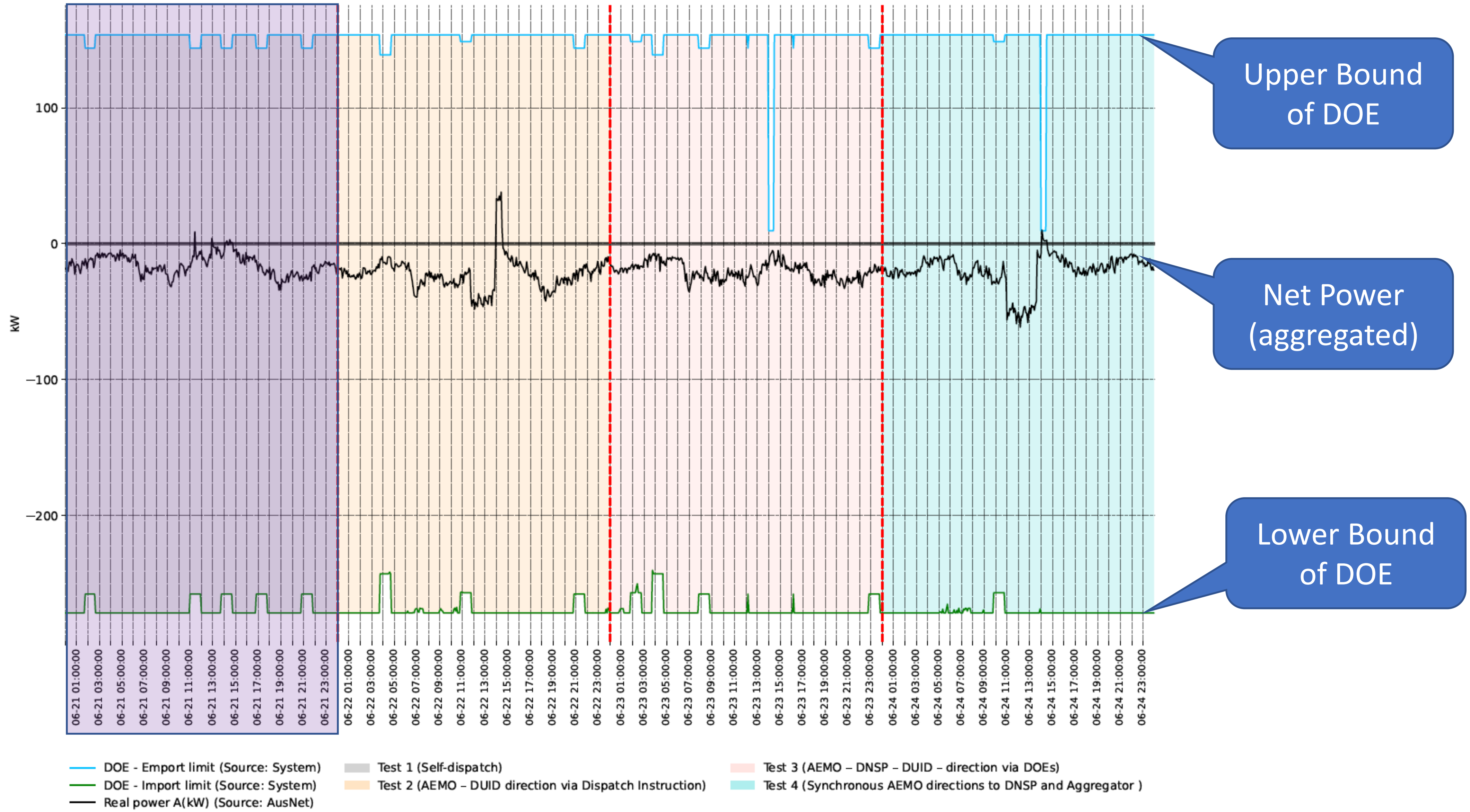
What did we do?

Test	Summary
Test 1 **Self-Dispatch (no AEMO direction)**	• In lieu of capability to dispatch VPPs at scale ('Controllability') i.e current state, AEMO needs visibility (telemetry) and predictability (forecasts via boffers) to consider when directing large scale resources • **Q: What do VPPs do without AEMO direction?**
Test 2 **AEMO -> DUID direction via Dispatch Instructions**	• Under market suspension AEMO instructs generators/loads test is for future where controllability exists for VPPs (i.e test will provide setpoints for aggregators to follow). • **How reliably can VPPs follow AEMO directions that differ from market incentivised behaviour?**
Test 3 **AEMO –> DNSP –> DUID direction via DOEs**	• Currently AEMO instructs NSPs to maintain a profile within their network, NSPs currently do this by shedding load or generation. • **Are DOEs a better mechanism than directing VPPs under a non-market use case (e.g market suspension) ?**
Test 4 **Synchronous AEMO directions to DNSP and Aggregator** **(Test 2+3)**	• Testing synchronous instructions from AEMO to DNSP and Aggregator to see if this helps reduce potential conflicts. Test 2 & Test 3 together. • **Is it worth building capability to do both mechanisms for redundancy?**

Findings to be shared in coming weeks and relate to some gaps as highlighted in the Engineering Frameworks Paper[1]

1 At https://aemo.com.au/-/media/files/initiatives/engineering-framework/2021/nem-engineering-framework-march-2021-report.pdf?la=en&hash=3B1283D31B542115CC56E0ECCDFB3D69

Test 1 – Actual Net Active Power from Portfolio

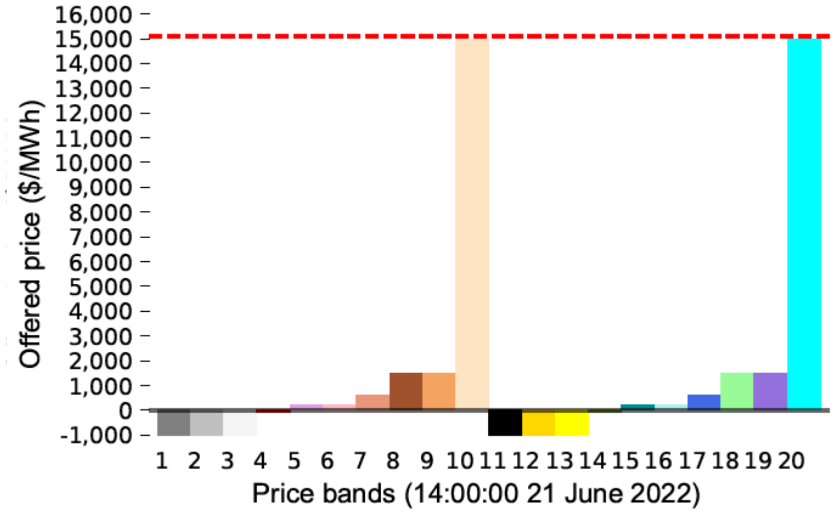


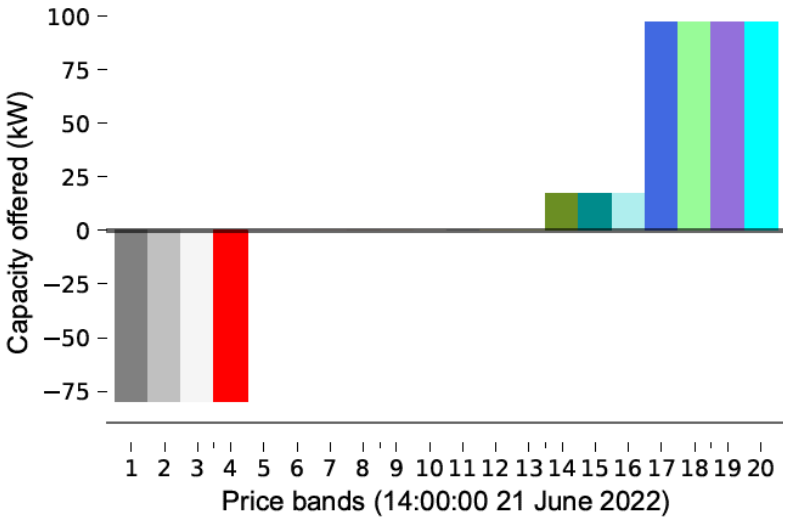
Test 1

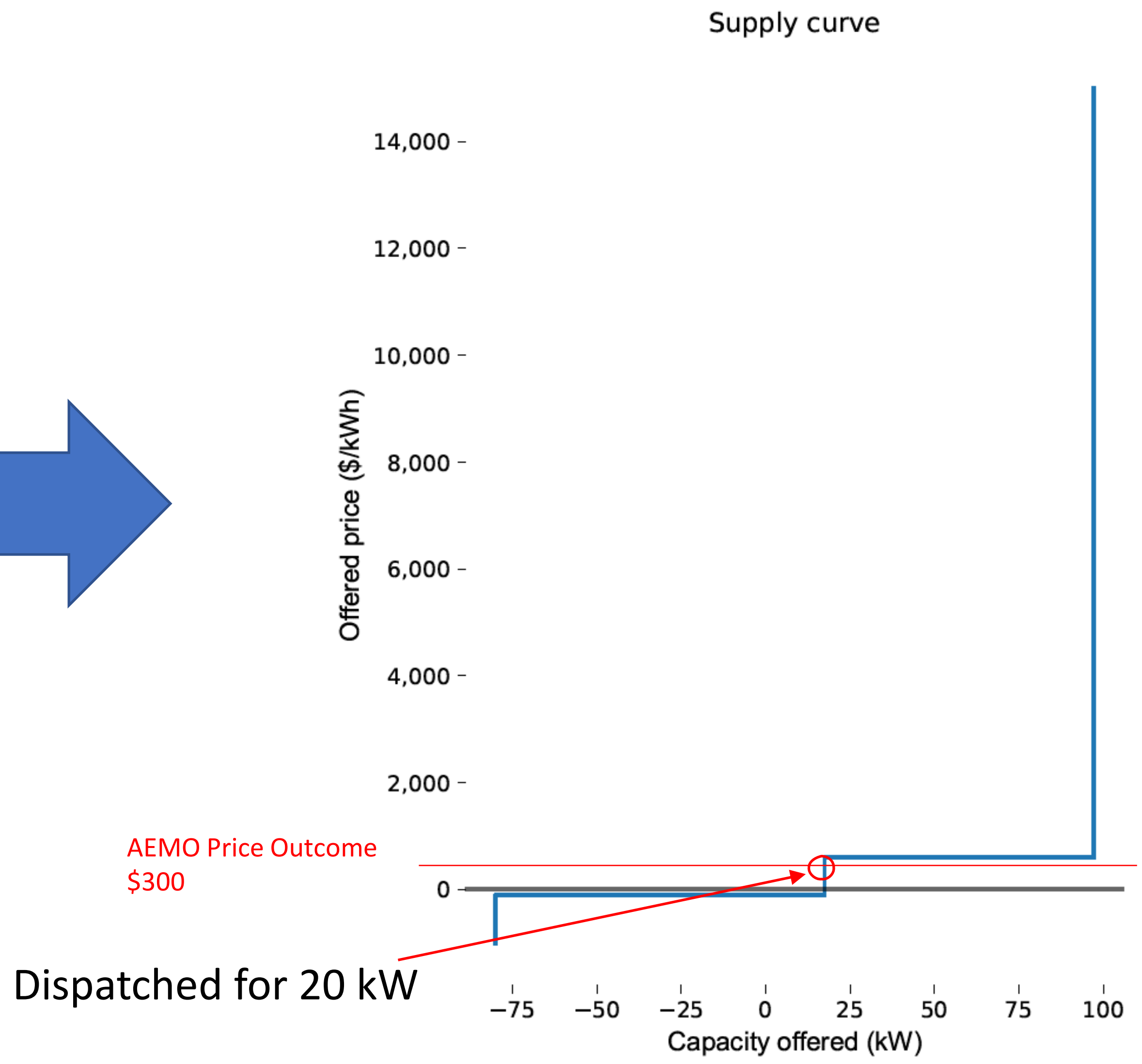
Q: What do VPPs do without AEMO direction?

Self-Dispatch (no AEMO direction)

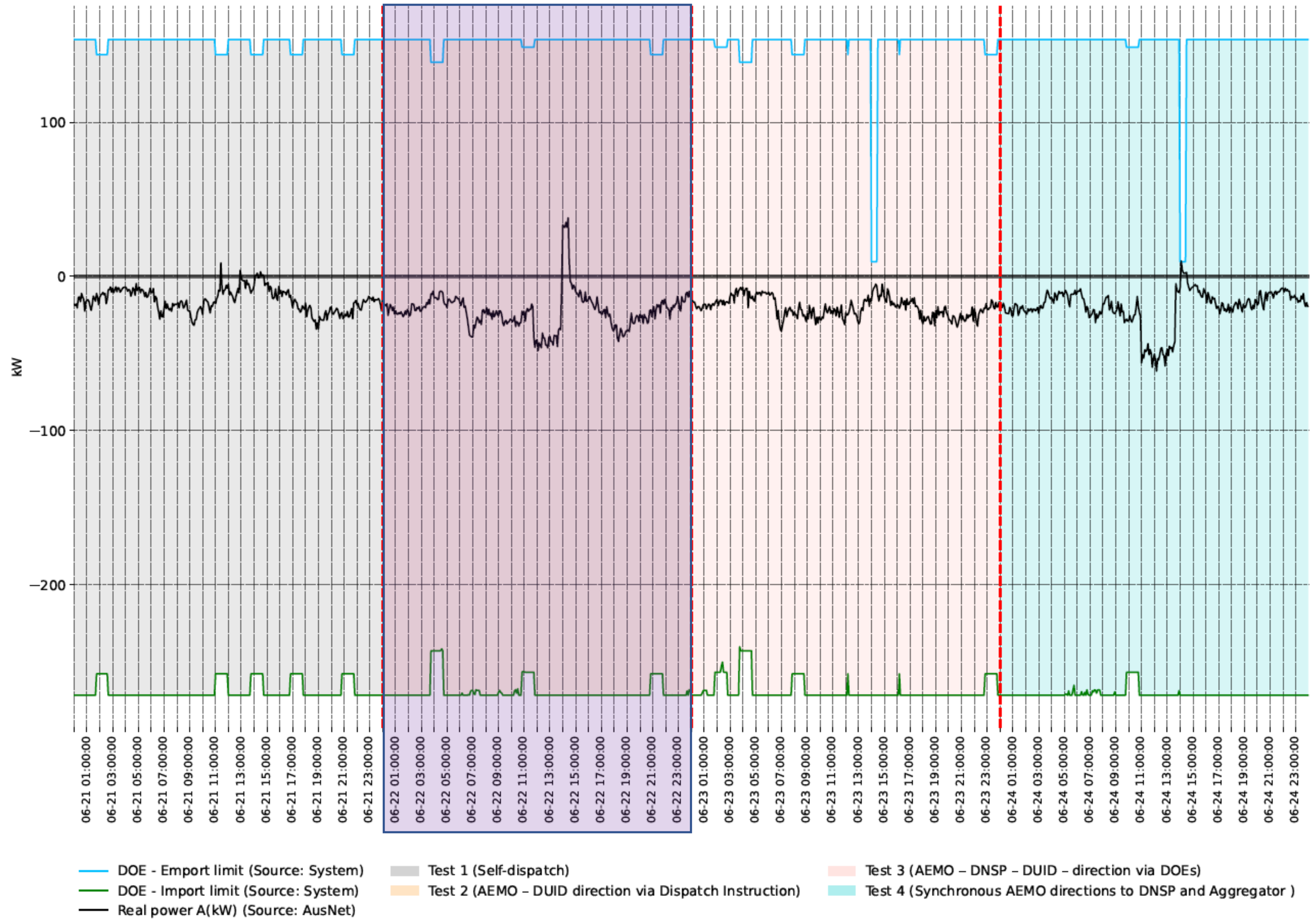
In lieu of capability to dispatch VPPs at scale (‘Controllability’) i.e current state, AEMO needs visibility (telemetry) and predictability (forecasts via boffers) to consider when directing large scale resources







Test 2 – Actual Net Active Power from Portfolio



Test 2

Q: How reliably can VPPs follow AEMO directions that differ from market incentivised behaviour?

AEMO -> DUID direction via Dispatch Instructions

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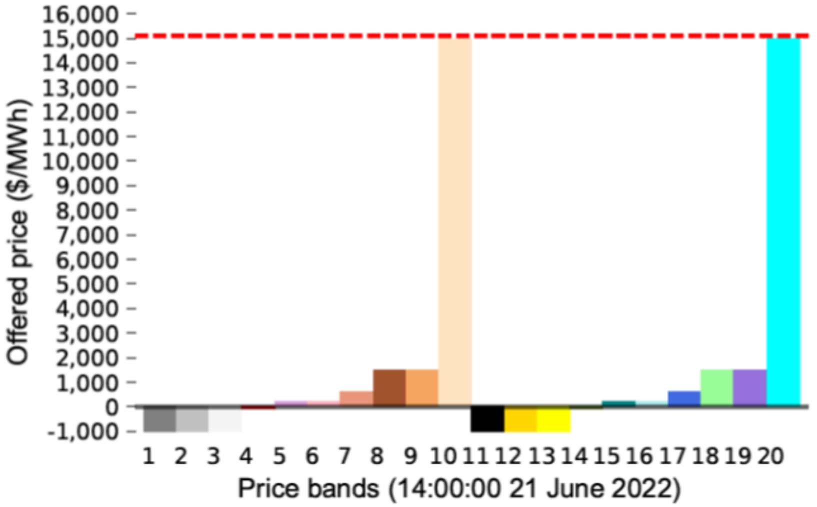
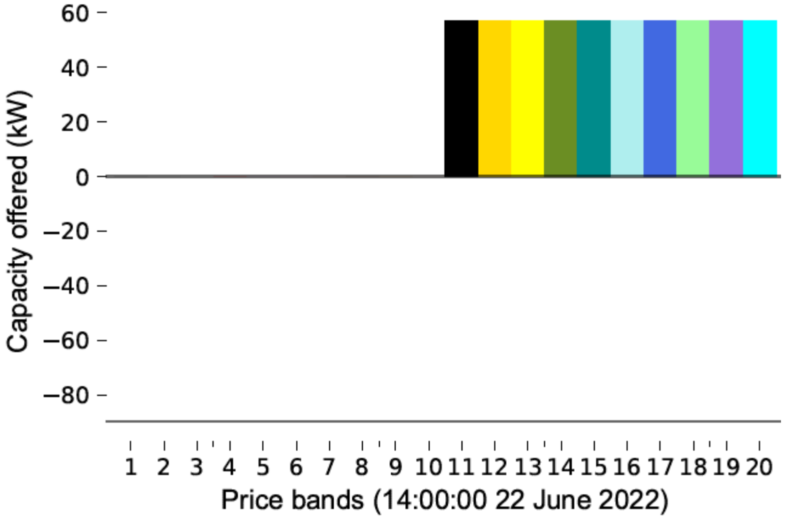
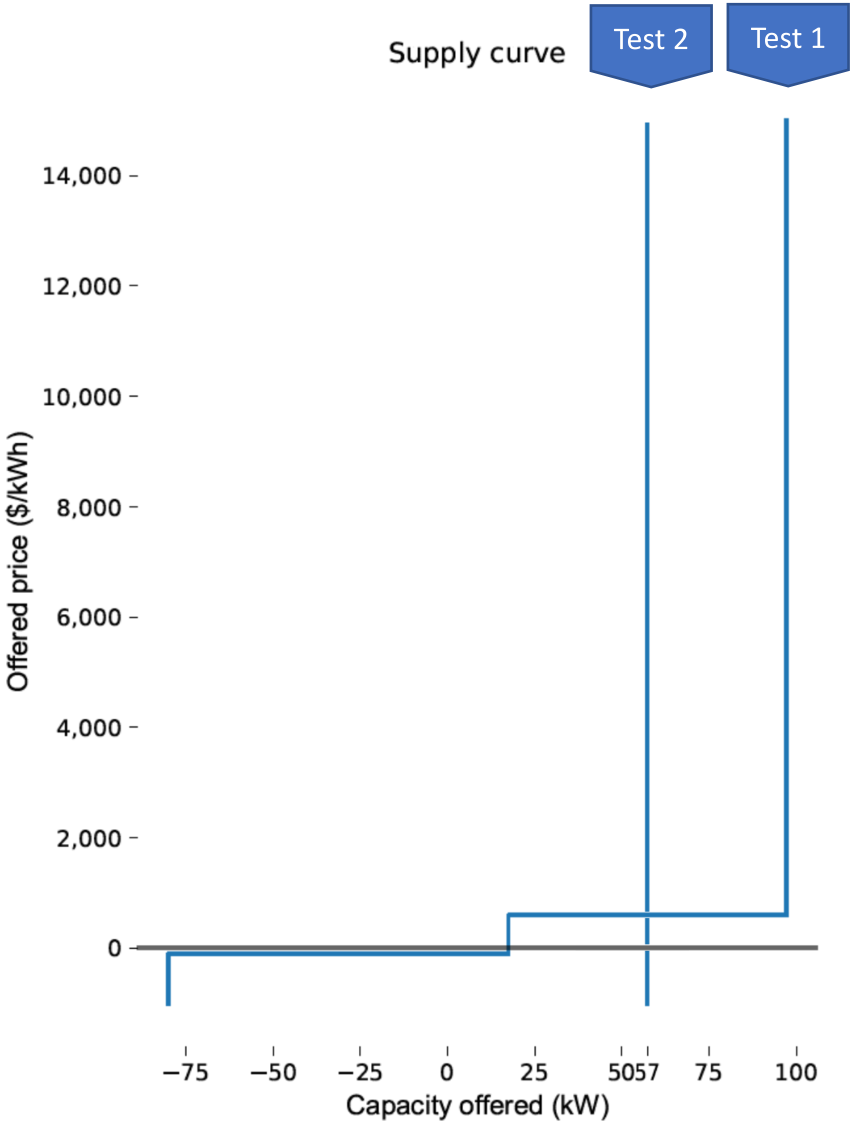






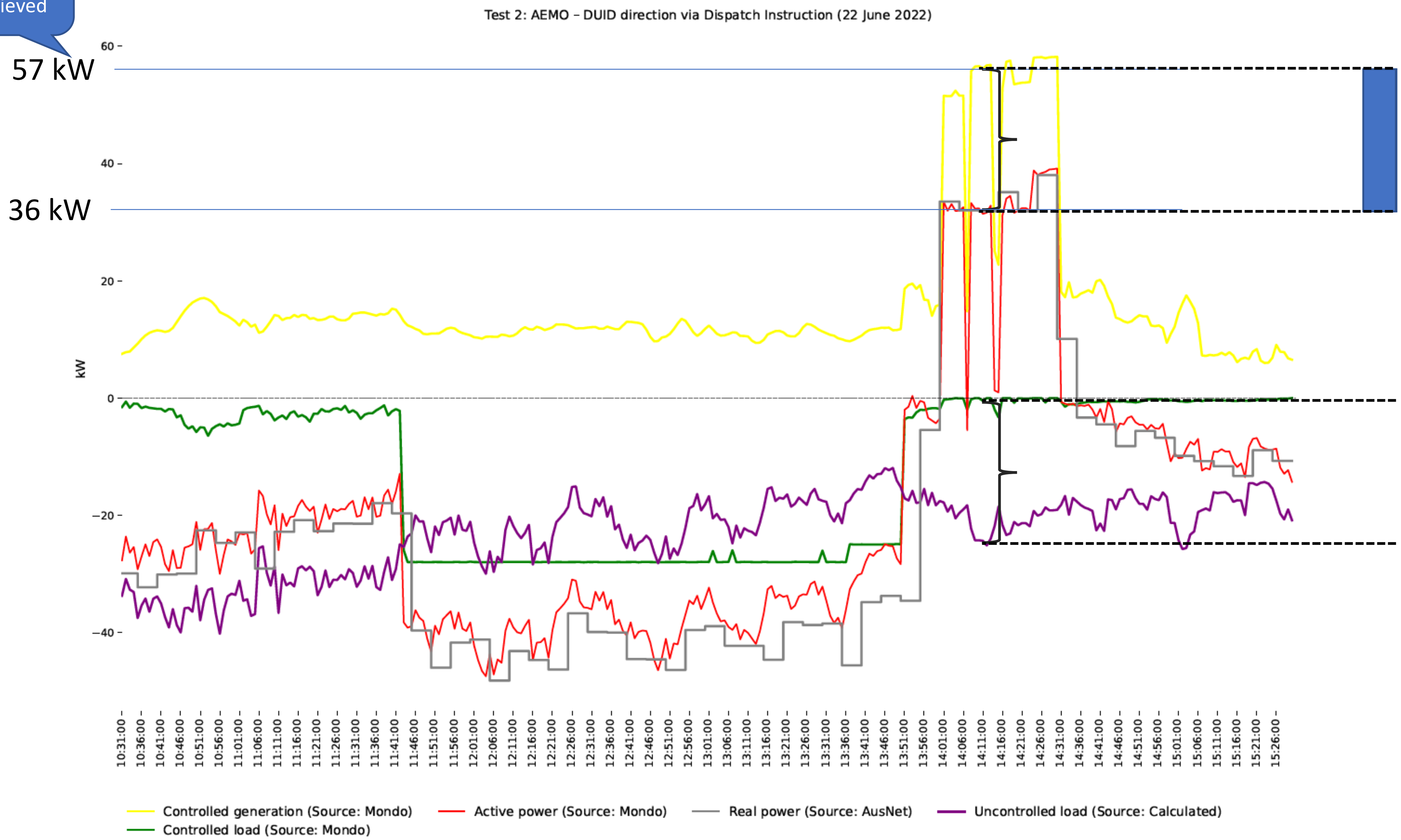
Finding Question:
How should boffers which have been directed by AEMO be formed.

Trial simulated a directions for 57kW of flexible export from 14:00-14:30.

Energy Fixed Loading a better Boffer?

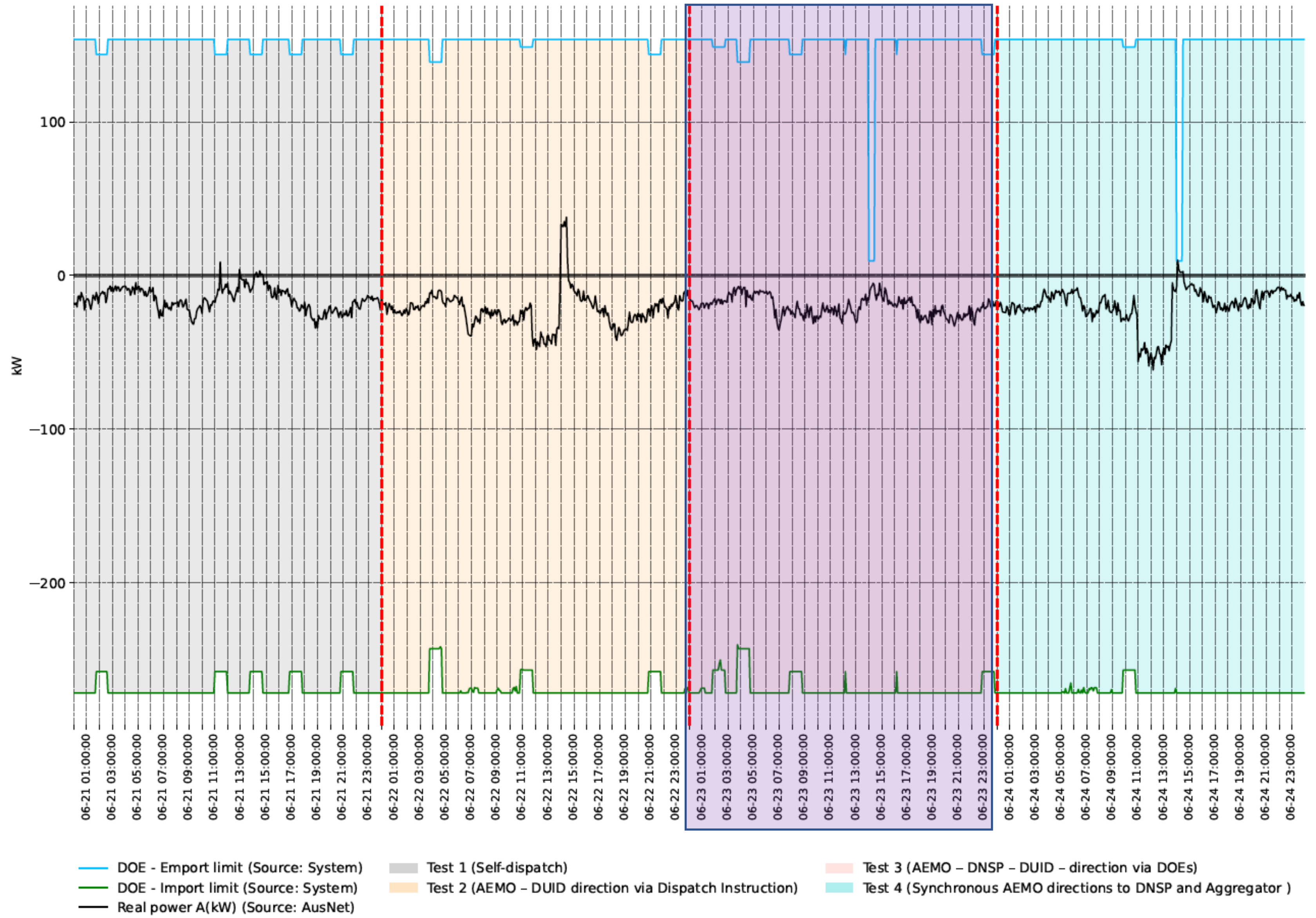
Flexible Target achieved

Trial simulated a directions for 57kW of flexible export from 14:00-14:30.



Difference between Flex and Net equals the amount of non-controlled load

Test 3 – Actual Net Active Power from Portfolio



Test 3

Q: Are DOEs a better mechanism than directing VPPs under a non-market use case (e.g market suspension) ?

AEMO –> DNSP –> DUID direction via DOEs

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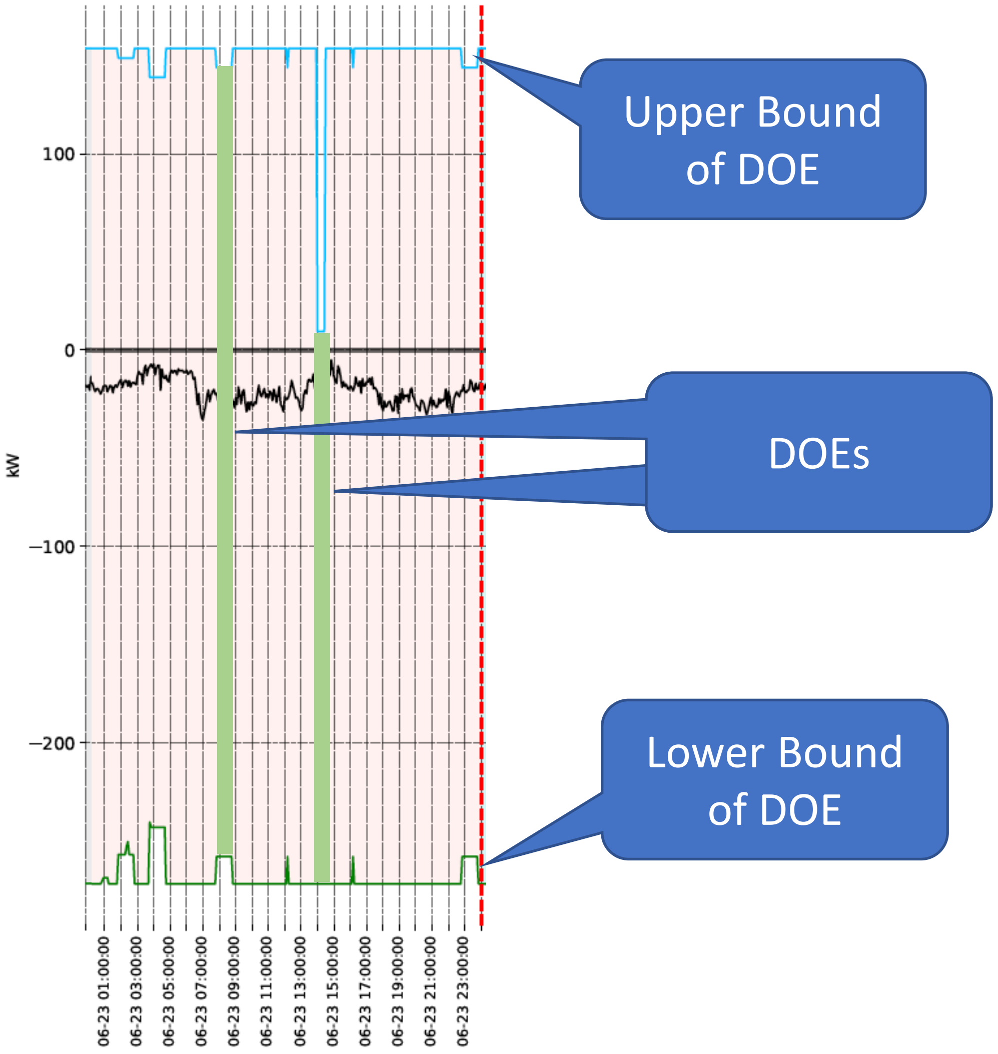

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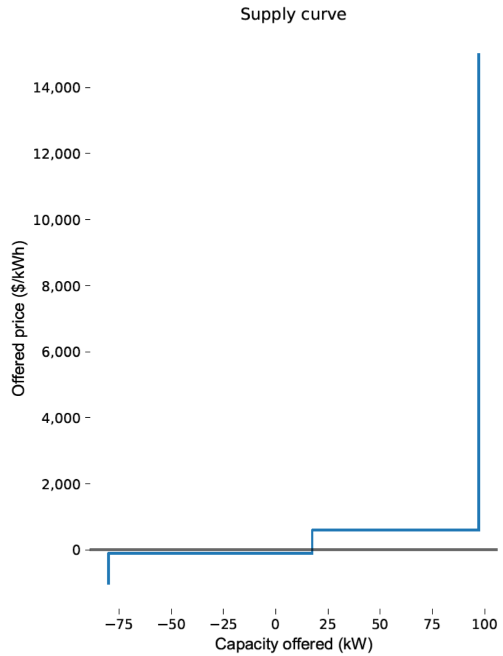
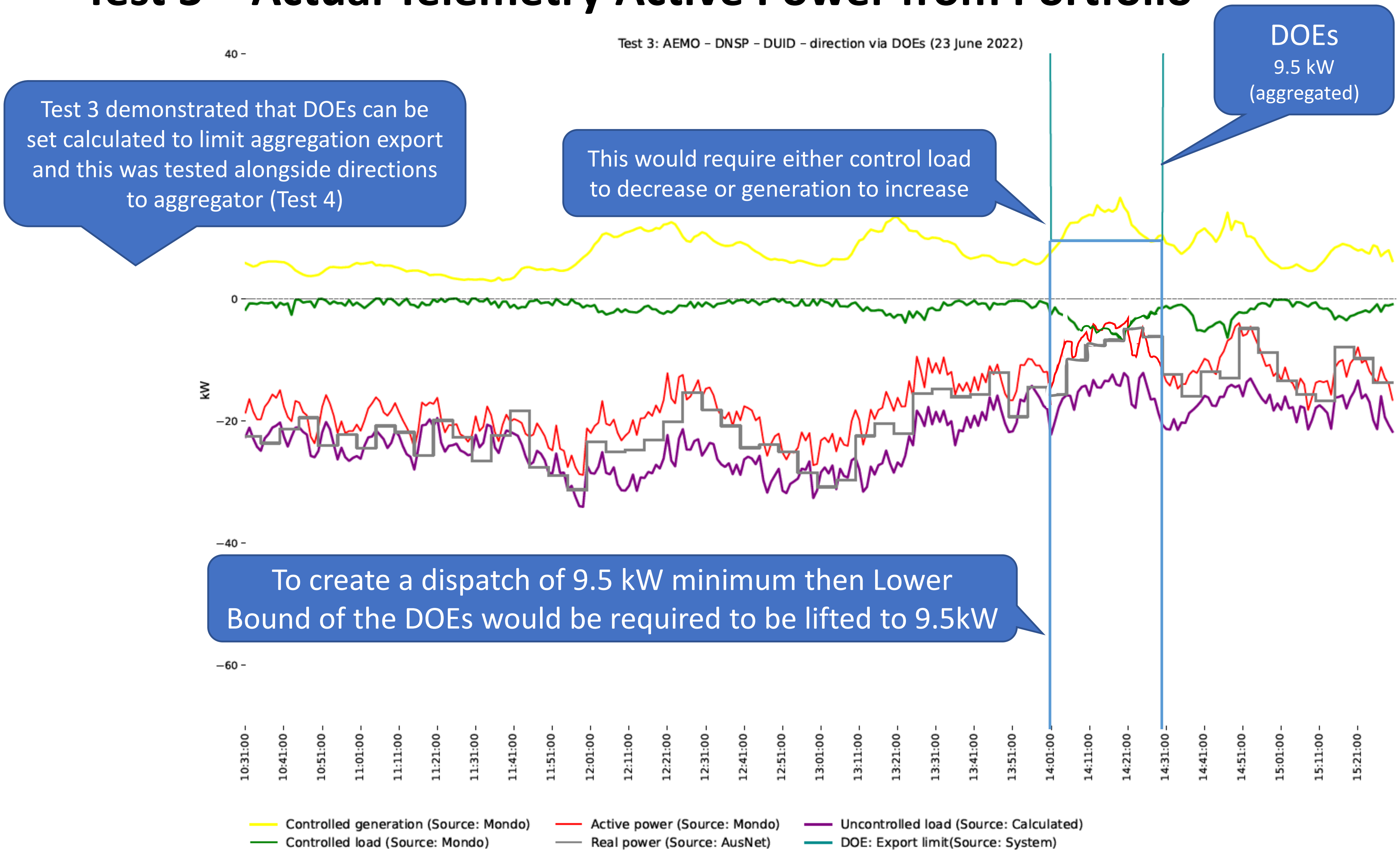
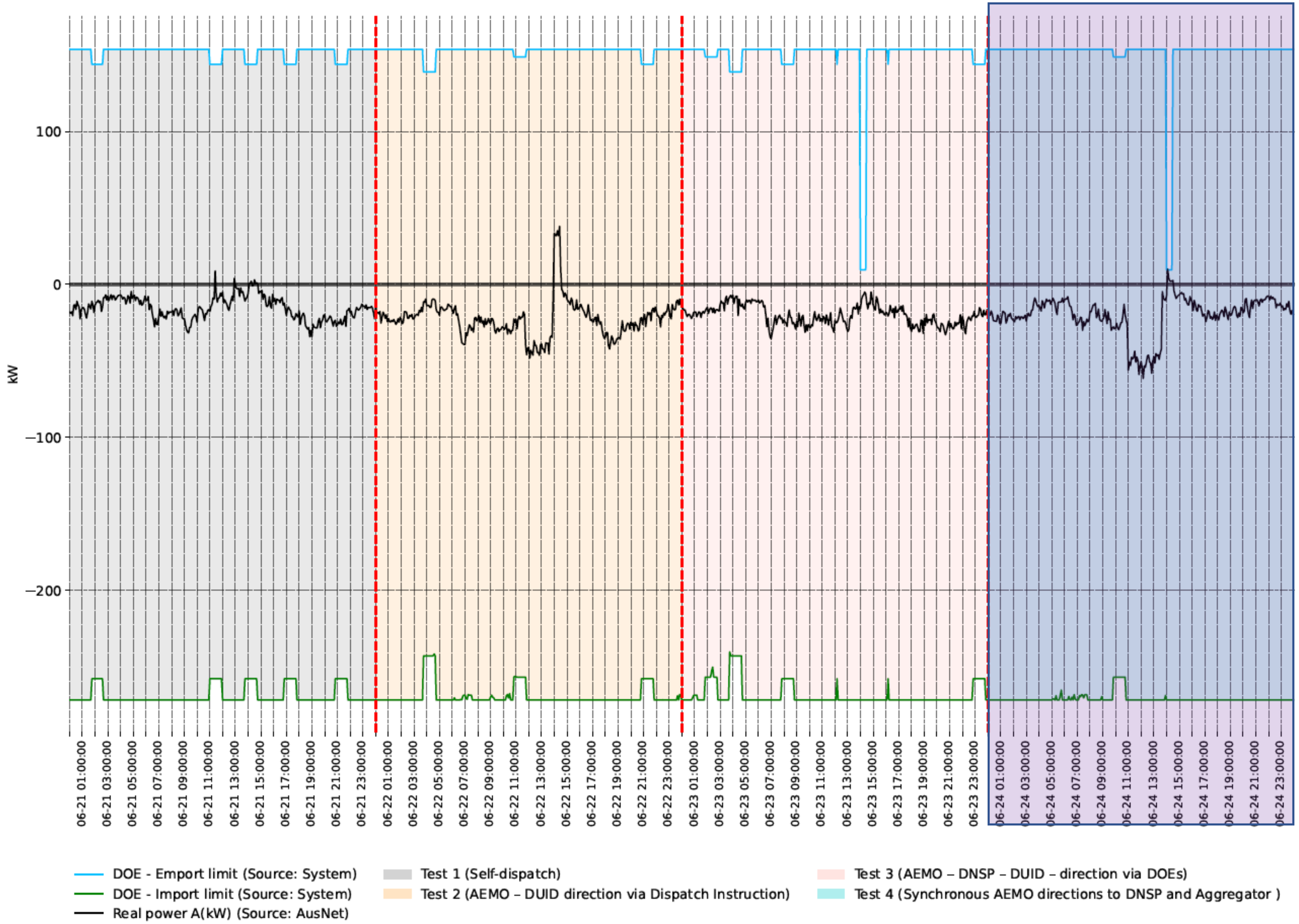


Test 3 – Actual Telemetry Active Power from Portfolio



Test 4 – Actual Net Active Power from Portfolio

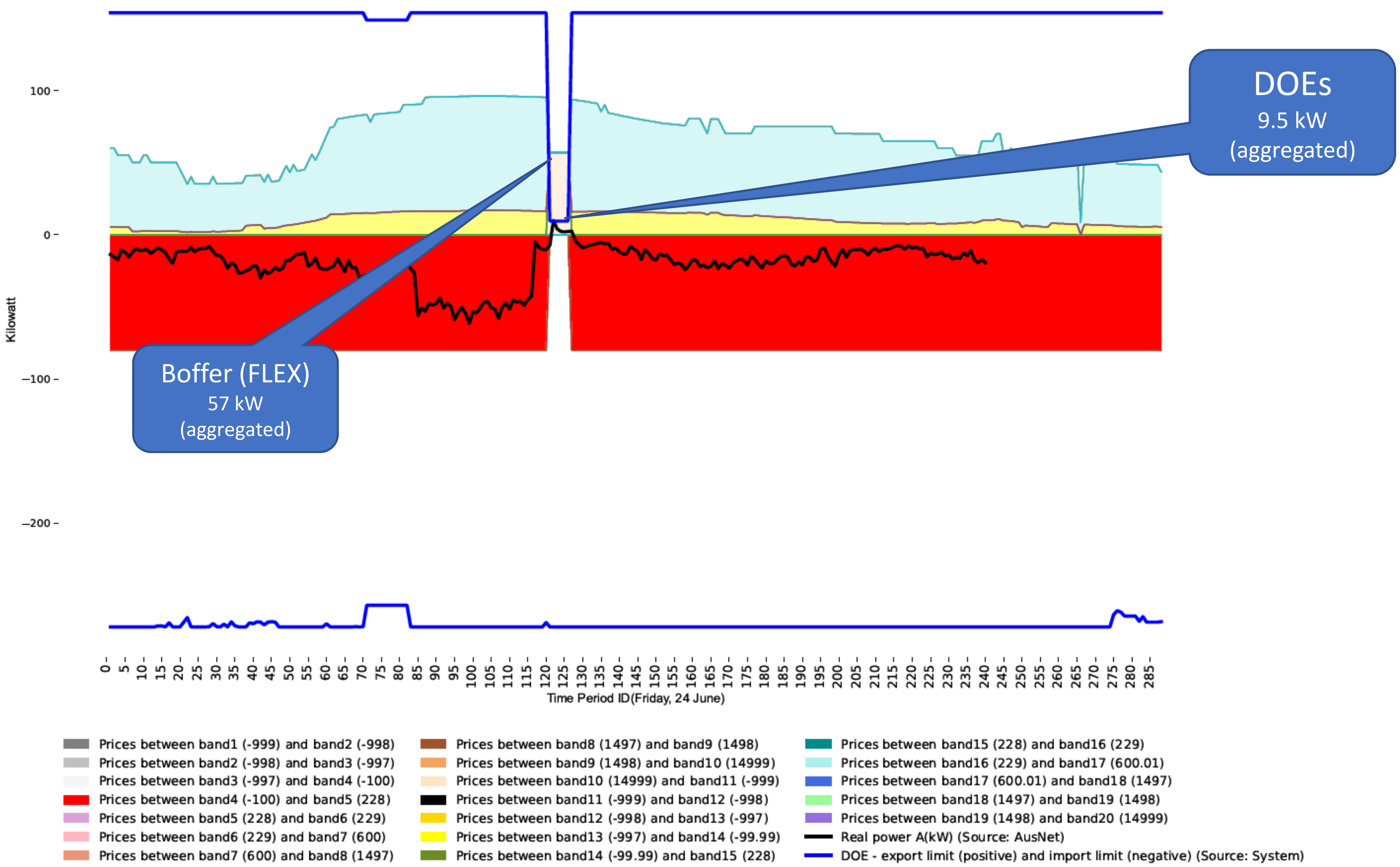


Test 4

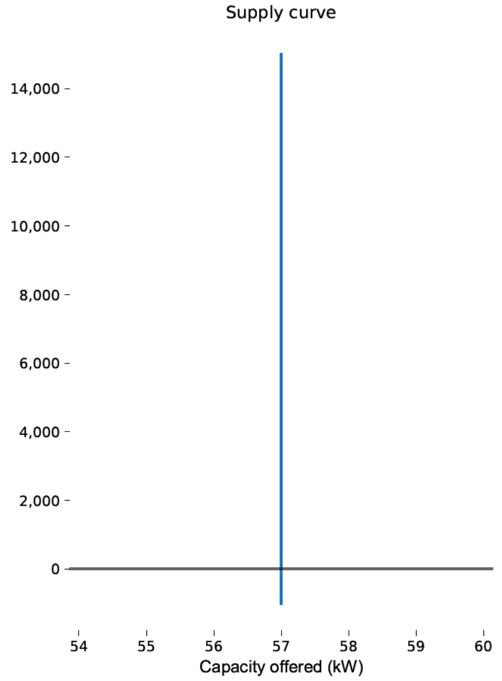
Q: Is it worth building capability to do both mechanisms for redundancy?

Synchronous AEMO directions to DNSP and Aggregator (Test 2+3)

Testing synchronous instructions from AEMO to DNSP and Aggregator to see if this helps reduce potential conflicts. Test 2 & Test 3 together.

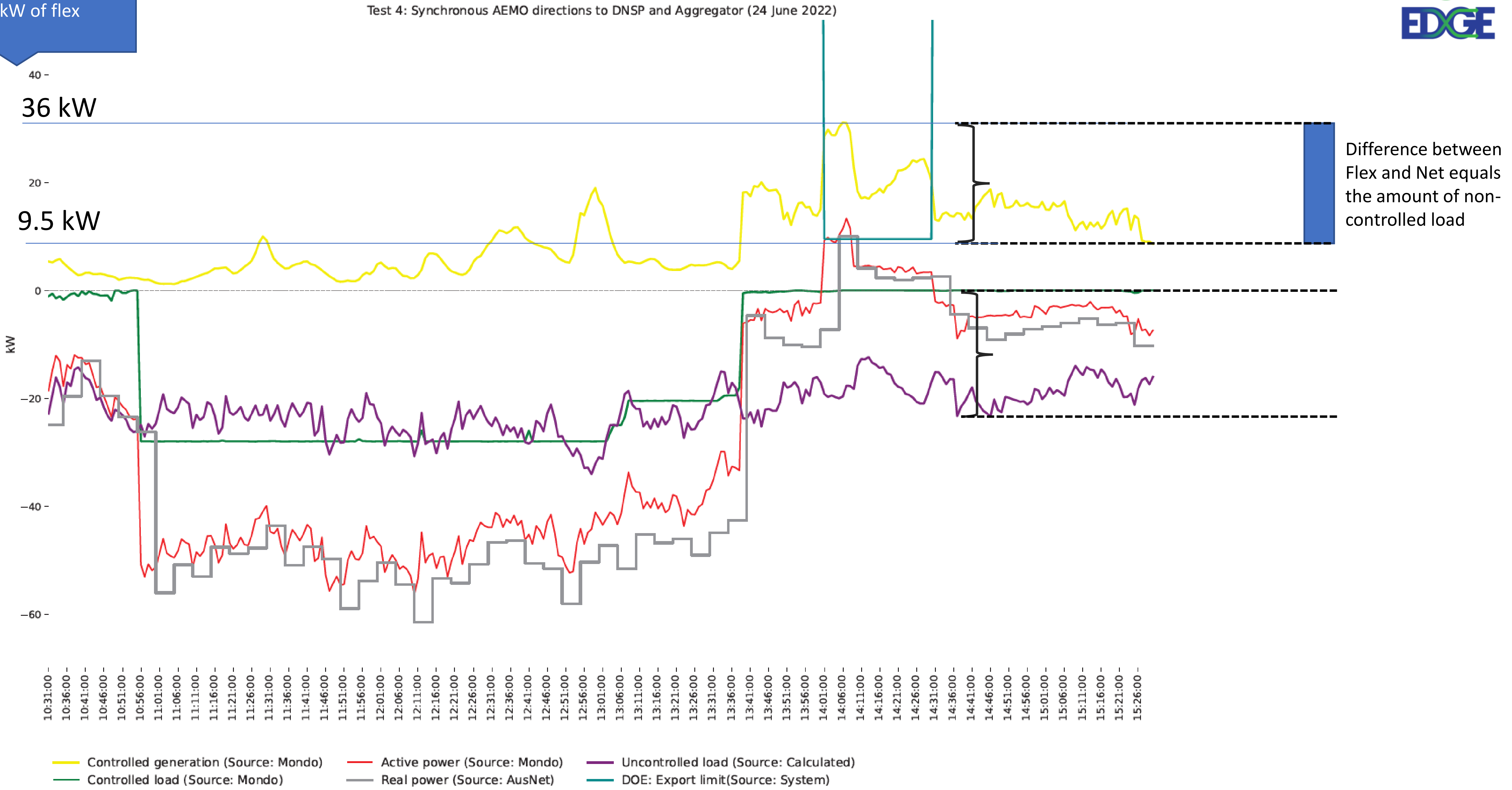


<u>Hypothesis 2:</u>
These two signals together will conflict at times and this needs to be understood to be managed in future operations.



Trial simulated directions for 57kW of flexible export from 14:00-14:30.

Unable to achieve 57kW of flex



EDGE Market Suspension field tests

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Key take aways

1) Aggs can hit intervention targets when directed
2) DNSP can calc DOEs to achieve a set point under certain conditions
3) DOEs take priority to keep network within operating limits
4) In designing directions to VPPs in future, AEMO needs to consider DOEs so that aggregators do not receive unachievable targets (test 4).
5) Visibility of DOEs in Project EDGE was provided by the Data Exchange Hub allowing multiple subscribers to include AEMO and Aggregators.
6) Target assessment was only achieved with telemetry of aggregated DER generation and load response ('flex') as opposed to only the site meter (Net NMI)

Findings to be shared in coming weeks and relate to some gaps as highlighted in the Engineering Frameworks Paper[1]

1 At https://aemo.com.au/-/media/files/initiatives/engineering-framework/2021/nem-engineering-framework-march-2021-report.pdf?la=en&hash=3B1283D31B542115CC56E0ECCDFB3D69

Project EDGE | DOE Objective Functions

Demonstrations Insight Forum | 16 August 2022

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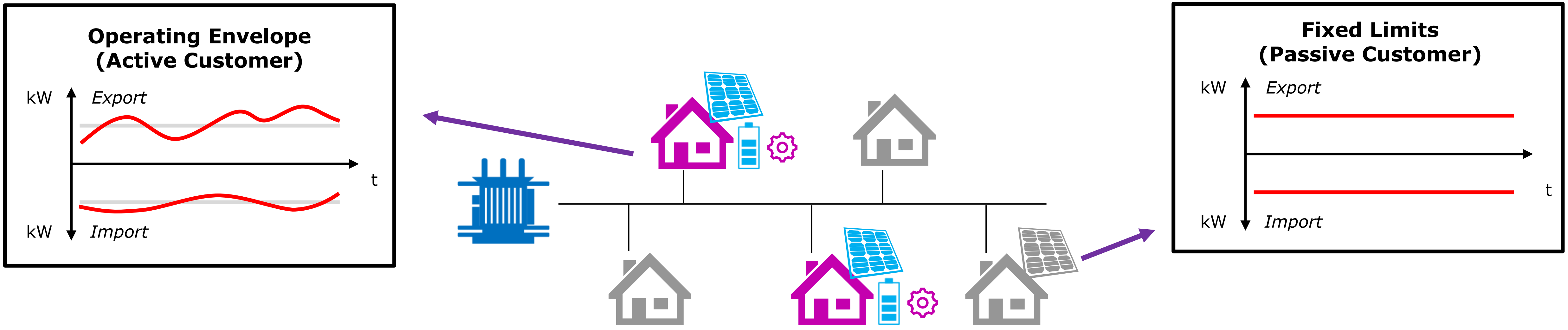
Contents

- Context
- Operating Envelope Objectives
- Assessment Metrics
- Simple Toy Network
- More Detailed Case Study
- Key Takeaways

Context



- How should capacity be allocated?
- Should the allocation methodology be “fair”?
- How does this align with the NEO?
- **Aim: Assess a broad spectrum of possible Operating Envelope objectives across technical, economic, and fairness metrics**

Spectrum of OE Objectives - Export

$\max P^{ex}$

A. Maximise Service

- No consideration of fairness
- Solely optimal power flow

$\max \sum \alpha_k P_k$

B. Weighted Allocation

- Each DER has a weighting coefficient assigned by the DSO.
- E.g., prioritise renewable DER:
  - PV have $\alpha_k = 2$
  - Other DER have $\alpha_k = 1$
- Or some DER may pay for "priority access"

$\max P^{ex}$

C. Proportional Allocation

- Each DER is allocated *X* % of its rated capacity, where *X* is constant across all participating DER.
- The value of *X* is determined by OE optimisation.

$$P_k = X\widehat{P_k^\tau}$$

$\max P^{ex}$

D. Proportional Unallocated DER Capacity

- Each DER has X% of its rated capacity left **unallocated.**
- The value of *X* is determined by OE optimisation.

$$P_k = (1 - X)\widehat{P_k^\tau}$$

$\max P^{ex}$

E. Equal Unallocated DER Capacity

- Each DER has *Y* kW of its rated capacity left **unallocated.**
- The value of *Y* is determined by OE optimisation.

$$P_k = \widehat{P_k^\tau} - Y$$

$\max P^{ex}$

F. Equity

- Each participating DER is assigned the smaller of:
  - *Y* kW
  - DER rated capacity
- The value of *Y* is determined by OE optimisation.

$$P_k = (1 - \zeta_k^{eq})\widehat{P_k^\tau}$$

$$P_k = \zeta_k^{eq} Y$$

$\max P^{ex}$

G. Equality

- Each participating DER is assigned *Y* kW
- This means DER may be assigned capacity greater then their rated capacity
- The value of *Y* is determined by OE optimisation.

$$P_k = Y$$

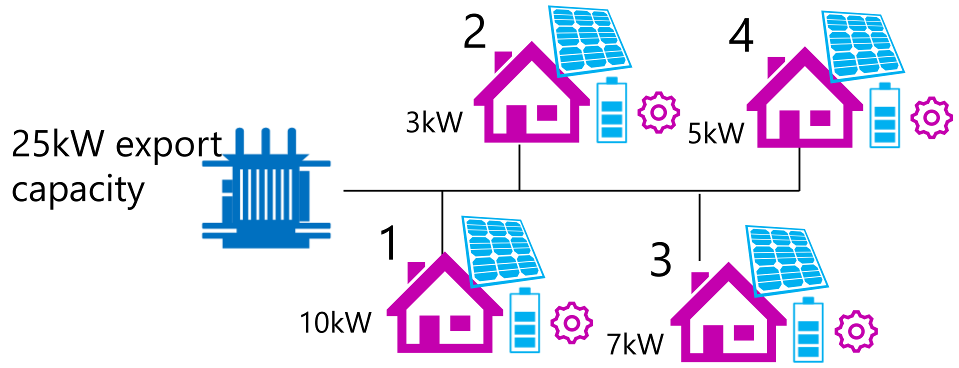
P^{ex}: Active power exported to the grid

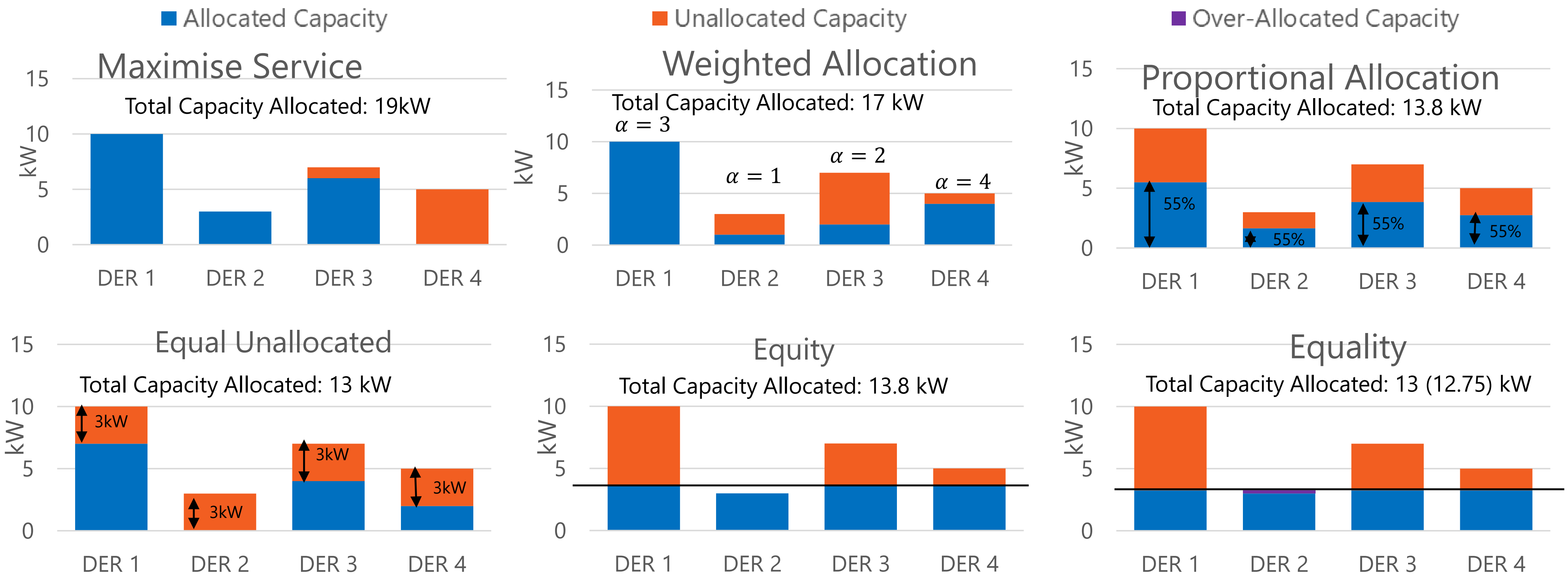
P_k: Active power injection capacity assigned to DER $k \in DER$

$\widehat{P_k^\tau}$: Rated capacity **or** forecast active power injection τ time ahead

$\tilde{P}$: Maximum individual DER constrained capacity

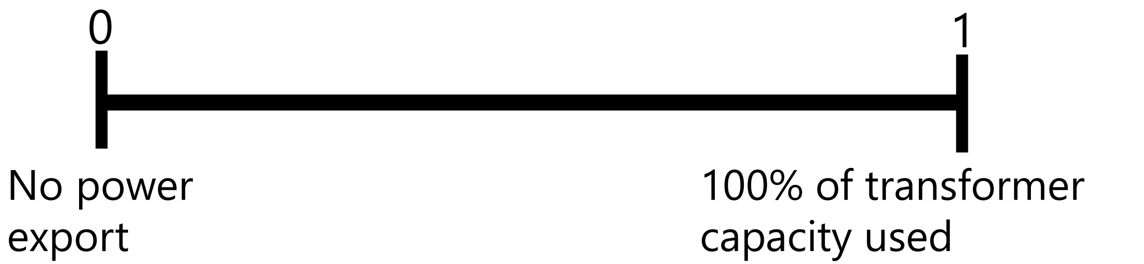
OE Objectives - Illustrative Examples





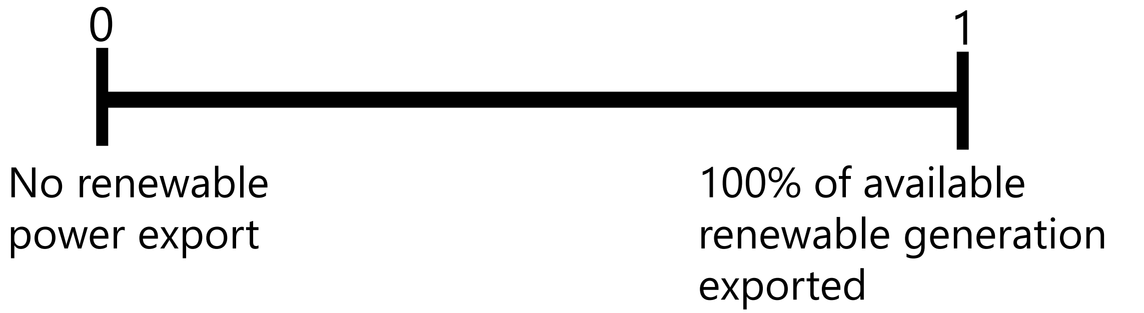
Assessment Metrics – Technical

- **Network Utilisation**
  - Tells you how much of the network export/import capacity is being used



- **DER Capacity Utilisation**
  - Tells you how much of the available DER capacity is unlocked

- **Renewables Utilisation**
  - Tells you how much of the available renewable generation is assigned capacity



NEO: Network Efficiency?

Assessment Metrics – Economic

- Local Network Social Welfare: ∑ DER revenue – ∑ DER cost

- Optimal Social Welfare: Social welfare achieved by centralised combined network and market optimisation

- **Relative Social Welfare**
  - Tells you how effective the OE is at unlocking economic value

No social welfare benefit from applying OEs

Optimal social welfare achieved.

Value of **relative social welfare** dependent on market price.

Higher **relative social welfare** likely to have wider system benefits (e.g., reduced market clearing prices) **–** not captured in current work

NEO: Market Efficiency?

How to measure fairness?

- What is desirable in a “fairness” metric?
- Population Size Independence
  - Doesn’t matter whether 10 DER or 100
- Scale and Metric Independence
  - Doesn’t matter if we measure capacity in W or kW
- Boundedness [0,1]
- Intuitive
  - 0 means absolutely unfair
  - 1 means completely fair

Because we can have DER of differing size, fairness metrics consider the **normalised capacity allocated**, not the absolute value of capacity.

NEO: Long term consumer interest? Quality of supply of electricity?

Min-Max Ratio Fairness [1]

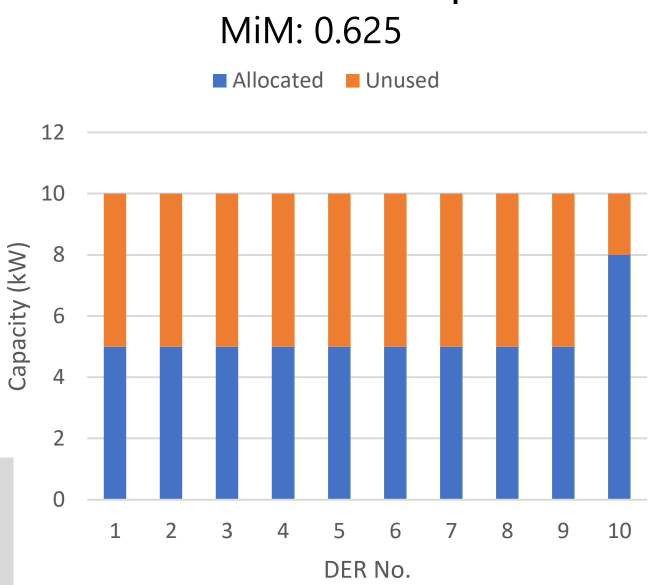
- Fairness measured by range of capacity allocated
- Defined by the relative difference between “best off” DER and the “worst off”
- Customer view of fairness: *The difference between the “winners” and “losers” should be as small as possible.*

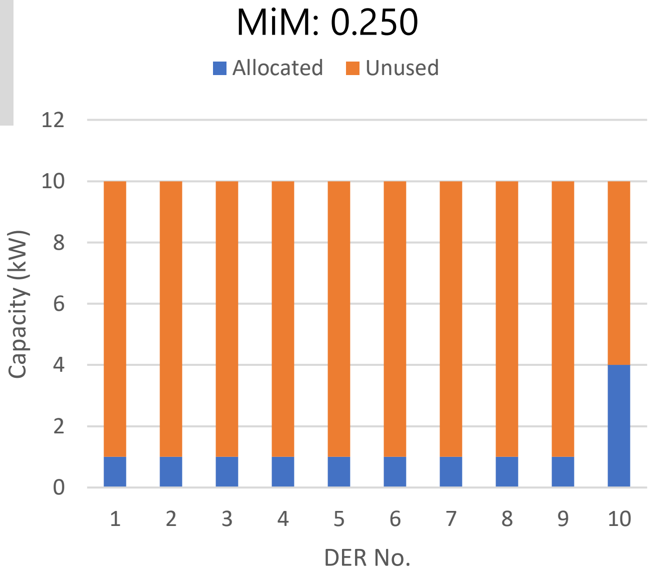
Any DER is assigned no capacity

All DER assigned capacity proportional to their rated capacity

Relative difference between winners and losers is greater in bottom graph

Theoretical Example





[1] R. Jain, W. Hawe, D. Chiu, “A Quantitative measure of fairness and discrimination for resource allocation in Shared Computer Systems,” DEC-TR-301, September 26, 1984

Quality of Service Fairness [1]

Quality of Service **DOES NOT** refer to baseline load fulfilment

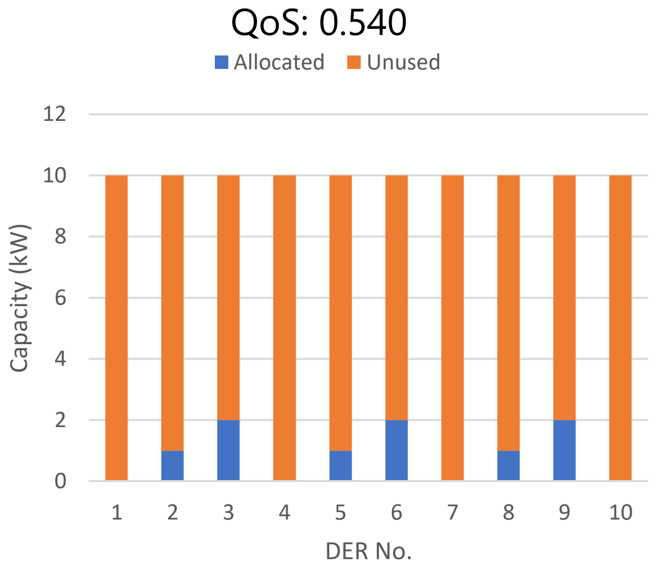
- Otherwise known as "Jain's Fairness Index"
- Fairness measured by coefficient of variation of capacity allocated
- Fairness in customer satisfaction with the service
- Customer view of fairness: *Everyone is entitled to capacity. It is important I get close to the same as my neighbour, but also the more capacity we are assigned, the fairer the system.*

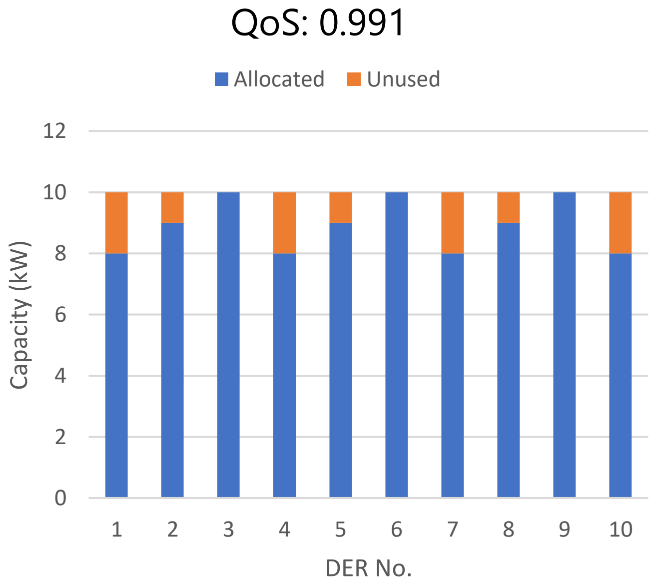
All DER assigned 0 capacity

All DER assigned capacity proportional to their rated capacity

Both have same distribution, but bottom graph has higher average

Theoretical Example





[1] R. Jain, W. Hawe, D. Chiu, "A Quantitative measure of fairness and discrimination for resource allocation in Shared Computer Systems," DEC-TR-301, September 26, 1984

Quality of Experience Fairness [2]

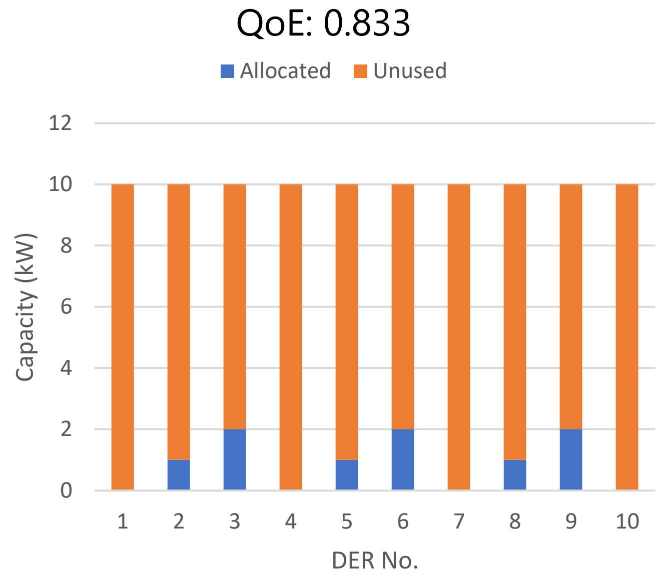
- Fairness measured by standard deviation of capacity allocated
- Fairness in **relative** customer satisfaction with the service
- Average capacity allocation has no impact on fairness
- Customer view of fairness: *We are all in the same boat. As long as everyone is impacted similarly to me, it is fair.*

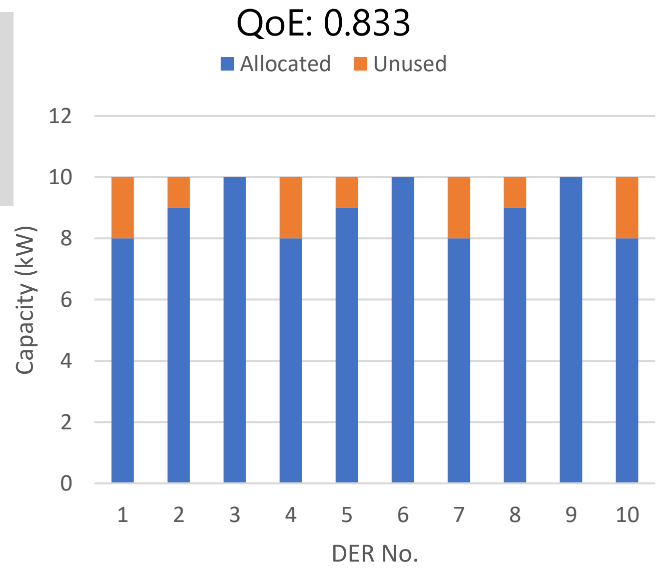
Half DER assigned full capacity, half assigned no capacity

All DER assigned capacity proportional to their rated capacity

Standard deviation of both allocations is the same

Theoretical Example





[2] Hoßfeld, T., Skorin-Kapov, L., Heegaard, P.E., Varela, M., 2018. A new QoE fairness index for QoE management. Quality and User Experience 3.. doi:10.1007/s41233-018-0017-x

Assessment Metrics – Fairness

- Min-Max Ratio

Any DER is assigned no capacity

All DER assigned capacity proportional to their rated capacity

- Quality of Service

All DER assigned 0 capacity

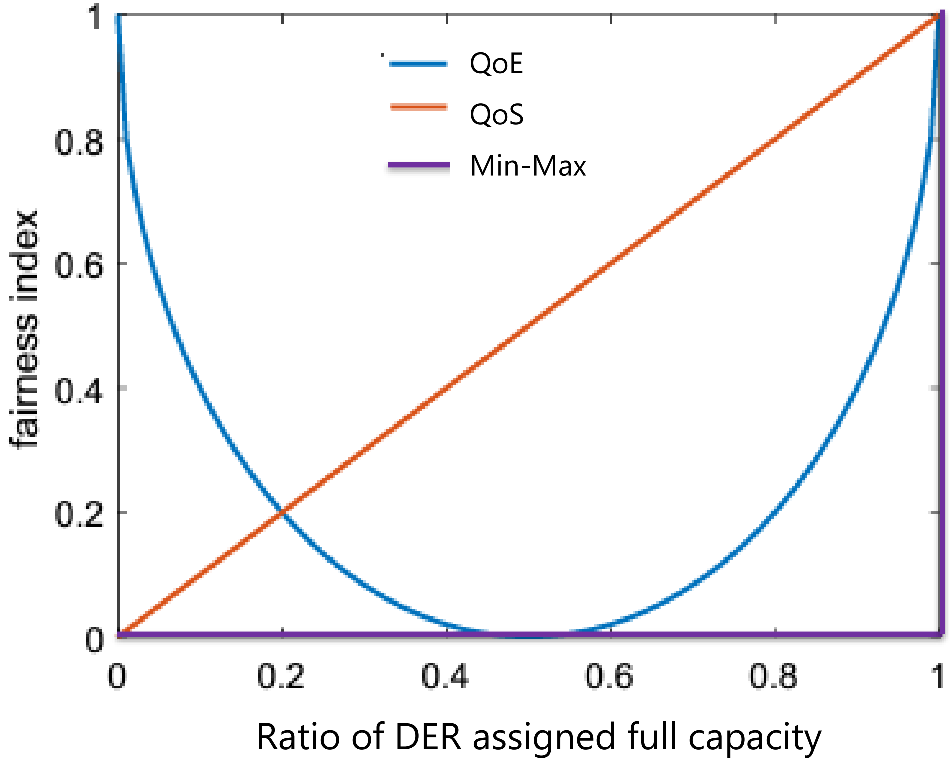
All DER assigned capacity proportional to their rated capacity

- Quality of Experience

Half DER assigned full capacity, half assigned no capacity

All DER assigned capacity proportional to their rated capacity

Example: DER either assigned full capacity or no capacity



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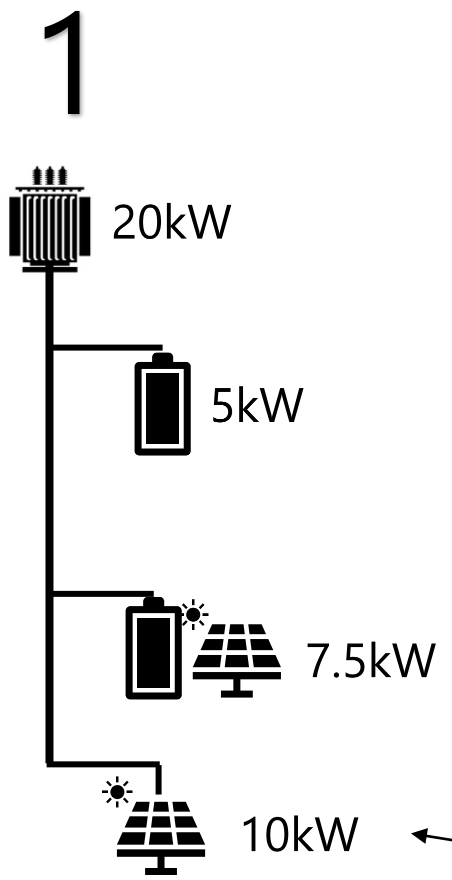
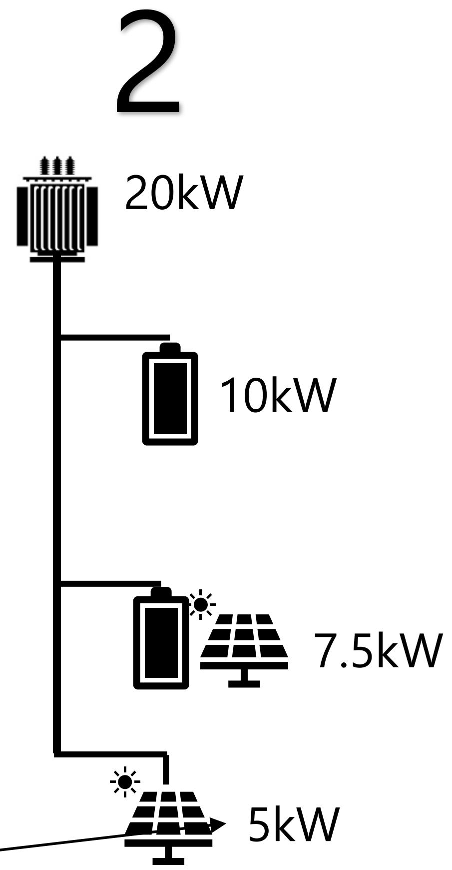
Simple Toy Network

- Allow us to fully understand the intricacies of the OEs.
- Investigated relationship of DER size and location to capacity allocated
- Examined each OE objective for 2 toy networks
- Both networks are constrained by voltage rise at the end of the feeder



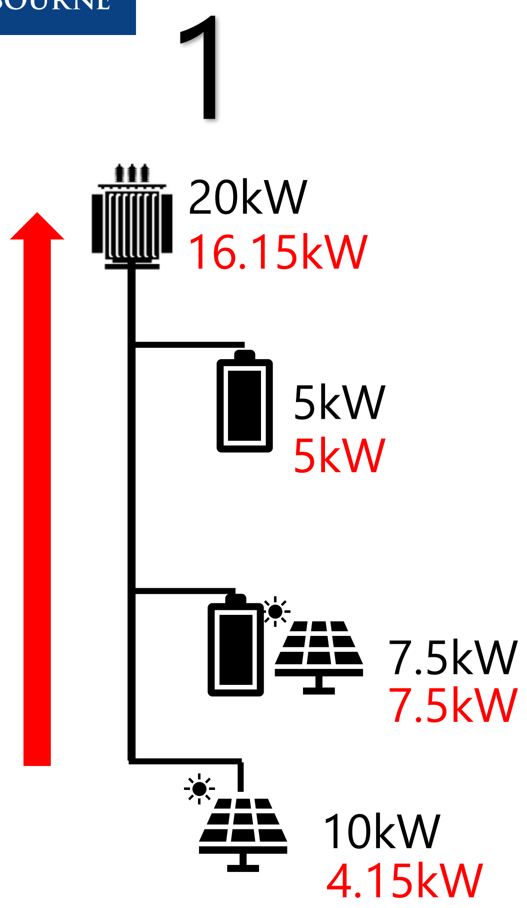


Rated Capacity

Maximise Service

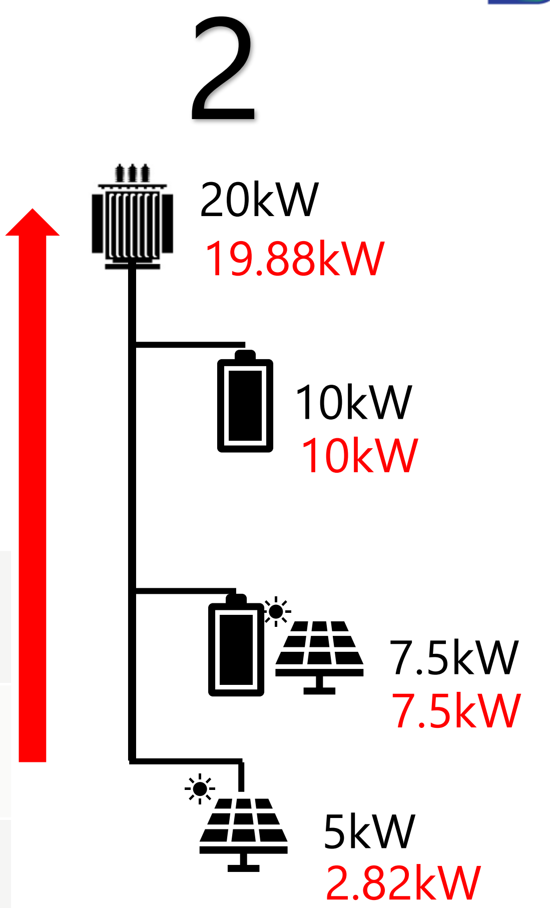
Rated Capacity

Capacity Allocated



- DER at the head of the feeder prioritised
- Location of DER has impact on total capacity that can be allocated

Network Utilisation	0.808	Network Utilisation	0.994
Capacity Utilisation	0.740	Capacity Utilisation	0.903
Renewable Utilisation	0.610	Renewable Utilisation	0.782
QoS	0.895	QoS	0.945
QoE	0.448	QoE	0.589
MiM	0.415	MiM	0.564

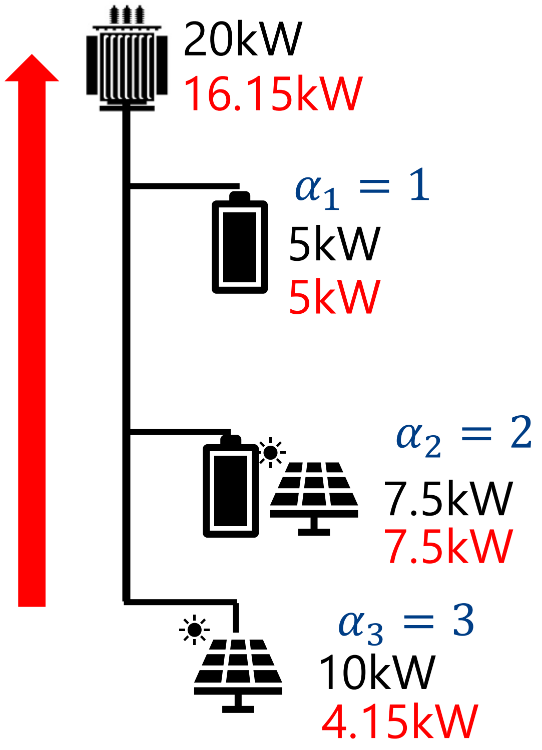


Weighted Allocation

Rated Capacity
Capacity Allocated

Aim: Favour PV over BESS

1



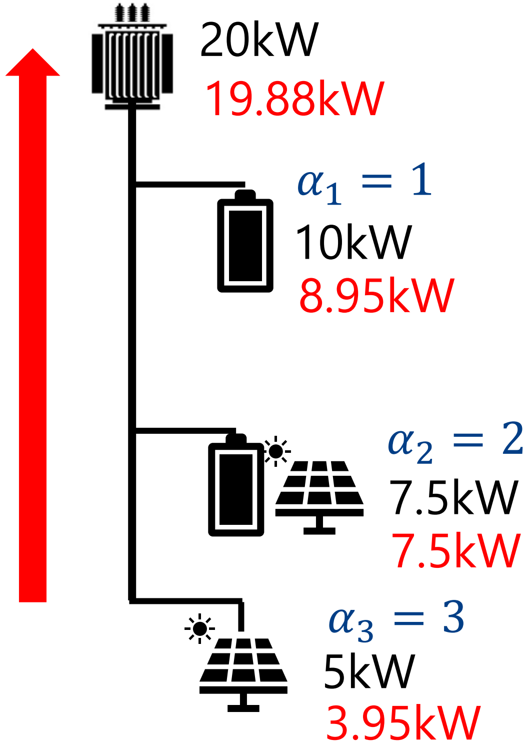
Same allocation as Maximise Service

Network Utilisation	0.808
Capacity Utilisation	0.740
Renewable Utilisation	0.610
QoS	0.895
QoE	0.448
MiM	0.415

2

Capacity shifted from BESS to PV (low weight to high weight) – increase RES use

Network Utilisation	0.994
Capacity Utilisation	0.907
Renewable Utilisation	0.895
QoS	0.991
QoE	0.829
MiM	0.790



Weighted Allocation – Larger Weight

Rated Capacity
Capacity Allocated

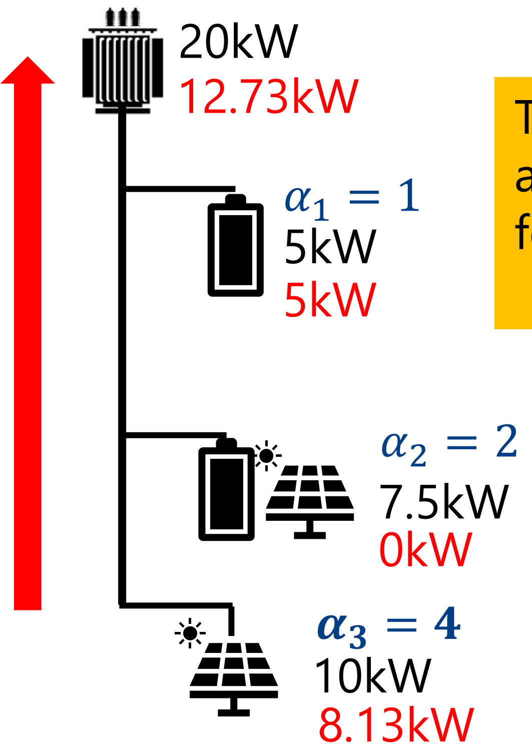
1

PV&BESS loses **all** capacity allocation

Weighted Allocation may have unexpected consequences

Capacity shifted from BESS&PV to PV (mid weight to high weight)

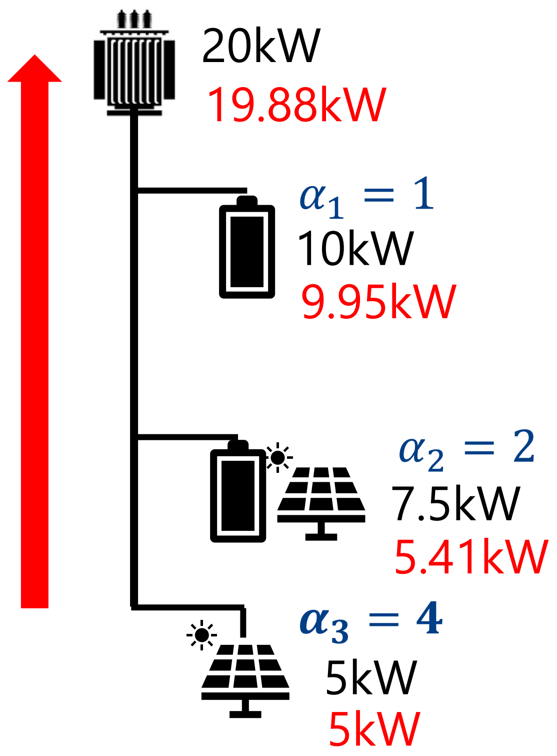
2



Total capacity allocated is reduced for Network A

Network Utilisation	0.637
Capacity Utilisation	0.584
Renewable Utilisation	0.542
QoS	0.660
QoE	0.132
MiM	0.000

Network Utilisation	0.994
Capacity Utilisation	0.905
Renewable Utilisation	1.000
QoS	0.980
QoE	0.740
MiM	0.721

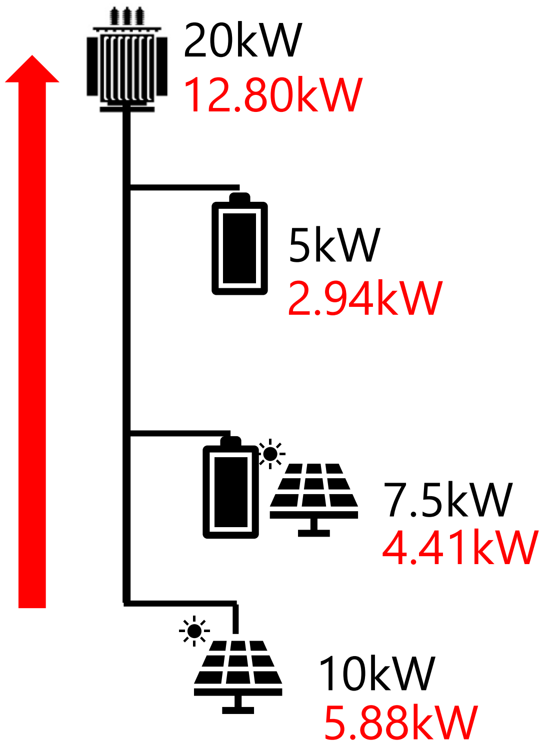


Proportional Allocation

Rated Capacity
Capacity Allocated

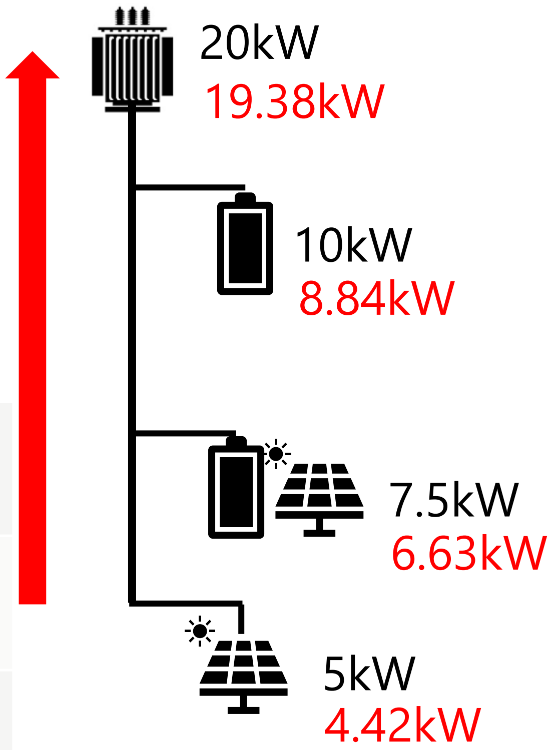
1

X%=~59%



2

X=~88%



- Location of resources has a significant impact on the capacity that can be allocated

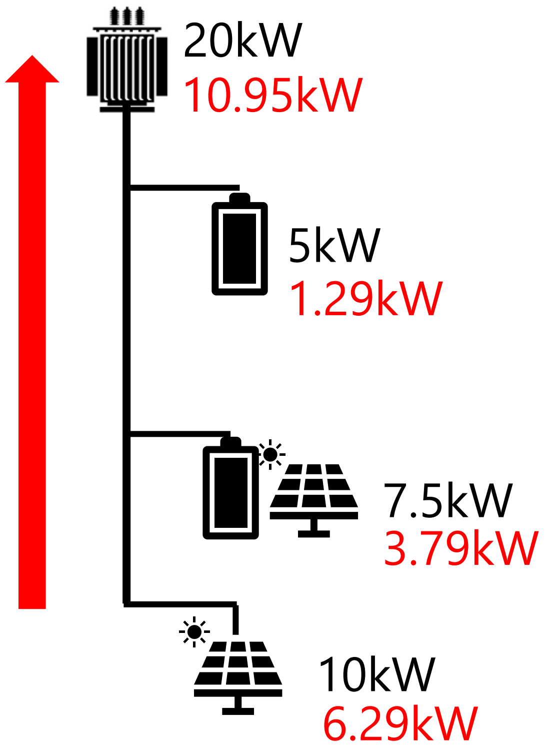
Network Utilisation	0.640
Capacity Utilisation	0.588
Renewable Utilisation	0.686
QoS	1.000
QoE	1.000
MiM	1.000

Network Utilisation	0.969
Capacity Utilisation	0.884
Renewable Utilisation	0.942
QoS	1.000
QoE	1.000
MiM	1.000

Equal Unallocated Capacity

Rated Capacity
Capacity Allocated

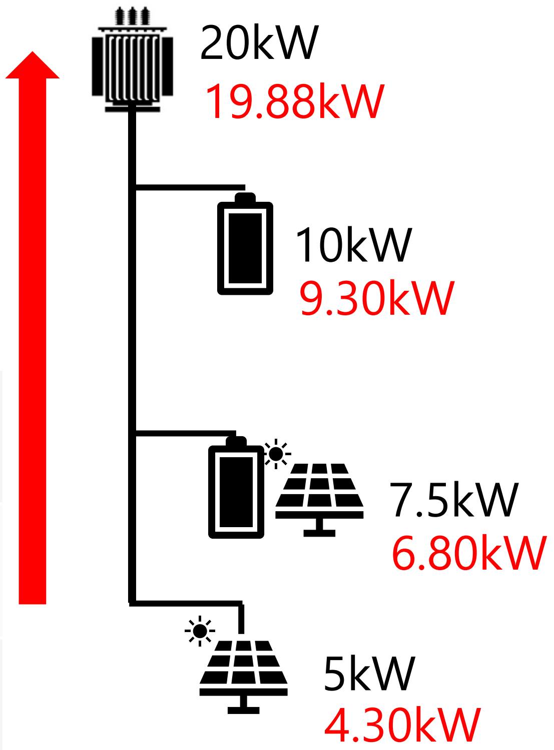
1 $Y = 3.71kW$



- Performs poorly when large resources at end of feeder

Network Utilisation	0.548	Network Utilisation	0.994
Capacity Utilisation	0.505	Capacity Utilisation	0.907
Renewable Utilisation	0.672	Renewable Utilisation	0.930
QoS	0.901	QoS	0.999
QoE	0.692	QoE	0.941
MiM	0.410	MiM	0.925

2 $Y = 0.7kW$

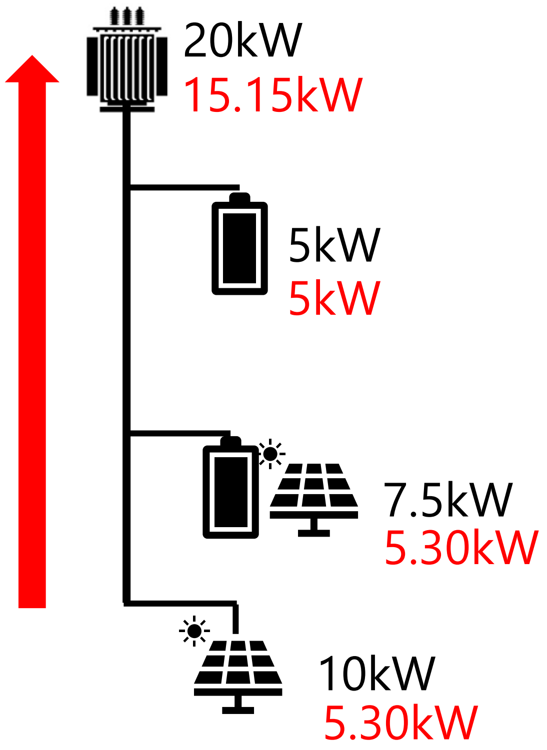


Equity

Rated Capacity

Capacity Allocated

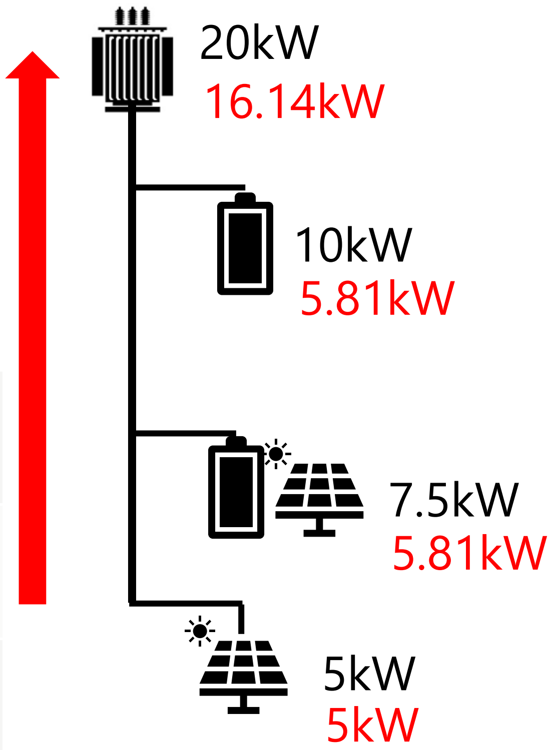
1 $Y = 5.30kW$



- Less impacted by location of larger DER

Network Utilisation	0.758	Network Utilisation	0.807
Capacity Utilisation	0.693	Capacity Utilisation	0.739
Renewable Utilisation	0.687	Renewable Utilisation	1.000
QoS	0.937	QoS	0.955
QoE	0.613	QoE	0.657
MiM	0.530	MiM	0.581

2 $Y = 5.81kW$

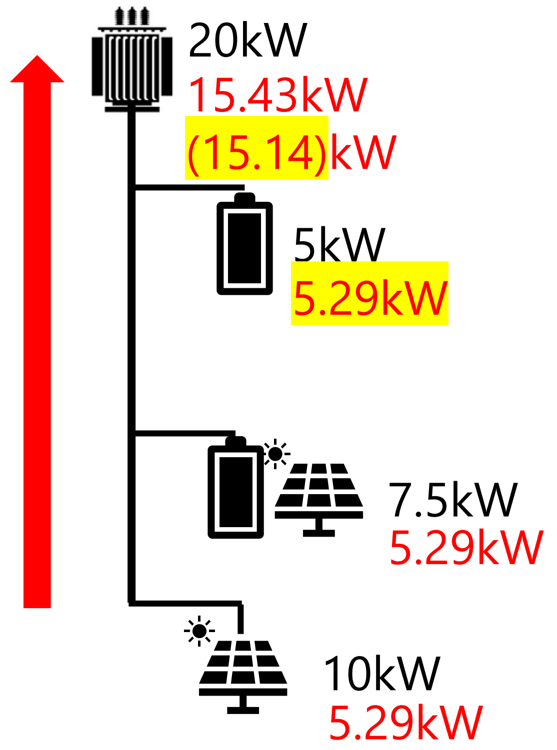


Fairness quite consistent

Equality

Rated Capacity
Capacity Allocated

1 $Y = 5.29kW$

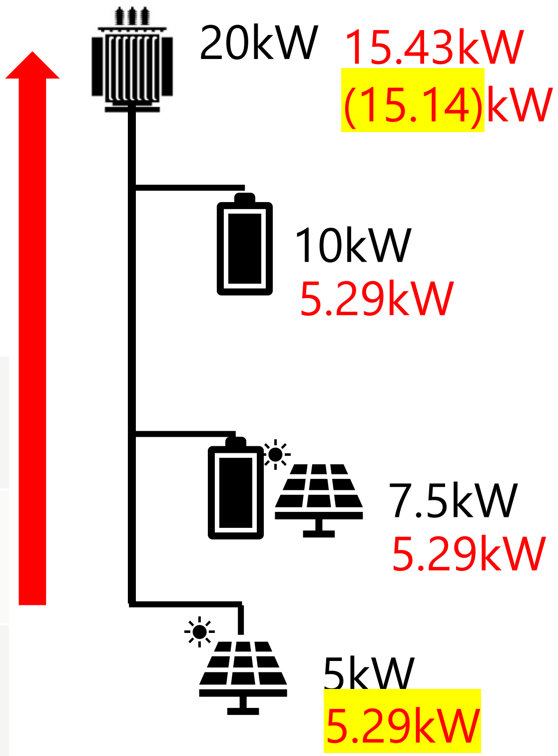


- **Unaffected** by location of larger DER

Network Utilisation	0.757
Capacity Utilisation	0.692
Renewable Utilisation	0.686
QoS	0.936
QoE	0.612
MiM	0.529

Network Utilisation	0.757
Capacity Utilisation	0.692
Renewable Utilisation	1.000
QoS	0.936
QoE	0.612
MiM	0.529

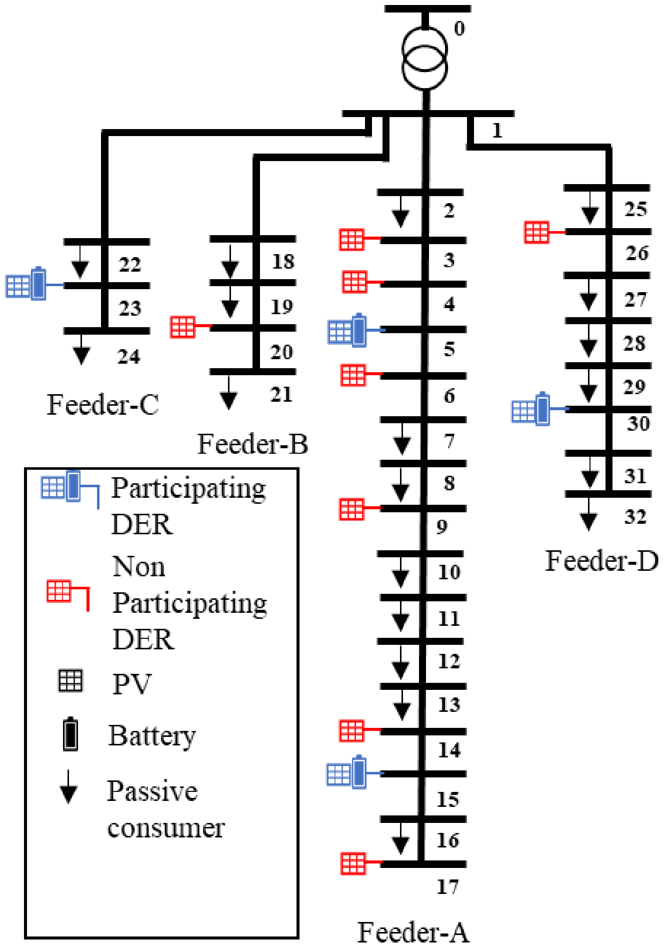
2 $Y = 5.29kW$



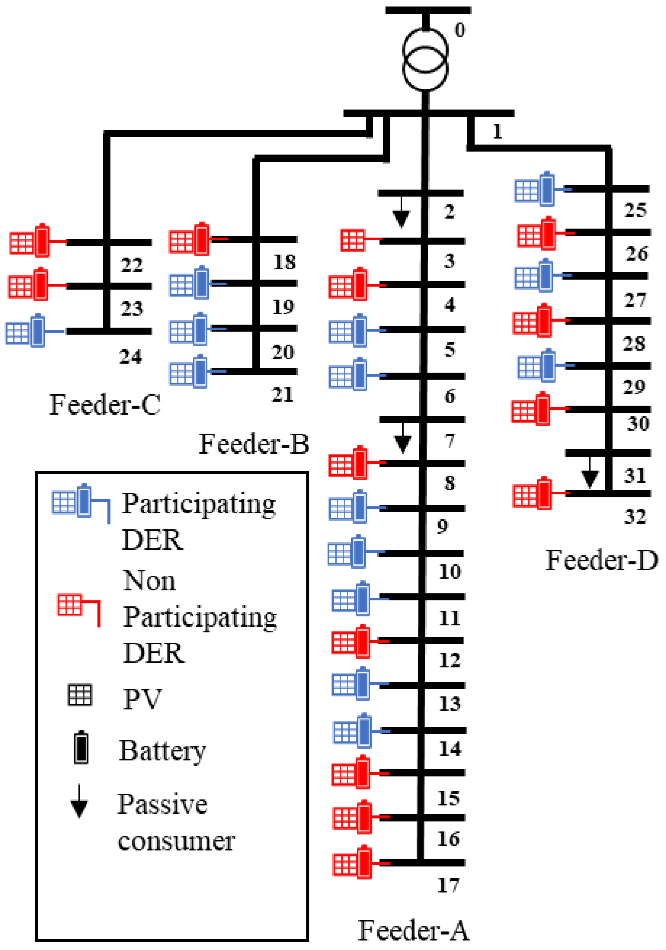
Toy Networks - General Results

- *Maximise Service* has highest network and capacity utilisation. Performs poorly in fairness metrics.
- A slight change in *Weighted Allocation* can have large impact on capacity allocation, deep understand of individual network physics can be important.
- *Proportional Allocation* will always have '1' fairness.
- Location & Size of DER significant impact on all metrics.
- Relative technical performance of *Equity* and *Equality* volatile across the 2 networks.
- The economic performance of *Equity*, *Equality*, and *Equal Unallocated Capacity* is volatile across DER placement and market prices.

More Detailed Test Cases



- Varied DER penetration and participation
- High, low, and negative prices
- Assessed high load and high generation cases
- Weighted Allocation – Economic weighting to prioritise cheaper DER



Average of all results

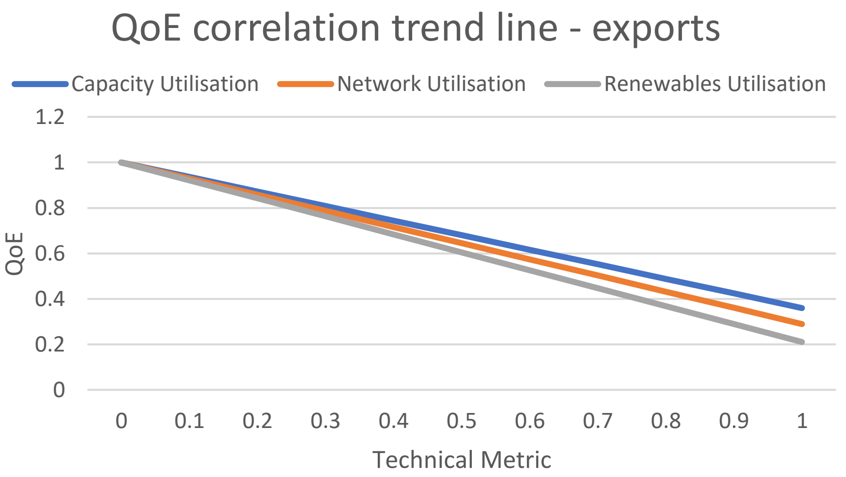
	Average								
	Network Utilisation	Capacity Utilisation	Renewables Utilisation (Export Only)	QoS	QoE	MiM	Relative Social Welfare - High Price	Relative Social Welfare - Low Price	Relative Social Welfare - Negative Price
Maximise Service	0.673	0.772	0.813	0.792	0.441	0.317	0.925	0.823	0.845
Weighted Allocation	0.672	0.769	0.822	0.805	0.462	0.353	0.921	0.927	0.862
Proportional	0.450	0.556	0.709	1.000	1.000	1.000	0.751	0.561	0.681
Equal Unallocated	0.431	0.547	0.689	0.822	0.862	0.500	0.707	0.381	0.604
Equity	0.457	0.560	0.726	0.973	0.875	0.676	0.767	0.655	0.690
Equality	0.430	0.546	0.719	0.965	0.813	0.622	0.760	0.655	0.690

Similar results

- *Maximise Service* and *Weighted Allocation* perform best in technical and economic metrics, and worst in fairness metrics
- *Weighted Allocation* beneficial in Low Price and Negative Price scenarios
- *Proportional, Equal Unallocated, Equity* and *Equality* perform similarly
  - *Equity* performs best in Technical and Economic metrics

Correlation of Metrics for Export Constrained OEs

Correlation of Export Constrained OE	Network Utilisation	Capacity Utilisation	Renewables Utilisation	QoS	QoE	MiM	Relative Social Welfare - High Price	Relative Social Welfare - Low Price	Relative Social Welfare - Negative Price
Network Utilisation	1.00								
Capacity Utilisation	0.99	1.00							
Renewables Utilisation	0.80	0.78	1.00						
QoS	-0.43	-0.36	-0.45	1.00					
QoE	-0.71	-0.64	-0.79	0.85	1.00				
MiM	-0.60	-0.55	-0.54	0.90	0.86	1.00			
Relative Social Welfare - High Price	0.99	1.00	0.81	-0.37	-0.66	-0.56	1.00		
Relative Social Welfare - Low Price	0.56	0.53	0.93	-0.10	-0.42	-0.19	0.56	1.00	
Relative Social Welfare - Negative Price	-0.03	0.01	-0.16	0.05	0.06	0.00	-0.01	-0.28	1.00

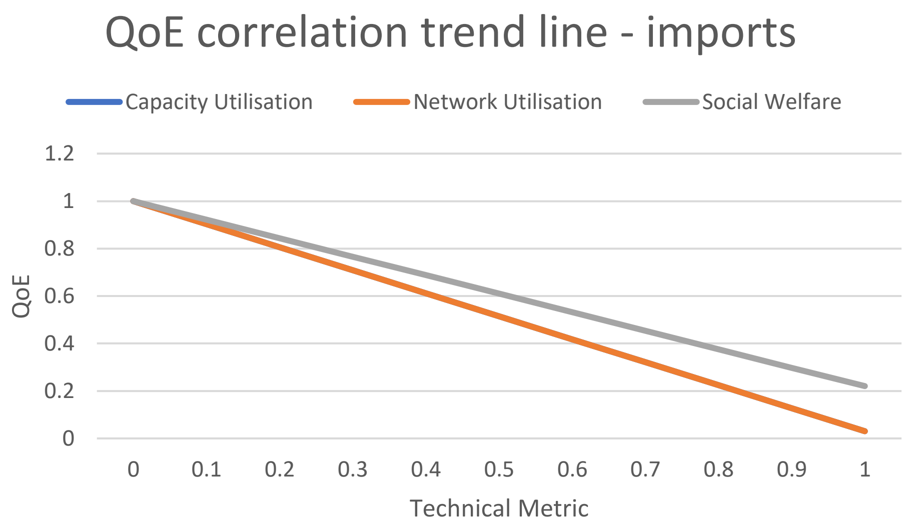


- Plotting the values of QoE against technical metrics for exports would results in these trend lines

- Fairness Metrics have **significant negative correlation** with technical metrics and High Price Social Welfare for exports
- Technical Metrics have **significant positive correlation** with High Price and Low Price Relative Social Welfare

Correlation of Metrics for Import Constrained OEs

Correlation of Import Constrained OE	Network Utilisation	Capacity Utilisation	QoS	QoE	MiM	Relative Social Welfare - High Price	Relative Social Welfare - Low Price	Relative Social Welfare - Negative Price
Network Utilisation	1.00							
Capacity Utilisation	1.00	1.00						
QoS	-0.70	-0.70	1.00					
QoE	-0.97	-0.97	0.82	1.00				
MiM	-0.72	-0.72	0.86	0.84	1.00			
Relative Social Welfare - High Price	0.30	0.30	0.13	-0.23	-0.09	1.00		
Relative Social Welfare - Low Price	0.45	0.44	0.03	-0.34	-0.06	0.66	1.00	
Relative Social Welfare - Negative Price	0.87	0.87	-0.44	-0.78	-0.50	0.55	0.76	1.00

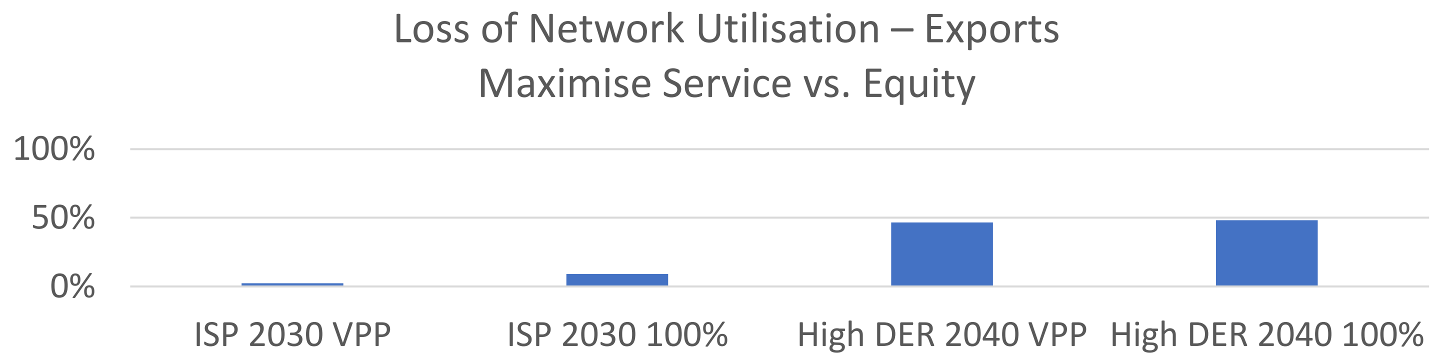


- Plotting the values of QoE against these metrics for imports would results in these trend lines

- Fairness Metrics have **significant negative correlation** with technical metrics and Negative Price Social Welfare for imports
- Relative Social Welfare – Negative price **strongly correlated** with technical metrics

Key Takeaways (1/2)

- The **more constrained** the network, the **larger negative impact** "fairness" has on technical and economic metrics.



- Applying *Proportional/Equal Unallocated/Equity/Equality* have similar impacts on technical and economic metrics (**20% reduction** on average).

- There is **significant negative correlation** between the fairness metrics and the technical metrics (and some economic metrics), most strongly for QoE.

- **High participation** levels benefit *Maximise Service* & *Weighted Allocation* but **can have negative impact on other OEs**.

- Economic *Weighted Allocation* effective, but requires additional information for the DSO to calculate OE

Key Takeaways (2/2)

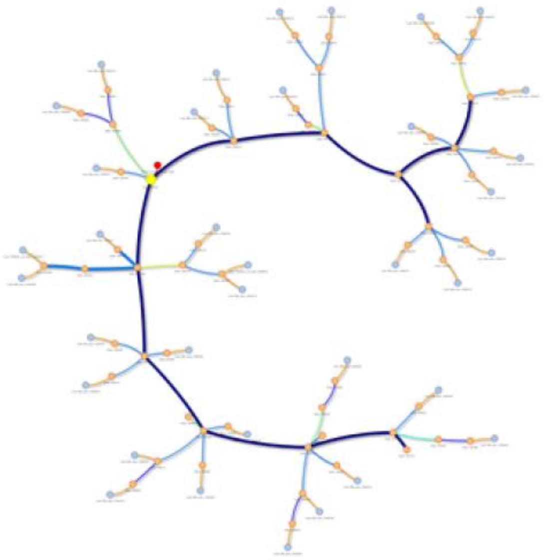
These results are **based on preliminary results only** – aim to test these findings on more use cases and networks

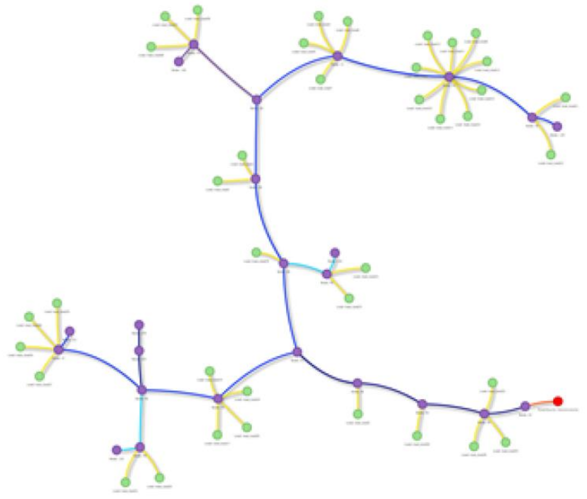
From these initial results **it seems that**:

- Increasing “fairness” will directly reduce capacity that can be allocated, and the social welfare of the network.
- Impact worse for higher participation and penetration levels
- **Fairness allocation objectives would appear to be in opposition to NEO efficiency principles.**

Next Steps - Scope

- Real world / Representative Networks
  - Taking guidance from the CSIRO LV Network Taxonomy Report
- Wider DER Penetration and Participation considerations
  - Including impact of changing static limits
- High level cost of implementation of different OE objectives
- Do these findings hold true in these expanded studies?





Close and next steps