Explaining the Cost Benefit Analysis performed on the potential of Distributed Energy Resources

Presentation for the Electricity Authority

30 August 2021

Our work with DER

David Reeve, Corina Comendant, and Toby Stevenson delivered "Cost-benefit analysis of distributed energy resources in New Zealand" to the Authority on 7 July 2021

However, work previously done on DER included:

- Productivity Commission report 2018 – DER contribution to decarbonisation
- Managing Distribution IPAG 2018 – Role of DSO in coordinating DER
- Where is this going? IPAG 2018 – Issues and opportunities for DER
- What could it look like? IPAG 2018 – Trends for DER coordination
- Support for Equal Access IPAG 2018
- Understanding the potential of DER Transpower 2020

Our major categories of DER

- Demand Response (DR) – smart home management and appliances that actively manage household consumption, including smart EV charging.
- Vehicle to Grid (V2G) – the use of EV batteries to inject back into the power system when needed.
- Residential rooftop solar and battery (PV+Br) – residential-scale rooftop solar PV with an integrated battery.
- Commercial rooftop solar and battery (PV+Bc) – commercial building-scale rooftop solar PV with an integrated battery.

The question we were asked

We were asked to develop a cost-benefit analysis of DER if it were to realise its unfettered potential against a future where it does not.

There are many problems in fully realising the value of DER due to the different nature of this technology compared to the technologies and market dynamics for which the industry and the regulatory arrangements were designed.

Issues identified by IPAG

Category of issues	IPAG issues
Information on power flows and capacity	Key network information is not collected and/or made available to DER providers.
	Providers and procurers of DER can't see DER "market" information.
Connection and operation standards	Technical specifications are not consistent or in some cases adhered to.
	Distributors may restrict technologies or network users.
	Distributors are not confident that DER can assist with service quality or is viable as a network alternative.
	Security and reliability at risk if DER use by transmission and distribution in conflict.
Market settings for equal access	Distributors may restrict technologies or network users.
	Transaction costs for facilitating DER trade are high.
	Distributors may favour in-house or related party solutions.
	Distributors may favour network solutions.
	Distributors may misallocate costs and revenues.
Operating agreements	Transaction costs for facilitating DER trade are high.
	Security and reliability at risk if DER use by transmission and distribution in conflict.
Capability and capacity	Distributors are not confident that DER can assist with service quality or is viable as a network alternative.
	Security and reliability at risk if DER use by transmission and distribution in conflict.
Efficient price signals	Distribution pricing does not signal the cost of DER to network operation (congestion and voltage excursions for example) or its value to distributors.
	Part 4 Incentives appear to be poorly understood.
	Distributors' DER investments are treated as regulated capital but the planning and operating services provided are contestable.

Comparing a fully utilised DER future versus baseline (what would happen anyway)

<u>Fully utilised DER</u>

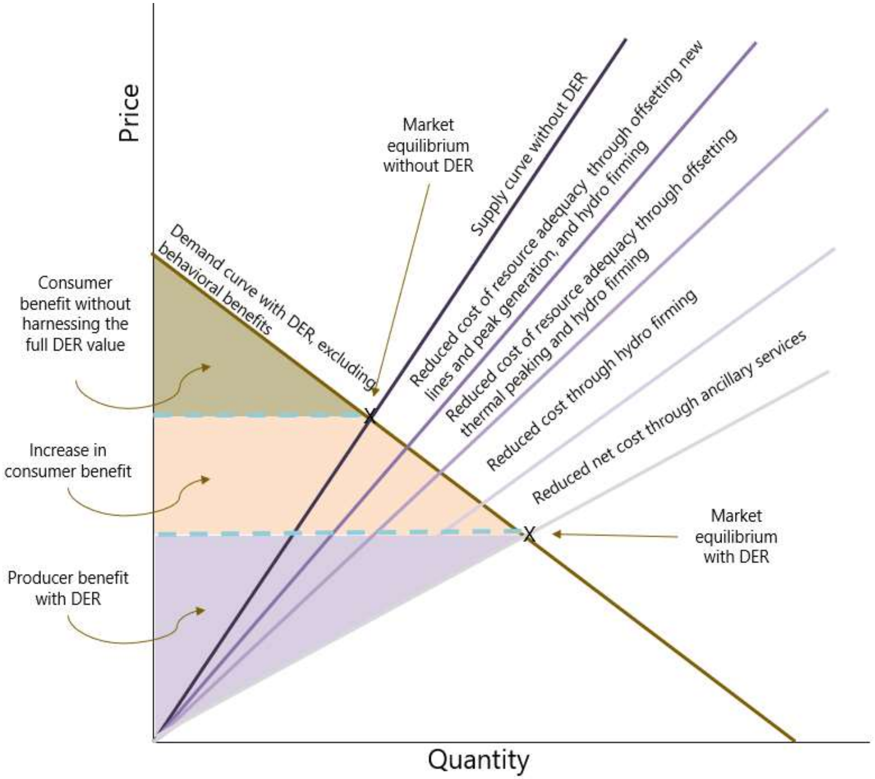
- Assumes DER can be coordinated to realise its highest value at any time
- DER capacity limits are applied
- Assumes significant demand growth through electrification to decarbonise

<u>Baseline</u>

- Assumes nothing further is done to coordinate DER beyond current regulatory/market design settings
- DER take up based on CCC Headwinds scenario
- Assumes significant demand growth through electrification to decarbonise

Approach

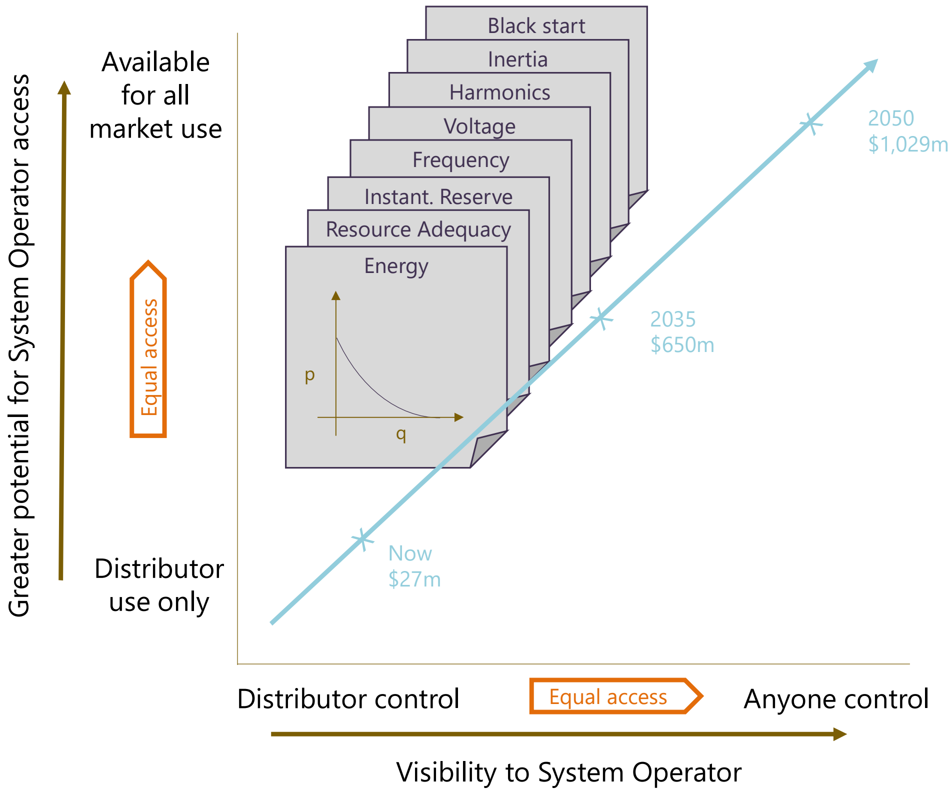
From the work we did on the potential of DER we thought we could do the supply and demand curves



But there are problems:

- As with most real industries and markets the supply and demand curves are not smooth
- To put capacity services and energy services on the same curves we needed a combined unit, predominantly per unit capacity but with a time dimension - $/kW p.a.
- As not all DER can provide all services we needed a conditional supply curve

Understanding potential value



- Started with 'value stacks' from international literature

- We found different groupings where more useful when trying to consider the demand curve, plus some value streams NZ specific, i.e. dry season risk

Building the demand curve

- Sort the value streams in descending order of value and identify quantities of DER required to fully provide the service
- Each volume is limited to a credible assessment of potential contribution rather than necessarily being allowed to fully offset service
- Not all value streams are additive, when we move to a new part of the curve some value streams replace previous values rather than subtract from them, e.g. offsetting voltage regulating equipment is not additive to resource adequacy: offsetting new lines and generation, it only applies when resource adequacy doesn't
- Zero volume axis anchored to a reasonable estimated cost of delivered energy - 30 c/kWh – our analysis suggests that there would be upward price pressure in the future without DER
- We limit price reductions in the demand curve so that price cannot be less than the value of residual grid services

Frequency keeping and Instantaneous Reserve

Some DER has the supply characteristics that can provide both FK and IR. This could be provided by aggregated control or local control functions.

<u>Benefits</u>

	2021	2035	2050
Volume (MW)	FK = 0 IR = 0	FK = 15MW IR = 300MW	IR = 300MW
Price ($/kW p.a.)	FK = 0 IR = 0	FK = 0.1 IR = 2	FK = 0 IR = 2

- Current rules and systems don't incorporate DER for FK or IR
- Assume FK is no longer required by 2050
- Supply costs for FK based on 15MW band at current annual cost $1.1 m
- Supply costs for IR based on 200MW in NI and 100MW in SI at annual cost of $14.4 m
- Costs flow through to the demand side differently, costs have been spread over the whole demand curve to determine offset price
- However, offset price only applied to volumes that could be provided by DER

Resource Adequacy – remove existing thermal peaking

Some DER has the supply characteristics that can provide peaking capacity to remove the need for existing fast start thermal gas turbines.

<u>Benefits</u>

	2021	2035	2050
Volume (MW)	250	250	250
Price ($/kW p.a.)	118	118	118

- Currently not removed, but the potential is there
- Conservative assessment that only the variable cost of peak generation is offset ($90/MWh)
- Conservative assessment that only 250MW of approx. 500MW can be offset

Resource Adequacy – offset new lines and generation

Some DER has the supply characteristics that can provide local capacity or shift load to different periods reducing the need for new peaking generation, transmission and distribution.

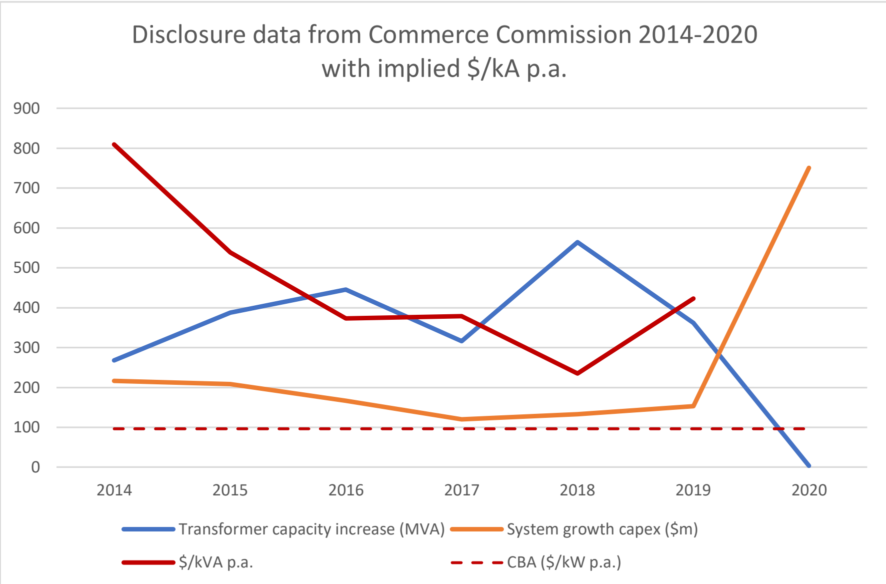
<u>Benefits</u>

	2021	2035	2050
Volume (MW)	100	2,400	3,300
Price ($/kW p.a.)	237	237	237

- 2021 volume is a rough guess
- 2035 and 2050 volumes were assessed on the basis of smart EV charging contribution from WiTMH (1,900 MW in 2035, 2,900 MW in 2050), plus residual peak assuming no thermal and some hydro offset (four Maraetai units)
- Peak cost breakdown – generation = $73/kW p.a., transmission = $68/kW p.a., distribution = $96/kW
- Generation based on partially loaded geothermal (assuming 100% renewable by 2030)
- Transmission from Transpower's assessment in Whakamana i Te Mauri Hiko
- Distribution also from WiTMH, but the methodology was explained to us by Transpower (PTO)

New distribution line cost

- The distribution costs were based on an analysis done for Transpower by Stakeholder Strategies, which we understood to prorate Transpower's capital costs with distribution capital costs. This number seems to be controversial.
- Data is highly aggregated but an order of magnitude assessment based on Commerce Commission Disclosures follows.



- From 2014 to 2019 the increase in transformer capacity was 2,340 MVA and system growth costs were $997m (2020 seems to be an outlier in both cost and capacity)
- Implies $426/kVA but numbers are indicators only, system growth includes new lines and new connections
- From 2013-2019
  - Customer numbers increased 5.6%
  - Line length increased 4.3%
  - Transformer capacity increased 11.7%
  - Implies in the order of half transformer capacity growth was due to increased peaking
- The order of magnitude of around $100/kW p.a. looks credible

Offset voltage management assets

Some DER has the supply characteristics that can support and manage voltage either through reactive power or as an active voltage source. This can reduce the need for voltage regulators and power factor correction within distribution, and in aggregate could offset transmission voltage problems

Benefits

	2021	2035	2050
Volume (MW)	300	0	0
Price ($/kW p.a.)	36	0	0

- Report had an error where the $/MWh price was given (28) rather than the $/kW p.a. price
- Report also had an error where we said we were using 2,800MW to offset around 900MVAr of grid and distribution voltage support
- We actually decided to be conservative and only offset 300MVAr, however 300 was entered as the MW
- The MW number should have been 3.2 times higher
- The 2021 supply curve doesn't extend to this point and so the clearing would not change
- Voltage management doesn't appear in 2035 or 2050 as it is displaced by resource adequacy: offsetting new lines and generation

Harmonic filtering

Harmonics is the only potential problem arising from DER where DER cannot also provide a complete solution. i.e. the value contribution from harmonics is potentially net negative even with coordination

Benefits

	2021	2035	2050
Volume (MW)	Q1 = 1,700 Q2 = 5,000	Q1 = 1,700 Q2 = 5,000	Q1 = 1,700 Q2 = 5,000
Price ($/kW p.a.)	P1 = -1 P2 = -2	P1 = -1 P2 = -2	P1 = -1 P2 = -2

- Harmonics shouldn't be a problem at low levels of penetration and haven't been noticed overseas
- Theoretically problems could be caused with significant backfeed
- Based on WiTMH scenarios we assessed that 1,700MW of DER would lead to significant backfeed within distribution networks that might require filtering
- The same assessment suggested 5,000MW would lead to most distribution feeders having backfeed at times, we didn't adjust these numbers for higher peak demand in 2050 but the numbers are small
- Costs are based on 90% attenuation (natural harmonic abatement) in the distribution network and the relative capacity and cost of harmonic filtering capacity on the HVDC

Hydrofirming

Hydrofirming is some form of reserve capacity that is held for when there is an extended period of low hydro inflows. Any form of capacity that can be held in reserve could perform this function

Benefits

	2021	2035	2050
Volume (MW)	5,040	5,040	5,040
Price ($/kW p.a.)	79	79	79

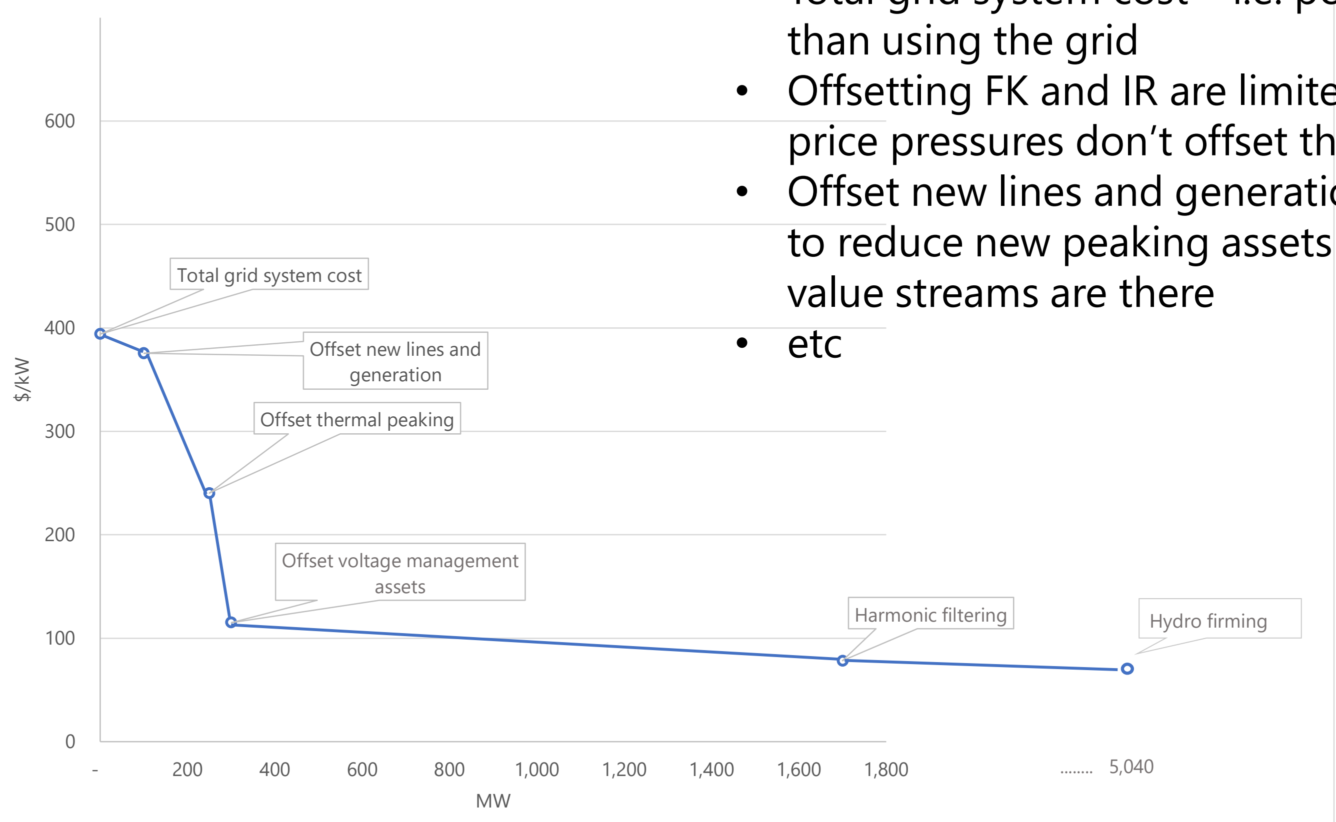
- Based on NIWA's climate database for sunshine hours and intensity over 1 April to 30 September, 5,040MW of solar PV (with batteries and DR to manage short term consumption profiles) on standby reserve could provide 3.1TWh of winter energy (i.e. meets the Winter Energy Margin)
- Costs based on offsetting thermal generation at $90/MWh (offsetting variable costs only) at a probability of 1:4.5 years (recent average)

Demand curve

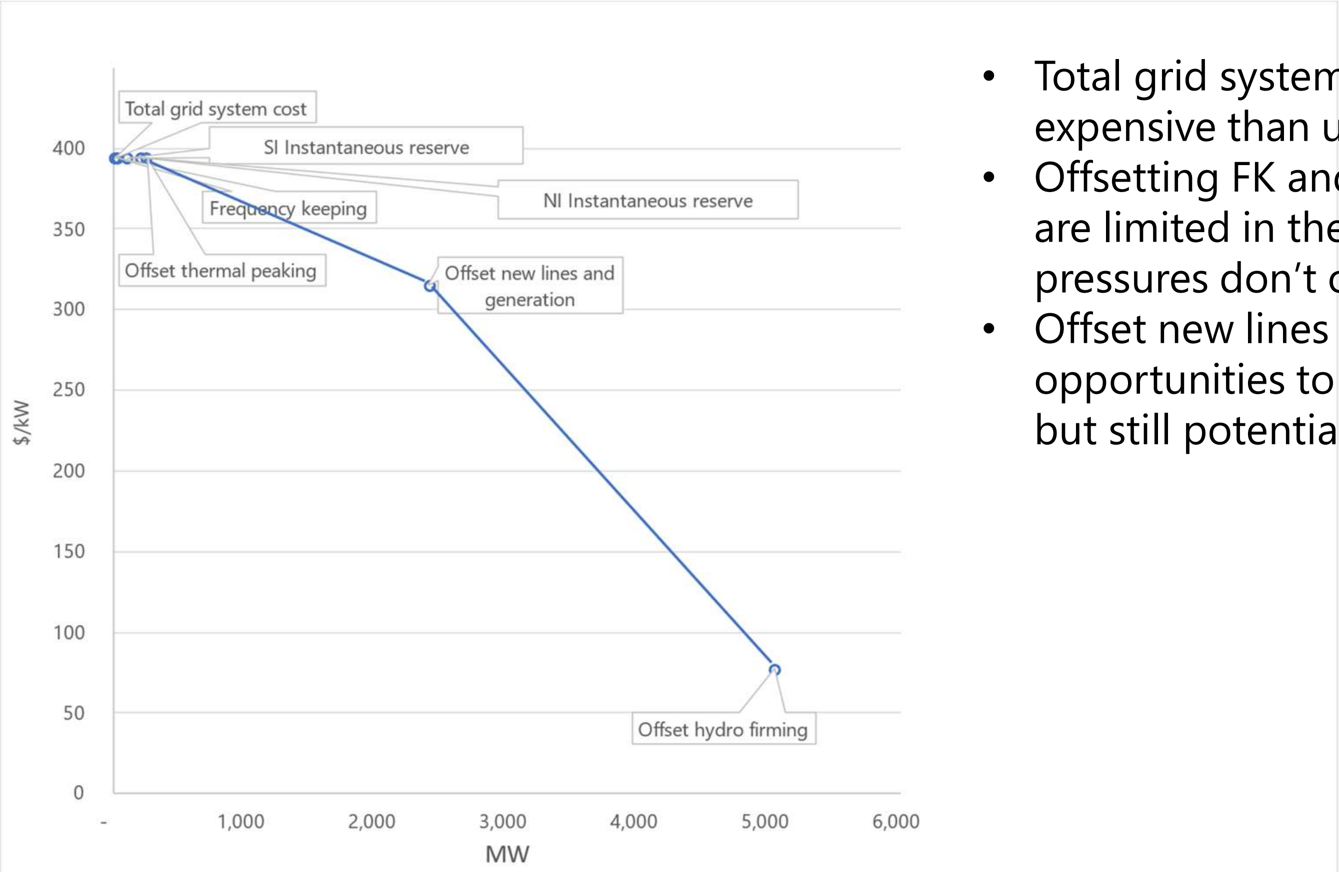
- A demand curve demonstrates how demand increases as price decreases
- A demand curve shows what could be provided (not necessarily what is provided) if supply can meet demand and price
- This demand curve is a complex mixture of additive and non-additive volumes, and additive and non-additive prices
- The highest value use depends on cumulative value streams and some are mutually exclusive, for example, new lines aren't built needing voltage support
- Judgement is needed in placing non-additive volumes, for example, generally DER could provide IR concurrently with other value streams
- The demand curve often isn't as simple as is implied, we have had to use judgement
- As the demand curve is already complex the conditionality and any physical restrictions on DER is built into the supply curve

2021 demand curve

- Total grid system cost – i.e. point where DER is more expensive than using the grid
- Offsetting FK and IR are limited in their price effect, i.e. upward price pressures don't offset these downward pressures
- Offset new lines and generation – the point where opportunities to reduce new peaking assets reduced but all lower additive value streams are there
- etc

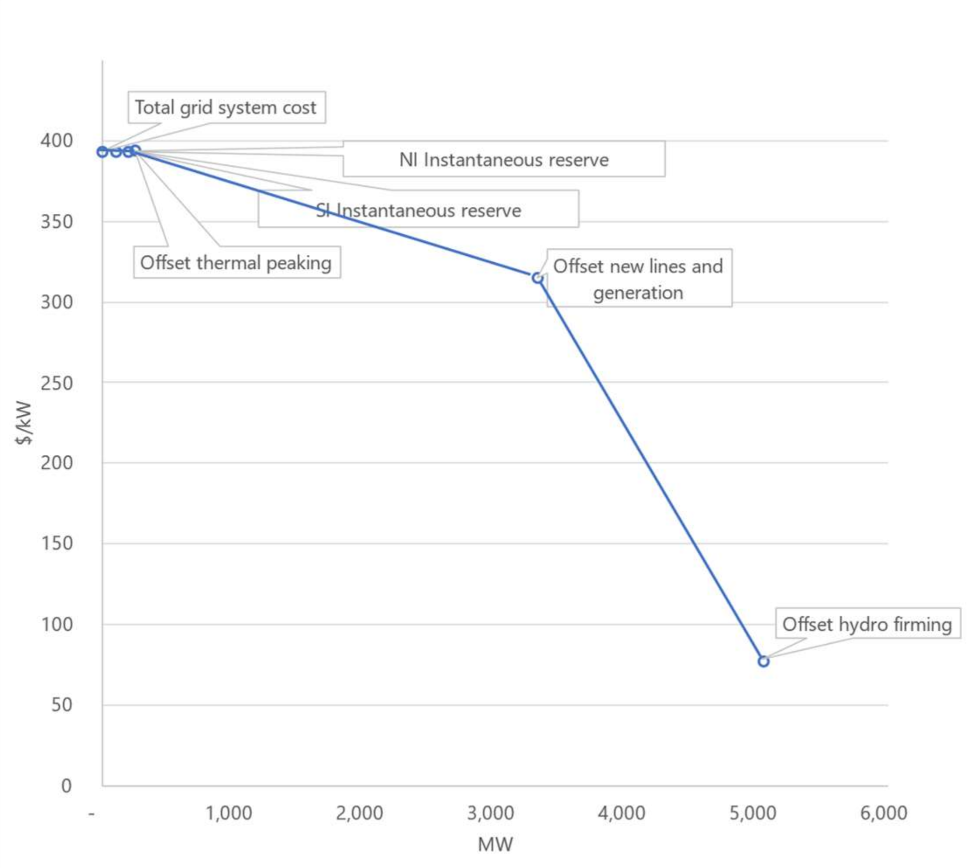


2035 demand curve



- Total grid system cost – i.e. point where DER is more expensive than using the grid
- Offsetting FK and IR and offsetting thermal peaking are limited in their price effect, i.e. upward price pressures don't offset these downward pressures
- Offset new lines and generation – the point where opportunities to reduce new peaking assets reduced but still potential to offset hydrofirming

2050 demand curve



- Demand curve is very similar to 2035
- Total grid system cost – i.e. point where DER is more expensive than using the grid
- Offsetting FK and IR and offsetting thermal peaking are limited in their price effect, i.e. upward price pressures don't offset these downward pressures
- Offset new lines and generation – the point where opportunities to reduce new peaking assets reduced but still potential to offset hydrofirming

Building the supply curve

- Supply curve builds up potential supply in ascending order of cost, i.e. cheapest production is used first
- Our supply curve has the complication that the form of DER must also be capable of providing the service segment in the demand curve, we describe this as a conditional supply curve
- This conditionality is taken from a capability map

Capability map for full DER potential

	Hydro firming	Offset thermal peaking	Offset lines/ transmission	Voltage management	Instant. Reserve/Inertia	Freq. keeping
DR - residential		■	■		■	■
EV inverters		■	■		■	■
Battery – residential		■	■	■	■	■
Battery – commercial		■	■	■	■	■
PV system – residential				■	■	■
PV system – commercial				■	■	■
PV + storage – residential	■	■	■	■	■	■
PV + storage – commercial	■	■	■	■	■	■

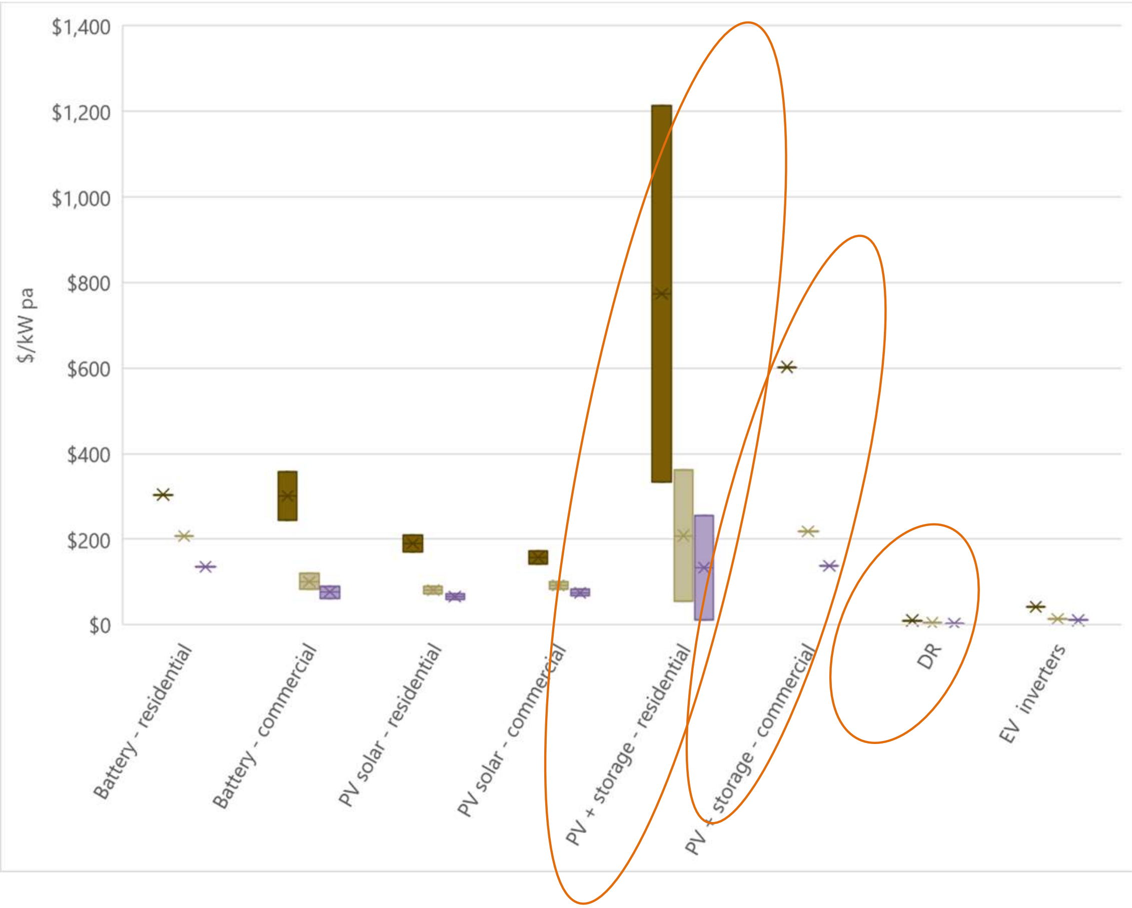
* Brown square denotes DER can provide the service

Capability map for full DER potential

	Hydro firming	Offset thermal peaking	Offset lines/ transmission	Voltage management	Instant. Reserve/Inertia	Freq. keeping
DR - residential						
EV inverters						
Battery – residential						
Battery – commercial						
PV system – residential						
PV system – commercial						
PV + storage – residential						
PV + storage – commercial						

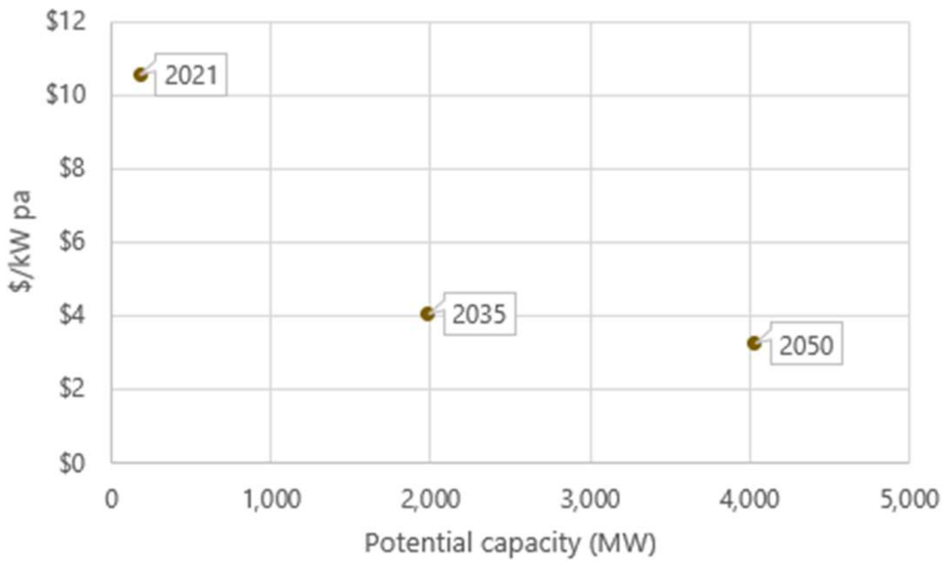
* Key difference between full DER potential and baseline is the services that can be provided without coordination

DER supply costs



- Dark brown = 2021
- Light brown = 2035
- Purple = 2050
- Sapere analysis based on data from NREL, Lazard, My Solar Quotes (NZ)
- Supply that forms the conditional supply curve is highlighted

Demand response

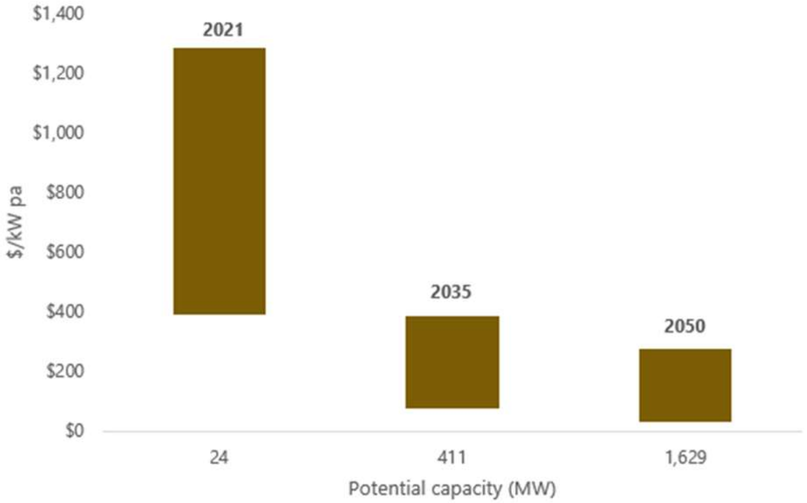


	Unit	2021	2035	2050	Source
Experience curve	Average annual cost decline, %	-10%	-7%	-2%	Battery storage experience curve as per (Schmidt, Melchior, Hawkes, & Staffell, 2018)
EV charging unit	Incremental annualised cost, $/kW	$8	$4	$4	Assumes $155 based on USD100 in 2015 as per (Rocky Mountain Institute, 2015)
Smart air conditioning		$8	$3	$2	Assumes $327 in 2019 based on existing sales
Smart dryer		$17	$6	$4	Assumes $286 in 2019 based on existing sales
Smart fridge		$8	$3	$2	Assumes same incremental cost as smart AC given similarity of technologies
Weighted average cost	**Annualised cost, $/kW**	**$10.09**	**$3.87**	**$3.08**	Costs weighted in proportion to capacity shares of different smart appliances

[1] https://www.homedepot.com/p/Emerson-Single-Stage-5-2-Day-Programmable-Thermostat-P150/207173074 and https://store.google.com/us/product/nest_learning_thermostat_3rd_gen?hl=en-US

[2] https://www.whirlpool.com/laundry/dryers/electric.html?plp=%253Arelevance%253Acategory%253ALaundryDryersElectric%253Acategory%253ALaundryDryersElectricDryerMatchesTopLoadWasher&plpView=grid

Solar PV and storage - residential

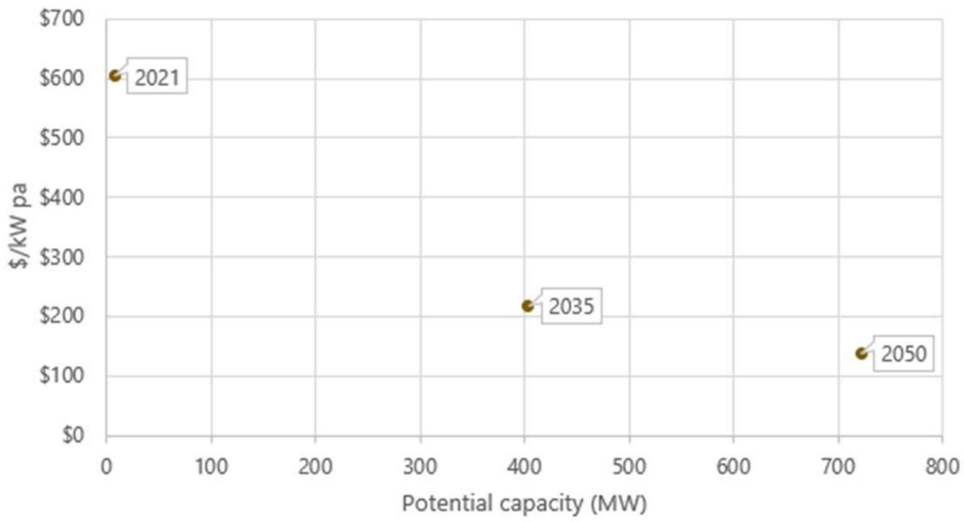


Energy costs are netted out as these aren't on the demand curve. The costs in the supply curve are residual costs after energy self-sufficiency

	Unit	2021	2035	2050	Source
Experience curve	Annual reduction in cost over the period	-8%	-7%	-2%	Weighted average of experience curves for standalone PV and standalone battery, assuming battery cost out of total PV + storage system cost is 46% (small battery) or 68% (large battery), with the proportions derived based on data from (Ardani, et al., 2017)
Battery lifetime	Years	10	10	10	(Lazard, 2019)
PV system lifetime	Years	25	25	25	(MBIE, 2016)
O&M costs	% capex	1.2%	1.2%	1.2%	Weighted average of O&M costs (as % capex) for standalone PV and standalone battery
PV (3 kW) + battery (6 kW)	**Annualised costs, $/kW**	**$393**	**$76**	**$29**	Assumes a total cost of $17,000 in 2020, and nets out electricity cost savings
PV (5.6 kW) + battery (3 kW / 6 kWh)		**$619**	**$155**	**$91**	Based on 2016 capex of USD 21,029 based (Ardani, et al., 2017), and excluding US-market specific cost components. Electricity cost savings are then netted out
PV (5.6 kW) + battery (5 kW / 20 kWh)		**$1,213**	**$362**	**$255**	Based on 2016 capex of USD 36,016 based (Ardani, et al., 2017), and excluding US-market specific cost components. Electricity cost savings are then netted out

[1] https://www.mysolarquotes.co.nz/about-solar-power/residential/how-much-does-a-solar-power-system-cost/

Solar PV and storage - commercial

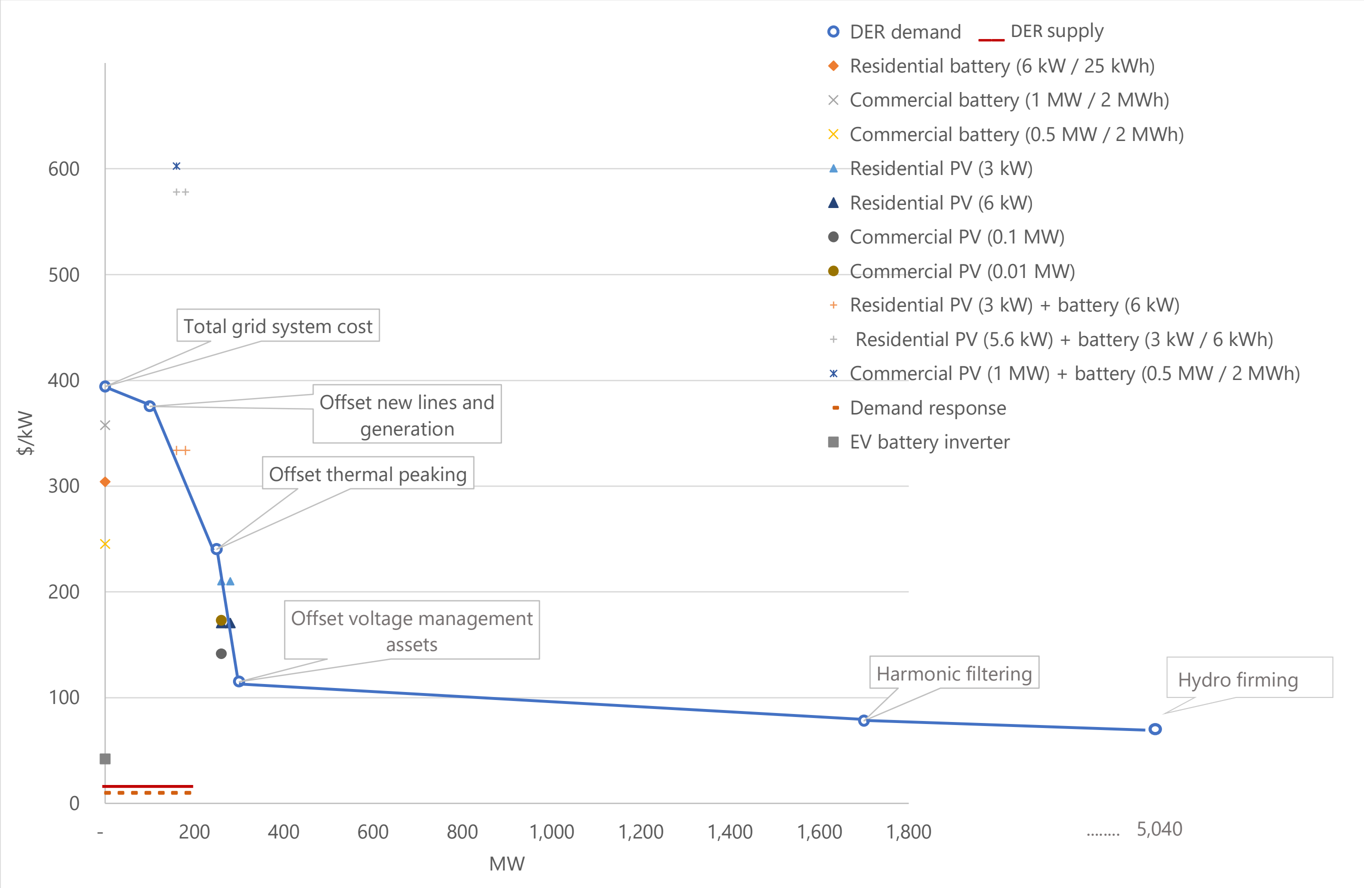


	Unit	2021	2035	2050	Source
Experience curve	Annual reduction in cost over the period	-7%	-6%	-2%	Weighted average of experience curves for standalone PV and standalone battery
Battery lifetime	Years	10	10	10	(Lazard, 2019)
PV system lifetime	Years	25	25	25	(MBIE, 2016)
O&M costs	% capex	1.2%	1.2%	1.2%	Weighted average of O&M costs (as % capex) for standalone PV and standalone battery, assuming battery cost is 47% total PV + storage system cost
PV (1 MW) + battery (0.05 MW / 2 MWh)	**Annualised cost, $/kW**	**$604**	**$218**	**$138**	Assumes a total cost of USD 4,086,500 in 2019 as per (Lazard, 2019), and nets out electricity cost savings

Energy costs are netted out as these aren't on the demand curve. The costs in the supply curve are residual costs after energy self-sufficiency

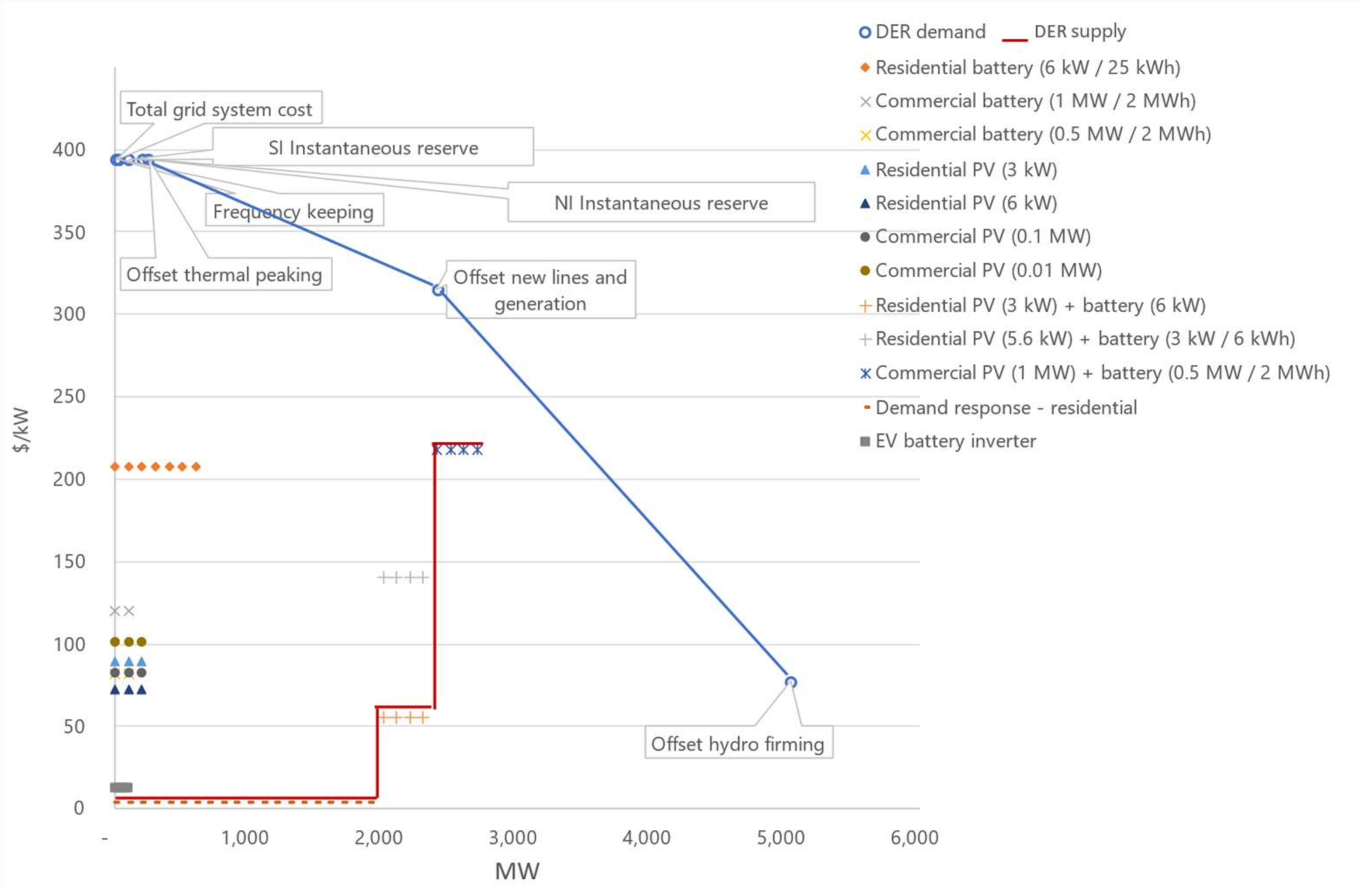
* The report had some numbers from a previous draft before a discount rate change from 7% to 6%, the numbers are corrected here

Supply and demand - 2021



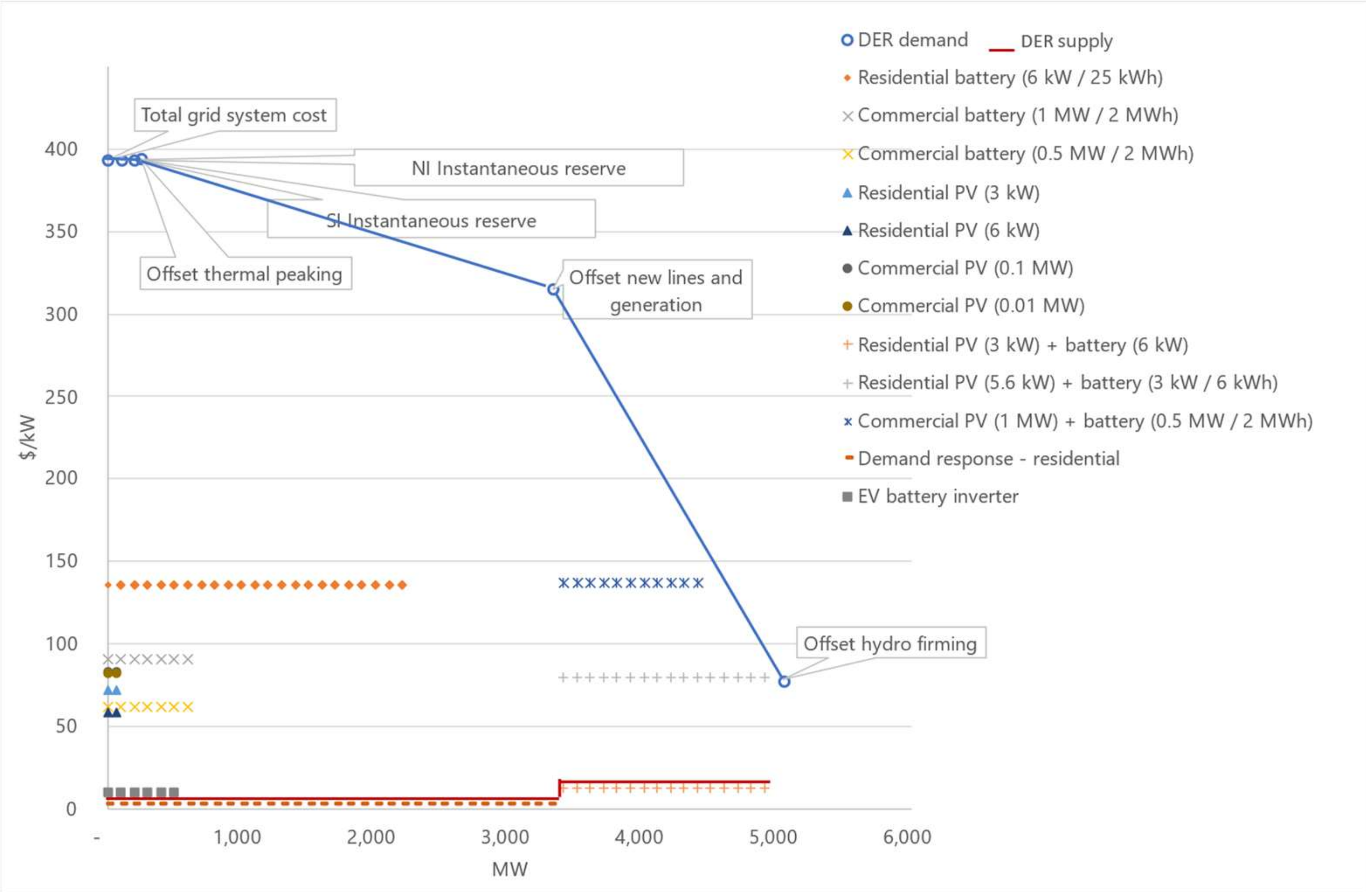
- The economic surplus for the ideal scenario is the area between the DER supply and the demand curve
- The economic surplus for the baseline scenario is the area between the DER supply and ONLY the 'Offset thermal peaking' component
- The incremental benefit from facilitating DER is the difference between the ideal and the baseline

Supply and demand - 2035



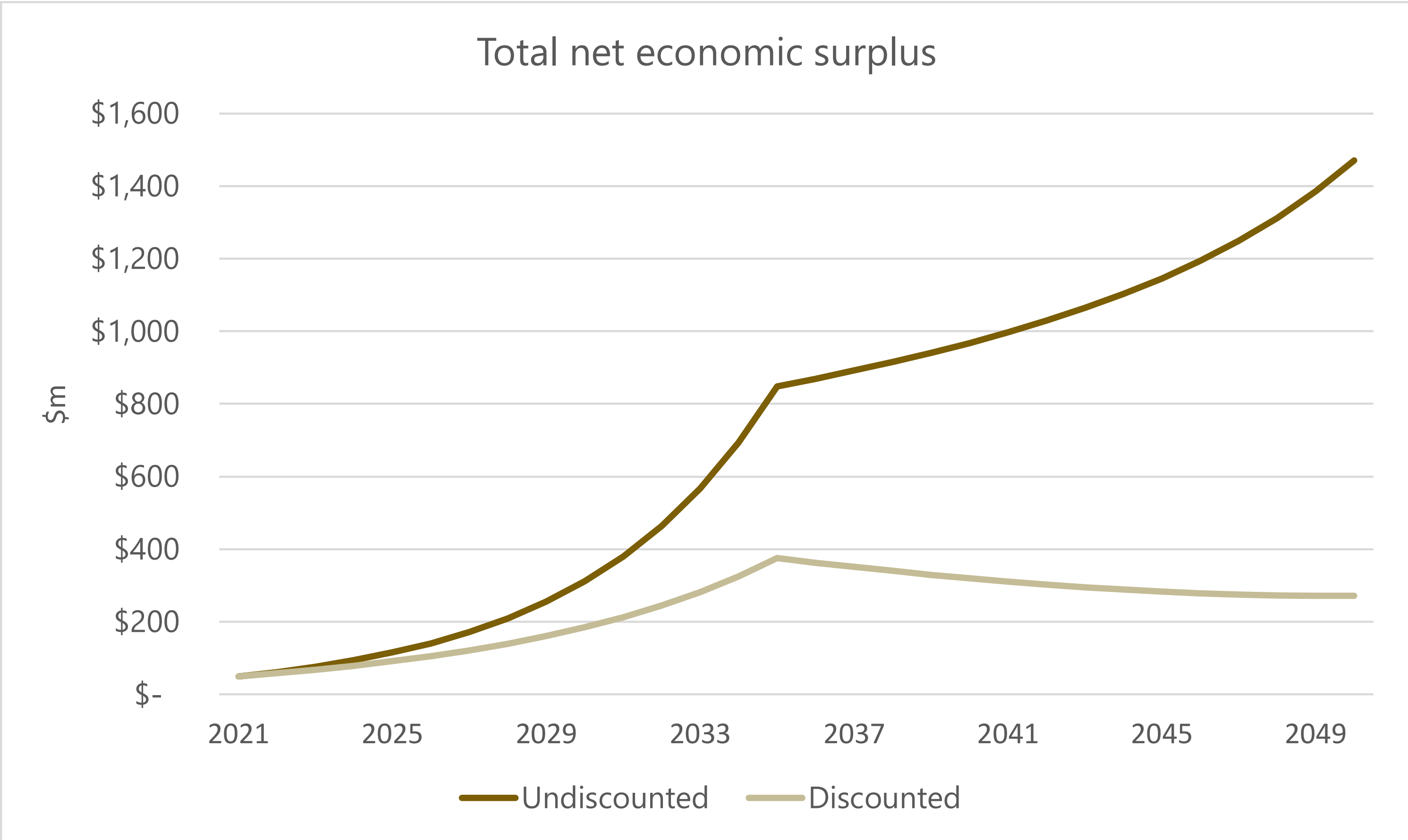
- The economic surplus for the ideal scenario is the area between the DER supply and the demand curve
- The economic surplus for the baseline scenario is the area between the DER supply and ONLY the ‘Offset thermal peaking’ component
- The incremental benefit from facilitating DER is the difference between the ideal and the baseline

Supply and demand - 2050



- The economic surplus for the ideal scenario is the area between the DER supply and the demand curve
- The economic surplus for the baseline scenario is the area between the DER supply and ONLY the 'Offset thermal peaking' component
- The incremental benefit from facilitating DER is the difference between the ideal and the baseline

Discounted cashflow



David Reeve
dreeve@thinkSapere.com
021 597 860

independence, integrity and objectivity