Distributed energy resources: Understanding the potential

Executive Summary

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Introduction

Transpower is seeking to advance the discussion about how the electricity industry and market may need to evolve with increased penetration of DER.

Transpower, in its role as system operator, has commissioned the authors to investigate DER in a New Zealand context. In its work on the future of electricity (Te Mauri Hiko), Transpower has identified how critical DER, and its potential flexibility, is to achieve New Zealand's greenhouse gas emissions goals. This can be achieved both by supporting renewable supply growth to electrify transport and industrial process heat, and to directly reduce emissions from the electricity sector. Transpower is seeking to advance the discussion about how the electricity industry and market may need to evolve with increased penetration of DER.

The timing of this work is significant. Transpower analysis suggests there could be significant uptake of DER within 5 years. The authors analysis confirms this. Our assessment also suggests that higher specification equipment would be needed than might otherwise be installed to unlock the full value potential of DER. To ensure that the best decisions are made for DER technology, investment signals for the services DER can provide should be put in place now.

The Authors also note that innovative business models are already installing high spec DER at scale today.

Executive Summary

This is the Executive Summary of a paper commissioned by Transpower to consider:

- The **value** of DER to the New Zealand Electric Power System
- The **use** of DER that could be encouraged with economic incentives
- The impact of **barriers** to deployment and transaction costs.

The summary presents overall results and insights identified from considerable analysis and research. This builds on the authors' previous work on decarbonisation and technology transformation, as well as other work that considers the value of DER such as Te Mauri Hiko and the IPAG recommendations.

The report seeks to encourage further discussion on the future path of the New Zealand Electric Power System and the integration of DER into it.

Definition -What is DER?

Definitions of DER can vary slightly, for example, some definitions of DER do not include Demand Response.

For clarity, the definition for DER in this report includes:

- **Distributed Generation** (e.g. solar PV, within the distribution network or within consumer premises).
- **Battery Energy Storage Systems** (within the distribution network or within consumer premises).
- **Demand Response** (including existing HW load control plus new forms of DR made possible with remote or automated control).
- **Electric Vehicles** (both as a smart load and potentially BESS).
- **DER related ancillary equipment** (equipment that may be required as a consequence of DER up take, e.g. harmonic filtering stations)

A three-stage approach

- ## Establish the potential value of DER

  First, a rough estimate was made of the value potential for DER. The value opportunities were quantified by service, e.g. reactive power/voltage, capacity, energy, etc, looking forward as far as practicable; and quantifying the high level, direct costs (including opportunity costs) for DER providing such services.

- ## Evaluate the potential supply of DER

  Second, the incentives and need (supply and demand) of the value opportunities were considered. This stage extended the assessment from stage 1 developing them into supply and demand functions. This informs possible efficient levels of DER investment in the various services and the implied efficient price. This describes, theoretically, what could be achieved through price incentives.

- ## Identify the barriers to greater access to and deployment of the flexibility DER offers

  Third, the transaction costs and barriers to the supply of and procurement of all forms of DER in the marketplace were investigated. Where barriers to entry or other market failures might discourage the efficient level of aggregation then mandatory mechanisms for DER coordination may be warranted, especially in the short-term.

Context

In Whakamana i Te Mauri Hiko, Transpower identified the significant impact DER is likely to have to the NZEPS. Transpower realises that this has implications for the energy market, transmission utilisation, dispatch, security, reliability, and the stability of the NZEPS. Historically, Transpower, in its role as system operator has had substantial certainty and control over supply resources, and demand has been mostly predictable except at the margin. Given that system operators worldwide are tasked with maintaining secure supply of electricity, an energy service critical to modern economies, they are typically conservative and prefer clear rules and visibility of supply resources.

However, given that DER can provide services across wholesale and retail electricity markets, ancillary services, transmission and distribution, and that New Zealand has some time to consider the integration of DER into the NZEPS, the SO is interested in all integration approaches. Hence, the fundamental question that underlies this report is "What could be achieved through incentives?"

The author's insights are based upon analysis done for this report and previous analysis. Our analysis is 'first order approximation' and there is considerable uncertainty over the time horizon we have considered (up to 2050). Nevertheless, we believe that, to achieve the objective of encouraging debate and further analysis in DER, we need to 'take a position' on our insights despite the analytical uncertainty.

The role of incentives

Incentives can be thought of interchangeably as prices or pricing. However, incentives can sometimes be delivered more efficiently through other means, such as rules or standards. Prices can also be delivered through many methods such as two-way markets, one-way markets, exchanges, tariffs, cost allocation, and contracts; and all these methods are used in the New Zealand electricity industry. The authors have not considered how incentives would be most efficiently applied, but focus on the case for incentives, the level of incentive and what that could mean in terms of DER investment and getting access to the new flexibility DER offers.

A form of incentive not considered is subsidies. In this case, behaviour is influenced by the contribution of money to achieve an unquantified social or economic benefit. The incentives considered are reflective of the opportunity costs of the supply of services that consumers, in aggregate, are willing to pay for and where DER can potentially provide the services cheaper and/or to a higher quality (where that higher quality would be valued by consumers).The opportunity costs of services do include factors external to the NZEPS where those externalities are explicitly priced, i.e. carbon pricing.

1. Value

Energy, capacity and programmable

DER is valuable because it can operate very quickly and flexibly, which potentially helps manage the power system better. It can offset grid supply, and its flexibility can be used to offset the need for network capacity. It is also potentially programmable, which means energy companies, network companies, the system operator or aggregator intermediaries can harness it to manage the power system in ways that haven’t been possible before.

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Not all DER can do everything, though, and identifying where DER can add value means not just looking at the cost and value, but also the capability of each DER technology.

DER can also cause problems, which means that not only should DER be encouraged where and when it makes sense but discouraged where and when it causes problems. Or else signal that DER must meet a higher standard to avoid problems.

Regulatory philosophy

The current electricity market design was based on supply and demand technology from the 1990s, and modelling and computing technology from that time as well. This made it wise to separate aspects of electricity that were substantially competitive (energy – generation and retail) and substantially monopoly (transmission and distribution). DER blurs the boundary between these competitive and monopoly aspects as it can offset the need for both.

Energy and capacity – DER will force the industry to reconsider the role of capacity in our energy only wholesale market.

Capacity and lines services – DER will force the industry to reconsider whether, and what aspects of, transmission and distribution will become genuinely competitive.

Complexity is unavoidable

The industry will not be able to avoid more complex arrangements for the coordination of energy, capacity, quality and reliability. This is because the power system will be more complex to manage and not all aspects should be centrally controlled.

Where distribution networks are currently one-way systems that take power from the grid to consumers (with some DG), they will become two-way systems with lots of DER that resemble mini-transmission networks. Truly smart grids are complex.

Electricity should become simpler for consumers

Although the power system will be more complex, technology should make consumer participation simpler. Although it is undesirable to over-complicate arrangements, over-simplifying them will result in misused resources and misplaced innovation.

Avoiding new network peak capacity

The authors' analysis highlights **avoiding peak capacity as the major value stream** for DER. DER can reduce the need for new grid-connected peak generation, new transmission and new distribution. Adding new peak capacity can cost a lot, especially where DER could do the job more cheaply, especially as the cost of DER technology falls in the future.

The analysis suggests that up to $860m p.a. of peak capacity investment could be avoided by 2050 through the deployment of 3,300MW of new forms of DR, solar PV with battery and EV batteries. 70% of these gross savings are achievable by 2035.

It needs to be recognised that voltage is also a factor in network capacity, especially in distribution networks, and voltage isn't well handled in existing electricity market design.

Suitably spec DER is forecast to be cost competitive with network peak capacity investment for significant capacity by 2025.

Decarbonisation and reliability

As well as avoiding the need for new peak generation DER can offset existing peak thermal generation through being cheaper than using fossil fuels and incurring carbon charges. This could yield gross savings of $21 million p.a. by 2035 and $70 million p.a. by 2050. Only DER technology that can manage short-term reliability can be used for this, which includes DR, batteries and EV batteries.

Thermal generation can’t be completely offset due to the need for reserve energy when hydroelectric capacity is affected by dry weather.

However, PV and battery systems become cheap enough that they could provide around a third of the hydrofirming requirements by 2050.

This could be achieved by ‘over-building’ solar PV with batteries, getting the reserve energy from the extra solar and managing short-term security with the batteries. However, this requires that the solar ‘over-build’ is only used in dry years. If it is used in other years it will affect the wholesale market and offset grid renewable generation that would otherwise have been built, and will no longer be dry year reserve.

Inertia

There is increasing concern worldwide about inertia. Inertia stops frequency changing too quickly and makes the system more stable. Inertia is provided by large spinning machines directly connected to the grid. This is predominantly provided by grid connected generators and, to a lesser extent, motors in the network. As electronically connected generators (e.g. wind) and motors, and plant that doesn't spin at all (solar) replaces traditional machines, then inertia could reduce to problematic levels. This is not well understood yet.

If inertia does become a problem in New Zealand then large rotating machines may have to be retained simply to provide inertia.

This could add costs of up to $21 million p.a. by 2035 and $85 million p.a. by 2050.

While DER is part of the problem it can also be part of the solution. It is possible for battery systems to be programmed to simulate inertia and/or provide ultrafast reserve that can respond to frequency very quickly.

Frequency

Current frequency markets (frequency keeping and instantaneous reserve) don't offer a lot of value to be realised through DER. While FK and IR are worth reasonable amounts on a $/MWh basis the volumes are small. Only ±15MW in each island for FK and perhaps a few hundred megawatts for IR. However, it is worth opening these markets to DER if transaction costs can be kept low.

However, the performance and contribution of these markets are again designed around plant performance and computer modelling technology from the 1990s. DER can be programmed to respond the same way as traditional technology but faster response and different response functions may be more valuable.

It would be worth reconsidering the design of our frequency markets, especially if rates of frequency change are increasing and incentives are warranted for inertia and faster reserve.

Harmonics

Harmonics are a form of interference that occur in AC power systems and can affect all sorts of equipment connected to the system. Harmonics are caused by electronic equipment of which there is a substantial amount in modern power systems. To date harmonics haven't been too much of a problem as equipment is made to meet New Zealand standards of Total Harmonic Distortion. DER creates harmonics but must also meet New Zealand standards.

However, a problem could develop when large amounts of DER injection (e.g. solar PV and battery discharge) reduces power flow on distribution lines but doesn't also reduce harmonics. The ratio of harmonic interference to the net power flow could reach unacceptable levels. This potential problem isn't yet well understood but could cost $1 million p.a. in filtering costs by 2035 and $7 million p.a. by 2050.

Understanding the problem and providing incentives for harmonic levels could encourage innovative filtering solutions and/or higher performance of DER assets

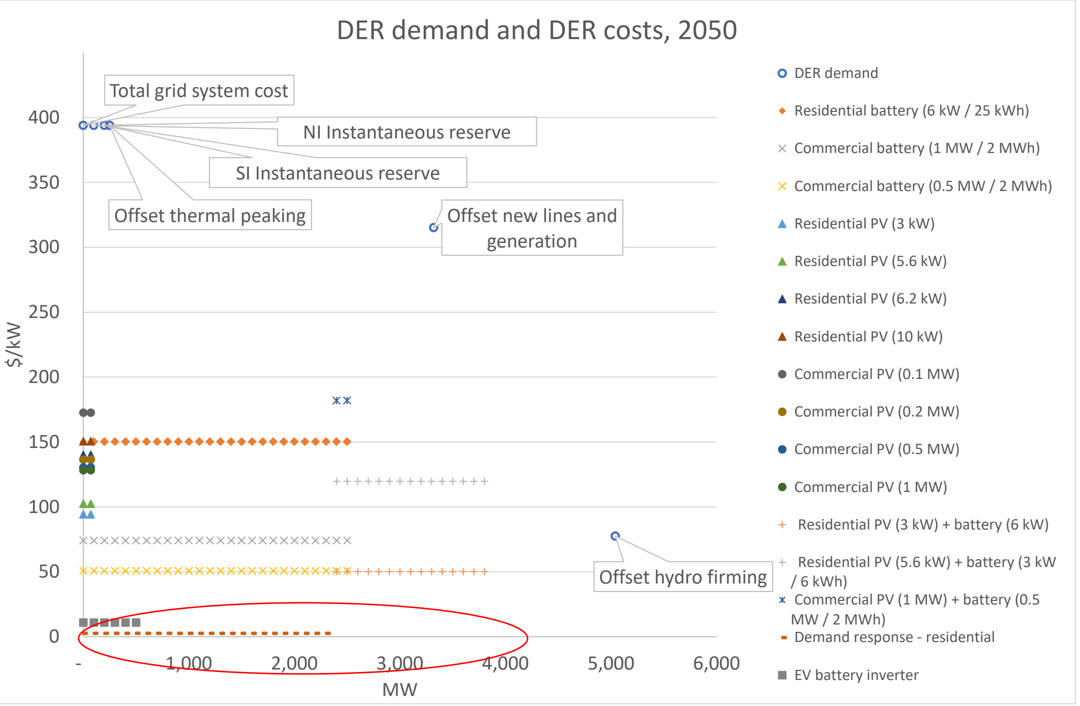
2. Supply

DER that meets cost and spec

The authors analysed the types and volumes of DER that could be economically encouraged through the value opportunities above. To meet these opportunities DER types had to not only be a cheaper alternative but also meet the specification to contribute to that value.

We identified that between 2,500 and 3,000MW of DER could be encouraged by 2035 and up to 4,000MW by 2050, made up of:

- EV battery storage
- DR
- Solar PV with battery



Demand response

Many reports have identified that DR is an economic way of managing supply and demand. However, the convenience of electricity is part of its value and most consumers prefer low engagement. We consider it informative that the most successful form of DR (ripple control and pilot wire) so far, requires low engagement from consumers and utilises energy storage (e.g. water heaters) to disconnect demand management from consumer service.

The authors think there are three technologies that will unlock the full potential of demand response as a valuable way of offsetting peak demand.

1. Energy efficiency – will continually improve the thermal storage inside consumer's buildings (e.g. fridges/freezers, aircon, heat pumps, water heaters, etc.) allowing for greater use of demand management without service degradation.
2. Digitally controlled inverters – will allow incremental control of loads to manage demand and service in a fine tuned way rather than the current paradigm of all on or all off.
3. Building automation and smart appliances– Appliances that are capable of self-energy management and communicating with external systems are already on the market. Such appliances could be integrated with building automation systems to manage building demand. Predictive analytics should further ensure that thermal storage can be utilised to maximise the consumers private benefits in maintaining service at lowest cost.
This technology should become cheaper and more widely available, especially if there are incentives in place to utilise the technology to manage system costs.

For this system to work it would need to be a complete energy management system. Water heaters would also need to transition from current control to these distributed systems.
EV battery charging would be a significant contributor to DR potential.

Solar PV with battery

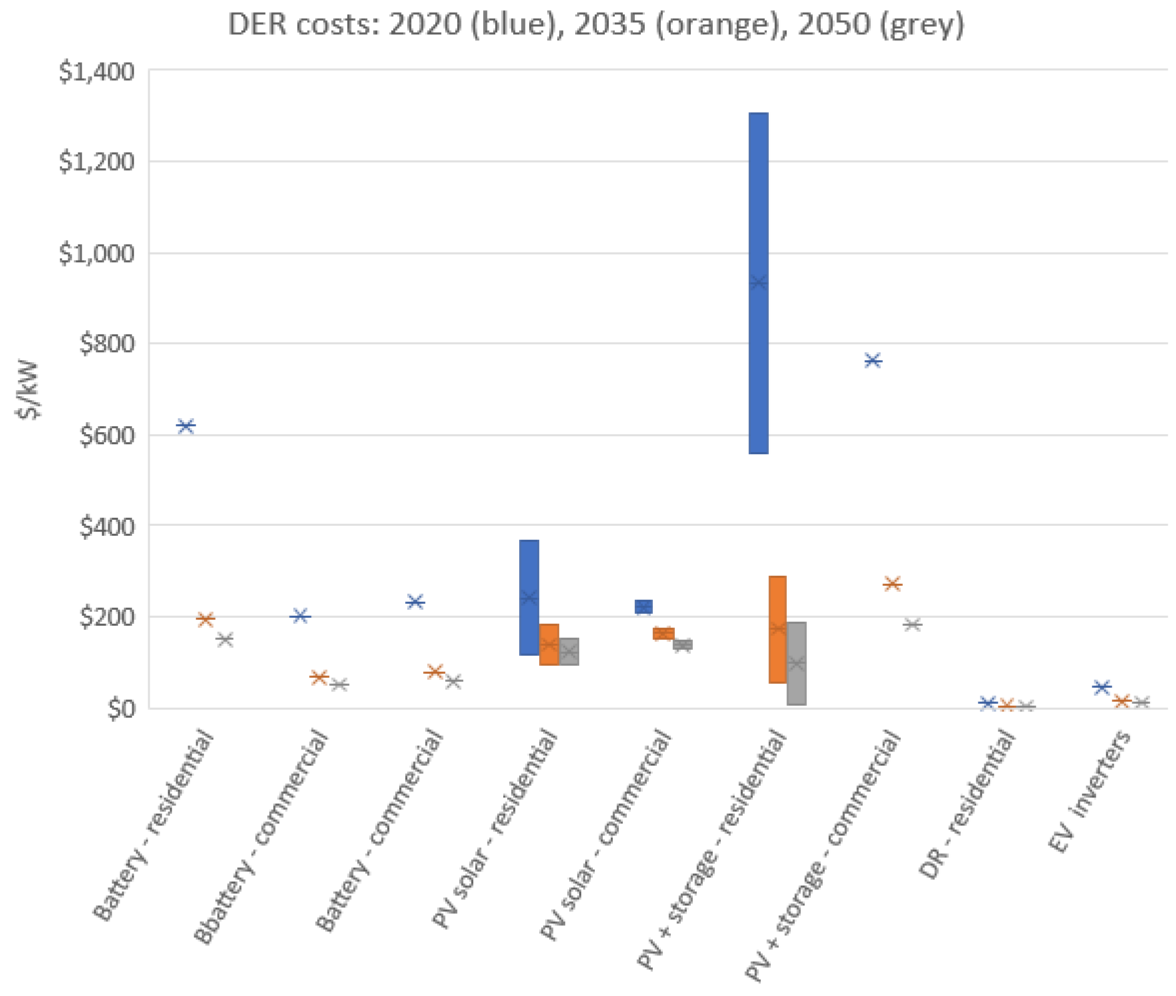
Supply costs were determined separately for different DER options in 2020, 2035 and 2050, using experience curves (i.e. annual technology cost reductions) estimated from available sources such as Lazard, US National Renewable Energy Laboratory (NREL), local NZ sales data, EECA and other.

The supply costs are calculated in terms of annualised $/kW per available DER capacity net of self-energy supply.

The authors' conclusions are driven by the generally low residual cost of DR and EV batteries (net of primary use) and the significant reduction in costs over time for residential solar PV and batteries. By 2035 the EV battery capacity and DR that we have assessed as available is completely utilised. The analysis indicates significant take up of residential solar PV with batteries.

The analysis indicates by 2050 EV battery storage, DR and residential solar PV with battery is fully utilised and some commercial solar PV with battery is also deployed.

Residual DER costs over time



Price as a control signal

The role of pricing in the coordination of DER is a critical discussion that needs to happen.

There is a limit to what can be achieved through prices alone. Generally, however, the greatest levels of capital efficiency and innovation will occur through signalling price incentives.

In a distributed system that self-dispatches, price would effectively become a control signal. Point prices can encourage over-response, which can lead to system instability.

In a self-dispatching system, prices need to be either highly dynamic or price functions. It should be noted that this is no less complicated than would be needed to establish a stable, distributed volume dispatch.

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Such complex pricing is arguably of little value to consumers. In the long-run however, operating response would be handled by technology, and investment would be handled by agents competing for consumers.

3. Barriers

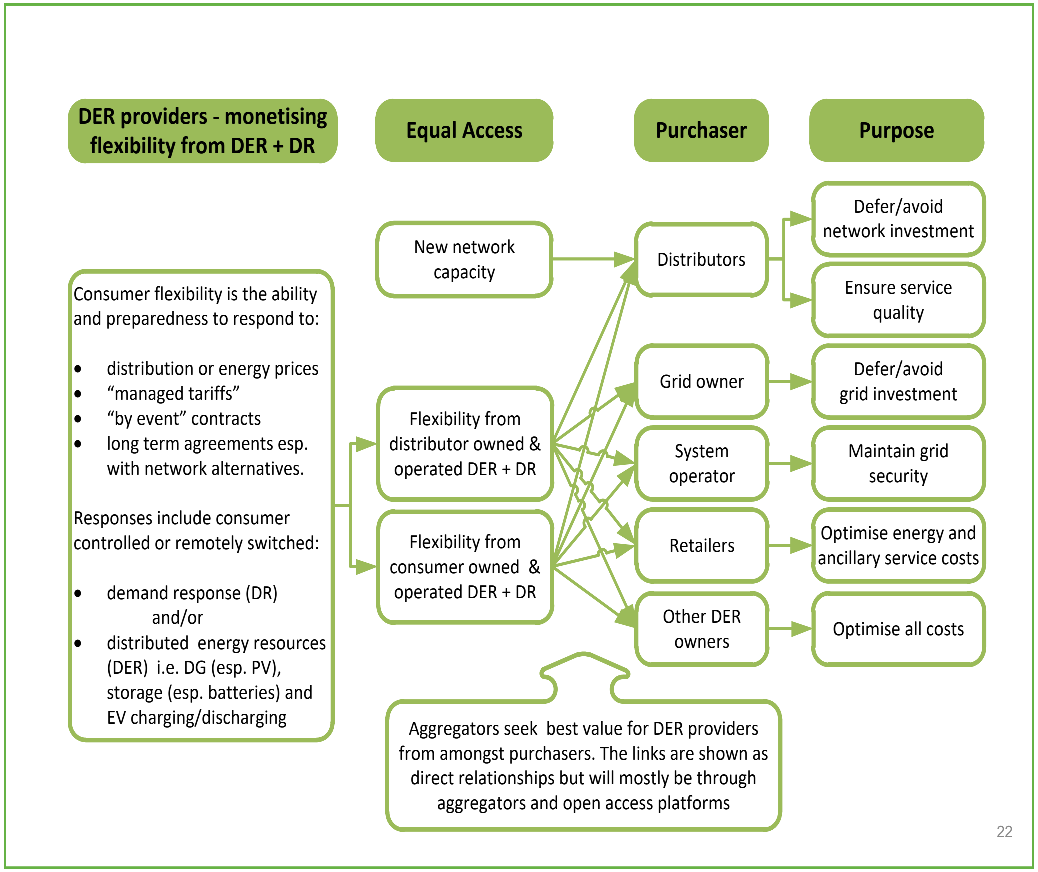
Barriers and transaction costs

Barriers and transaction costs inhibiting providers of DER and potential users of DER arise because they need to be able to identify each other, navigate the logistics of accessing the service, need to be able to agree a price for the service and need to be able to make/receive payment.

The fact is that institutional arrangements, protocols, rules and systems we use were not set up with this sort of dynamism in mind.

IPAG describe the overriding issue by noting that getting the best out the flexibility DER offers will require a new set of relationships, some of which would be multiple relationships for DER providers, to be established. This is understandable as the industry goes from a simple one-way relationship involving a service supplied by a single provider to two-way relationships potentially with multiple providers.

IPAG's framework for a DER market



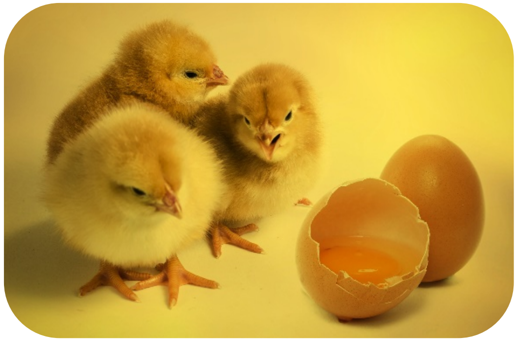
IPAG unpicked the DER "problem" into 13 separate problems. At the heart of these lies some core issues:

- Technical information about procurers' requirements are not easy to find. In this case procurers include distributors and other parties who might deploy DER flexibility
- 5 separate input services need to be improved to allow for DER to be "traded" between providers and all potential users of DER
- Price signals for providers offering their services are not well formed or, where they are formed, well signalled.
- Distribution pricing does not signal the cost of DER to network operation (congestion and voltage excursions for example) or its value to distributors
- Distributors have a technological, contractual and access hold over existing demand response in the form of hot water heating managed by ripple control

Difficult transition is a barrier – IPAG's 'chicken and egg'

Consumers won't engage until benefits are certain and participation means choice.

Regulators will not ease hard rules until participation is two-way and competition normal



Technology development will be slow until potential for participation is real.

Distributors will need to impose limits and/or minimum standards until coordinated participation is certain.

4. What next?

Change is inevitable and profound

Even without incentives from other value streams, there will be significant investment in DER.

In the absence of economic and technical coordination the deployment of DER, and the industry reaction to it, will cause significant costs to the economy and frustrate decarbonisation goals.

The economic and technical integration of DER and distribution networks with grid supply resources will be as profound a change as New Zealand's transition to an electricity market in 1996.

Waiting for international solutions may be too late, especially as key international jurisdictions with DER experience are already 'playing catch up'.

Factors for change

Using the 1990's development of the electricity market as a blueprint, the authors note some key factors for successful change:

Industry leadership
With dominant resources and motivated for change ECNZ underpinned the WEMDG study and Transpower provided significant technical development into nodal pricing. Mistrust of ECNZ led to the Government inspired WEMS study. The two studies lead to a very well-designed wholesale market.

Broad support
While individual motivations were quite different, the New Zealand Electricity Market was broadly supported by most stakeholders.

Stakeholder engagement
While not perfect, the combination of WEMDG and WEMS involved stakeholders in the design process.

Major questions

- Where does the industry leadership come from for DER integration into the current system and arrangements, where the problem is economically and technically complex, and the solution could be a world first?

- Is there broad enough support for a difficult transition and, if not, how can that be secured?

- What is the process to involve an even more diverse set of stakeholders than in 1996, which now needs to include innovators, aggregators and technology developers?

Other issues and questions (1)

As far as the authors are aware, ours if the first analysis to try to quantify DER costs and the specific value opportunities in the New Zealand market. Further empirical study would assist future decision-making.

The discussion needs to occur on electricity market design where:

- Security and reliability may be economically provided by an ‘overbuild’ of DER.
- Aspects of transmission and distribution may transition from substantially monopoly to substantially competitive arrangements.
- Coordination of DER may require incentives for capacity within transmission and distribution networks. That discussion should also include voltage.

Other issues and questions (2)

Further discussion is required on the role of price incentives in coordinating DER investment and operation. It should also be recognised that broad price incentives might cause ‘rate shock’ on those that do not have the resources to respond to the price incentives.

Further investigation and study should be done on inertia, harmonics and voltage coordination using DER.

Discussion on frequency market design should consider whether DER, and other technology, could provide a higher standard of service at lower cost than existing technology. And, especially if inertia is reducing and warrants incentives to encourage more inertia and substitutes.

It would be advantageous for the industry to better understand, and have better visibility, on the technology and cost path of building automation and smart appliances.

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