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Promoting behind-the-meter battery storage: options for more effective government support and regulation

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Abstract: We examine the use of subsidies to promote behind-the-meter battery installation, the limitations and perverse outcomes created by these subsidies, particularly as a result of suboptimal spatial concentration. We suggest the use of consumer subsidies to promote behind-the-meter batteries is unlikely to lead to optimal outcomes in aiding the integration of distributed generation sources (solar PV). It is also possible batteries could reduce the reliability of the grid. The problems identified relate to the undirected installations of batteries within the grid due to the reliance on consumers to take part in a subsidy scheme. Recommendations for policy makers and regulators are to encourage optimal installations through directing subsidies, and in lieu of that, to orchestrate and/or coordinate individual installed battery capacity.

Keywords: behind-the-meter batteries; consumer subsidies; innovation; technology; energy storage; energy security; regulation; electricity sector transformation; policy analysis.

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1 Introduction

Due to reliance on fossil fuels, electricity systems contribute approximately 40% of global greenhouse gas emissions (IRENA, 2014). In response, sources of renewable energy generation have been implemented with installations of renewable capacity outstripping those of fossil fuels in 2015 (IEA, 2016). In contrast to historically centralised and large-scale electricity sectors, modern technologies are enabling consumer participation, creating so-called ‘prosumers’ (Parag and Sovacool, 2016). Experts have predicted by 2050, 30%–50% of electricity supply will be produced by consumers rather than by centralised generators (CSIRO and ENA, 2017). Following the implementation of a variety of policy instruments to promote installation, over 1.7 million Australian consumers have installed rooftop solar photovoltaic (PV) systems (CER, 2017) – one of the highest per capita penetrations in the world (Agnew and Dargusch 2017).

Australia’s national electricity market (NEM), like any other electricity sector transitioning toward renewables, is facing issues due to a change from centralised, synchronous generators to distributed, non-synchronous, intermittent renewable generation. This creates challenges for system security, reliability, strength, and stability because power systems were historically designed for one way power flows (Zahedi and Aldeen, 2014). Therefore, benefits that renewables, particularly distributed solar PV, provide can be counterbalanced with possible harms to system operability, including voltage fluctuations, frequency control issues, and reverse power flow (Passey et al., 2011).

Storing energy is one way to combat issues of synchronicity and potentially provide a number of services to consumers and the electricity system more broadly (Fitzgerald et al., 2015). Adding energy storage to electricity generation systems is far from novel; hydroelectricity from stored water in dams is the most common storage option (IEA, 2016). There are however many other storage technologies in existence – both physical (flywheels, compressed air, solar thermal) and chemical (power to hydrogen) (Aneke and Wang, 2016). Battery storage technologies have received considerable recent attention following rapidly decreasing costs and increasing learning rates – the cost reduction following a cumulative doubling of production, due largely to the mass production of lithium ion batteries used in electric vehicles (Nykvist and Nilsson 2015). While there are many storage options available, “battery storage is forecast to provide the dominant new source of energy balancing” [see CSIRO and ENA (2017), p.55].

An enduring belief in their widespread capabilities is epitomised in the claim of James and Hayward (2012, p.63) that batteries “can be put anywhere and can do anything, within reason.” Justifiably then, various national and sub-national jurisdictions have implemented policies to encourage installation of batteries (IRENA, 2015). Our interest here is the role of government in achieving system security, and an Australian case study has much to offer. Australia is one of the highest per capita carbon dioxide emitters, with 85% of electricity fossil fuel generated (DEE, 2017). Due to Australia’s very high penetrations of small-scale solar PV it is suggested to become one of the largest battery markets in the world (Sunwiz, 2017). Moreover, behind-the-meter batteries (hereafter just ‘batteries’) coupled with solar PV could constitute some 57% of installed storage capacity worldwide by 2,040 (BNEF, 2017). The Australian Capital Territory (ACT) was chosen specifically as it was the first Australian jurisdiction to implement a battery subsidy and has previously developed energy policy innovations of global interest (Buckman et al., 2014). Inclusion of this sub-national element therefore offers insights into the wider governance of Australia’s battery response.

Government involvement in innovation and the promotion of new energy technologies is necessary because two market shortcomings exist around energy production:

1 global warming and local pollution caused by fossil fuel use

2 under-investment by firms in research and development because knowledge spillovers deter them from making the first move (Jaffe et al., 2005).

Typical characterisations of policy instruments tend toward ‘technology push’, such as funding for R&D, or demand ‘pull’ whereby policy stimulates demand to achieve economies of scale and hence decreased cost (Nemet, 2012; Battke & Schmidt, 2015). Consequently, the majority of literature on governments and new energy technology focuses on the promotion of innovation through ‘push’ and ‘pull’ rather than how technology integrates with the system it operates within (Sørensen 2013). This is perhaps a result of the long held belief in some cultural contexts that when addressing climate change, government policy should be ‘technology neutral’, and leave detailed technology choices to the market (Hoppmann et al., 2013). However, governments do ‘pick winners,’ by promoting specific storage technologies, and as Azar and Sanden (2011) advise, avoiding ‘winners’ should not be the main guiding principle in the meeting of policy goals. Perhaps of more concern is any government attempting to transform the electricity sector must address the ‘energy trilemma’: affordability/equity, system security, and (environmental) sustainability (Grubb et al., 2014).

It is beyond our scope here to analyse the technical capabilities of batteries to address all of the electricity system issues recently highlighted in the literature (see Katsanevakis et al., 2017). Rather our contribution is to explore the opportunities and limitations of using subsidies to promote batteries for improvements in energy security, with particular interest in issues arising from spatial concentrations. Our findings are based on policy analysis of one jurisdiction’s battery subsidy program, the Next Generation Renewables Program (NGRP) of the ACT. Our analysis produces suggestions for subsidy programs in other jurisdictions, though our findings are of broader relevance to regulating battery installations, given that batteries will proliferate with or without subsidies.

The paper is structured as follows: Section 2 summarises the transformation of electricity sectors due to renewable energy penetration, as well as the characteristics of the Australian electricity sector. Section 3 defines the methodology. Section 4 outlines the benefits and limitations on battery applications and current mechanisms for promoting their installation. Section 5 introduces the NGRP, and develops a policy analysis framework which we then apply to the NGRP. Section 6 is the discussion of the analysis shown whether the program will meet its stated goals. Section 7 provides conclusions, lessons learned, and recommendations to improve policy design and implementation of battery-based solutions for energy system security.

2 The Australian context

Many jurisdictions have restructured their electricity sector over recent decades, moving from traditional integrated monopoly arrangements toward market-oriented approaches (Macgill and Healy, 2013). Restructured electricity industries comprise a number of sub-industries – generation, transmission, distribution, and retail (Sue et al., 2014), along with consumers of electricity. Demand side participation developments have created a new actor, 'aggregators,' that combine services from individual consumers to increase profits and participate in markets (Eyer and Corey, 2010).

Australia's NEM provides some 90% of the electricity consumed, and services the eastern states with each state operating as a separate regional spot-market; Western Australia and the Northern territory are serviced by separate, smaller grids (AEMO, 2017a). Along with sub-industries that operate in de-monopolised sectors, there are several actors governing the sector. In the NEM, the Council of Australian Governments Energy Council coordinates energy governance, policy development and strategic leadership. The Australian Energy Market Commission (AEMC) is the rule maker, the Australian Energy Regulator enforces the national electricity rules (NER), and the Australian Energy Markets Operator (AEMO) is the system operator and national transmission planner (Vertigan et al., 2015). The NER set out the roles and responsibilities of the different sub-sector actors and how the market and grid function (AEMC, 2018). This arrangement is further complicated by the federal system of government in Australia and the complex sharing of responsibility for the electricity sector by state and federal governments.

3 Methodology

Analysis of the case study is based on primary data collection via interviews. In addition, secondary data was drawn from recent Australian government electricity sector reviews. Fourteen semi-structured interviews were conducted between November 2016 and February 2017 in person, by phone, and in some cases written responses to questions were provided pending the availability of interviewees. In-person and phone interviews lasted between 40–60 minutes. Semi-structured interviews were used so interviewees were not limited in their response. Participants were initially chosen based on expertise in the field and to cover a diversity of roles within the sector. From an initial two interviews, snowballing was used to identify further interviewees (Layder, 2005). Distribution companies were interviewed due to their familiarity and proximity to the technical transformation of the sector and because the research is part of a larger project funded by the Australian Renewable Energy Agency involving 11 of the 15 distribution network service providers (DNSPs) in Australia (ARENA, project: G00854). Themes discussed in the interviews included: interviewee awareness of issues about batteries, whether these issues could be overcome, and what interviewees foresaw for electricity grids considering the rapid changes occurring. These themes were mirrored in our analysis of the government reviews.

Interviews were analysed following Strauss and Corbin's (1994) grounded approach to highlight previously unidentified themes. The data collected was then analysed using triangulation, defined as "the mixing of data or methods so that diverse viewpoints or standpoints cast light upon a topic" [Olsen, (2004), p.2]. Triangulation was approached on a number of levels. First, interviews were analysed in reference to the literature review. Second, the interview material was cross-referenced with submissions to the Australian government reviews (Table A2). Third, interview responses and submission responses were used to corroborate claims from the literature. Taken together, these different processes help to create a more reliable and accurate policy analysis. Quotes and insights have also been used to corroborate and justify particular claims.

4 Behind-the-meter batteries for system security

Batteries can be installed at different scales depending on the point of connection in the grid – transmission, distribution, or behind-the-meter – installations of technology behind-the-meter of consumer residences or businesses (IRENA, 2015). The size of installations ranges between megawatt (MW) and kilowatt (kW) capacities – large, 'utility' scale batteries are connected to the transmission and distribution system while smaller batteries are installed by consumers behind-the-meter (see Katsanevakis et al., 2017). Though applications are possible at each of these scales, it is batteries that may provide the most benefits to the highest number of different actors – consumers, aggregators, and distribution and transmission system operators[1] (Fitzgerald et al., 2015).

Due to the possible suite of applications and benefits batteries can provide (Section 4.2), many jurisdictions have implemented policies to promote the installation of batteries including Germany, Japan, California, New York state, and the ACT (Moore and Shabani, 2016). The South Australian and Victorian governments have also recently invested in batteries (Government of South Australia, 2017). Recent figures show battery installations in Australia have risen from 500 in 2015 to some 6,750 (52 MWh of energy) in 2016, with the market forecast to triple in 2017 (Sunwiz, 2017). AEMO (2017b) forecast battery installation capacity could reach 5.6 GW by 2036–2037.

4.1 Battery system operation

Battery storage systems consist of several components. This includes the battery and associated generation source (solar PV in most cases), monitoring and control systems, and a power conversion system that converts DC to AC electricity to be fed into the grid or used at the premises (IRENA, 2015). The control and monitoring systems, often referred to as energy management systems, aim to fulfil the end user's energy needs "while realising certain objectives such as reducing operation cost, improving energy efficiency, balancing demand and supply, and reducing carbon emissions" [Bayram and Ustun, (2017), p.1208]. A battery's technical characteristics tend to focus on the power in watts (W) and energy output in watt hours (Wh) it can deliver (Eyer and Corey, 2010).

Battery management systems control charging and discharging of batteries and vary in complexity of operation. Increasingly, systems can be controlled and monitored remotely, and it is hoped current weather forecasts and the behaviour of other batteries will one day be integrated (IRENA, 2015). Two Australian trials for battery application valuation and integration are the Bruny Island (CONSORT, 2017) and the decentralised energy exchange (deX, 2017) marketplace. Both remain in the testing phase.

Control systems are particularly important as they are designed to optimise consumer and electricity system outcomes more generally. Software exists in the Australian market, which optimises the battery system and acts as a communication interface with the grid (Reposit Power, 2017). This allows consumers to sell electricity back to a retailer or aggregator at times of high demand and price. Beyond sophisticated control of single systems, a 'virtual power plant' uses software to aggregate several distributed generation sources, so they improve system reliability by acting as an orchestrated unit (Pandžić et al., 2013). Batteries that are not part of a virtual power plant or lack some sort of virtual control will tend toward being optimised based on the desires of the user.

4.2 Battery applications: opportunities and limitations

Batteries are a multi-purpose technology that has "several distinct, economically relevant applications primarily focused on one or a few sectors" [Battke and Schmidt, (2015), p.336). Different applications produce economic value for specific customers or user groups. There is however an important distinction to be made between applications and benefits, in that an application is a use while a benefit connotes a value (Eyer and Corey, 2010). A recent review investigating batteries found 31 different applications, and the authors suggest further applications. However, value streams are difficult to define due to the way in which different actors enjoy value from different applications (Malhotra et al., 2016).

The applications batteries provide can be divided into two general categories – balancing of supply and demand to balance intermittent renewables, and ancillary services which relate to the stability and security of the system (Moore and Shabani, 2016). Electricity system security consists of a number of characteristics of electricity generation, though it can be defined as "the ability of the power system to tolerate disturbances and maintain electricity supply to consumers" [Finkel et al., (2016), p.50]. Table 1 outlines definitions related to system security.

It has been suggested batteries create four sources of economic value – power quality, power reliability, increased utilisation of existing assets, and arbitrage – the temporal buying and selling of electricity to take advantage of peak pricing (Malhotra et al., 2016). There are, however, a variety of limitations on these applications.

Table 1 Characteristics of electricity system security

Characteristic	*Definition*
Reliability	A measure of the ability of generation and transmission capacity to meet consumer demand.
Frequency	Stable frequency is a measure of the instantaneous balance of power supply and demand.
Physical inertia	Physical inertia from synchronous machines plays an important role in slowing the rate of change of frequency when there is a mismatch between supply and demand, allowing time for frequency control mechanisms to respond.
Voltage	Areas within the network operate at different voltages, ranging from high voltage transmission lines to low voltage distribution networks. Voltage control is important for the proper operation of electrical equipment and to reduce transmission losses. Alternating current (AC) power systems control voltage by managing the production and absorption of reactive power.
Essential security services	Essential security services are synchronous inertia, system strength and voltage control. Synchronous generators provide all these services.
System strength	System strength is defined by how localised sections of the system react in the event of a fault (an abnormal flow of electrical current, such as a short circuit). System strength is usually measured by the available fault current at a given location.

Source: Finkel et al. (2016, pp.50–51)

4.3 Limitations on battery applications and benefits

Eyer and Corey (2010) outline two categories of constraint that can limit the delivery of services from different storage technologies.

1 Technical constraints refer to characteristics that may allow or disallow a particular operation: the difference between transmission and distribution infrastructure upgrade deferral, which may require infrequent discharging, and energy time-shift, which requires frequent charging cycles.

2 Operational constraints involve the potential competing uses of a storage installation – if a battery is being utilised for network upgrade deferral it cannot simultaneously provide backup power for service reliability.

Sue et al. (2014) propose a further institutional constraint:

3 "The rules, processes, and biases which unduly restrict access to multiple applications" [Sue et al., (2014), p.26]. A full institutional analysis is beyond the scope of the paper though certain aspects will be addressed below.

Finally, this paper also suggests a fourth constraint:

4 Spatial constraints that relate to geographical distribution of installations.

A number of these, as highlighted in the literature and identified through interview and submission responses are discussed below. A summary is found in Table 2.

Table 2 Constraints on battery storage applications from literature, interviews and submission responses

	Constraint category	*Issue*	*Impact*
1	Technical	Charging from grid	Emissions increase
2	Operational	Benefit aggregation	Stakeholder conflict
		Battery charging and discharge	Grid issues
3	Spatial	Value creation	Lack of maximum value creation
		Increased network upgrade	Increase cost for networks and subsequently consumers

Source: Compiled by authors

4.3.1 Technical and operational constraints

One method for overcoming the high, though decreasing, costs of batteries (McKinsey, 2017), is to combine applications to maximise value. A battery would supply both energy arbitrage and network services (Stephan et al., 2016). However, this is potentially prevented by the technical and operational constraints outlined above. Battke and Schmidt (2015, p.339) suggest "the combinability of applications is limited by operational, technical, physical and regulatory factors. As a result, most applications are incompatible or only partially combinable."

Additionally, because the values of different applications accrue to different electricity sector actors (consumers, DNSPs, etc.) the same incentives or preferences for particular value streams are not necessarily shared (interview 2) – a consumer installing a battery is more likely to prioritise reducing private costs over possible network upgrade deferral, unless they are properly compensated.[2] Competition between different actors is highlighted by Nykamp et al.'s (2013) finding that peak shaving objectives of distribution companies – a reduction in peak demand leading to reduced need for grid upgrades and/or less centralised generation capacity, conflicted with the motivations of retailers and consumers to prioritise buying and selling of energy. Stakeholder interactions become particularly pertinent given individual batteries are being aggregated by particular actors to bundle benefits (see NER 2.3(a) small generation aggregator). Conflict could arise if an aggregator prompts a large number of batteries to discharge during a peak pricing event, which could cause voltage or frequency fluctuations (Section 4.3.2). One interviewee from a distribution company suggested "[a]s more participants enter the market, such as aggregators and alternative electricity retailers, they will influence charging and discharging regimes based on wholesale electricity prices and their own priorities, which won't necessarily align with the distributors' priorities" (interview 4).

4.3.2 Spatial constraints on battery storage application

Spatial distribution of installations is particularly relevant to the installation of distributed storage. This has several impacts, depending upon the outcomes desired. Recent research has suggested that due to peer and support mechanism factors, 'spatial clustering' of solar PV installations is occurring, which results in high concentrations in certain areas (Dharshing, 2017). Given the co-location of battery storage with solar PV systems, this could also occur with battery installations. CSIRO and ENA (2017, p.40) have claimed "mass scale battery charging profiles could lead to export/import imbalance in distribution networks or new peak demand events, which would drive additional network investment." Additional network investment occurs as a result of batteries responding to time-varying market spot prices, which can cause reverse power flow or increased peak load (Ratnam et al., 2015)

One interviewee suggested batteries were likely to pose an equivalent threat to system security and quality as solar PV (interview 2). However, this overlooks the major difference in the way the two technologies operate and are controlled. Solar PV responds only to changes in solar radiation, which over short periods of time are forecastable (see modelling work of Solcast, 2017). In contrast, batteries are controllable and optimised to a particular set of preferences, and as above, can be discharged at times that may increase system upgrade requirements. This is in direct conflict with the claimed benefits batteries may provide.

Spatial distribution is also important in light of the demand and network characteristics of the NEM. Demand profiles of particular areas vary enormously within regions and across the NEM. This is highlighted by recent mapping that identifies areas of high peak and/or aggregate demand, and the future need for network upgrades (ISF, 2017). If batteries are used for their network upgrade deferral benefits, installations should arguably occur in constrained areas or where upgrades are needed.

Finally, the spatial distribution of installations can have a significant effect on batteries' benefits. Babacan et al. (2016) assert batteries need to be optimally placed in a network for benefits to be maximised. Further, the optimisation depends upon the application desired (voltage control, network upgrade deferral, solar PV integration) (see Motalleb et al., 2016). This spatial requirement would challenge the idea that software or control optimisation can ever provide the ultimate solution if batteries are not optimally placed to begin with.

4.4 Other possible impacts

4.4.1 Emissions increase

The NER provide a high level of end user reliability and quality, so the main value to consumers installing batteries is the opportunity for energy arbitrage and PV self-consumption. Fares and Webber (2017) have shown emissions could in fact increase from inefficient battery charging if this uses grid energy at times of low solar production. Because batteries are largely meant to help emissions mitigation, this would be a significant shortcoming. In Western Australia, where solar concentration in some grids is close to saturation and grid energy is at capacity, installers of batteries are prevented from charging from the grid to ensure system stability (interview 6). Though none of the NEM DNSP interviewees mentioned a need for limiting charging at this point, it will become a consideration in future if previously mentioned forecasts for battery installations are correct.

4.4.2 Triggering penalties for system actors

The NER places responsibility for maintaining system reliability and quality on the AEMO, through a number of requirements for AEMO to maintain frequency and voltage within specific limits. If these limits are exceeded, financial penalties are incurred (AEMC, 2018). If the suggestions of CSIRO and ENA (2017) and Nykamp et al. (2013) are correct, AEMO could face significant cost imposts if concentrated systems are discharged simultaneously in response to regionally determined spot prices. The possible increased need for network upgrades would also harm DNSPs, and consumers more broadly, as the retail price of electricity is likely to increase.

The previous sections have shown batteries could provide a large number of applications and therefore several economic value streams. However, the various constraints on these applications could prove problematic. The main issues identified relate to:

- spatial distribution of installations
- a lack of coordination of systems
- competition between different actors and the desired applications
- possible financial impacts on the actors responsible for maintaining certain characteristics of system security
- a possible increase in emissions.

The following section introduces the ACT's battery support program and then applies a framework of analysis, including these constraints.

5 Analysis of the ACT's NGRP

5.1 The ACT as policy leader

In 2016, increasing the previous target of 90%, the ACT Government legislated a new renewable energy target of 100% by 2020 (EPSDD, 2017a). Though many other Australian states have now increased climate and renewable energy targets, the ACT was the first and most ambitious mover. The government's main policy instrument to reach the 100% target was 'reverse auctions': companies provide the lowest possible monetary bid for a certain amount of the 650 MW of generation capacity (EPSDD, 2017b). Winners then receive feed-in-tariffs for the electricity supplied on a contract for difference basis, in that any shortfall in cost is paid to the generator by the purchaser. If market prices rise above cost of supply, this excess goes to the purchaser and is subsequently passed on to consumers (EPSDD, 2017c).

5.2 The NGRP

The final round of reverse auctions in August, 2016 included a requirement for the two winning proponents to provide $25 million in funding to support the next generation energy storage program (ACT Government, n.d.). Following a successful pilot in 2016, which saw 200 batteries installed in Canberra homes, the government awarded an additional $2 million through a competitive grants process leading to a further 600 installations to be completed by August 2017 (EPSDD, 2017a). Successful proponents of the competitive grants process were then required to provide subsidised battery installations to consumers (EPSDD, 2017a). Grants are paid on the basis of price ($) per kWh of sustained peak output – the peak output sustained for one hour. A maximum of 30 kW can be claimed per 'eligible energy storage system' (ACT Government, 2016a). In total, the program is expected to result in the installation of some 5,000 batteries with a total capacity of 36 MW (EPSDD, 2017a). The government's calculations suggest the 36 MW will save between $61 and $221 million in transmission and distribution investment (ACT Government, 2016b).

A number of conditions are also placed on installers and consumers. To future-proof installations and allow for higher levels of technological integration with the NEM, installed batteries must have a sophisticated control system (Ward, 2016), often termed 'smart' batteries. Data collection requirements are placed on consumers whereby parameters of the battery system are collected at five minute intervals and stored centrally (ACT Government, 2016a). Companies receiving grants under the program must also open an office in Canberra to accelerate "the development of a vibrant export-oriented energy storage industry for Canberra" (EPSDD, 2017a). Finally, the program will not subsidise a battery being added to a preexisting solar system: a consumer may only add more solar PV capacity and a battery to an existing system. This is likely done to avoid interactions with the ACT's Feed in Tariff scheme, which is closed to new entrants though payments for generation continue for existing recipients. As a result, about 16% of the installations thus far have been additions to existing systems, the remainder being new systems (Ward, 2016).

In summary, the NGRP aims to:

- support the installation of 5,000 batteries with a total installed capacity of 36 MW, saving $61–$220 million in network costs (government's calculation)
- promote an export-oriented energy industry in the ACT
- collect data to facilitate further research on battery integration.

The ACT Government further claims that

> "...to address climate change, over the coming decade other jurisdictions will need to follow the ACT's leadership in decarbonising the nation's electricity supplies. To achieve this across Australia, the intermittency of solar and wind energy needs to be addressed. Emerging, and increasingly cost-effective energy storage will help." (EPSDD, 2017a)

This would suggest the government believes other jurisdictions will also promote storage technologies. With this in mind, we develop an analysis framework.

5.3 *A framework for analysis*

To perform the policy analysis, an evaluation framework is adapted from Dovers and Hussey (2013, pp.134–135), who suggest 14 criteria under the broad categories of effectiveness and implementability with which policy makers can select instruments. As many of the categories are specifically related to choosing rather than assessing instruments, a truncated collection is used here. These have been selected to best assess the current case study.

North (1990) suggests society is shaped by constraints on individual's behaviour, and formal and informal rules, known as institutions, structure all social, economic, and political behaviour. Dovers and Hussey (2013, p.14) extend focus in public policy processes from single institutions to the *institutional system*: "complex, interactive systems of many institutions, organisations, and actors." To understand social and policy change, the interdependence in such systems needs to be understood.

To determine whether the policy has met its goals, the analysis needs to take into consideration the limitations on batteries discussed above, as well as the possible impacts on the institutional system. Table 3 summarises the categories used. Similar categories have been combined and others have been rearranged in their order to reflect the use of the framework in analysing, rather than selecting, a policy instrument. Category 1(d) has been changed to reflect the impacts that could occur in the institutional system.

Table 3 Criteria for policy analysis

Criteria			*Explanation*
1	Effectiveness criteria		Determining the likelihood of the instrument achieving goals in the absence of constraints
	a	Dependability	Will the instrument be more likely than other options to achieve the outcomes required?
	b	Flexibility in space and time	Can the rate or style of application of the instrument be varied depending on context, or as the situation or status of knowledge changes
	c	Efficiency, in terms of achieving outcomes	Will the instrument achieve the desired goals in an efficient manner, i.e., more unit of outcome per of investment?
	d	Complexity and cross-sectoral influence	Can the instrument be well-targeted? With either fewer or identifiable/controllable impacts on other policy, social goals, or the institutional system more broadly?
2	Implementation criteria		Determining the likelihood of the instrument being successfully advocated and implemented
	a	Equity implications	Who bears the costs of the application and impact of the instrument, and is this equitable or fair (includes the polluter pays principle)?
	b	Cost	Is the gross cost (especially financial, but also human, organisational, and informational resources) bearable in a practical sense? (This is an additional consideration to what instrument is the most efficient.)
	c	Monitoring requirements	Can the uptake of the instrument and/or its impact or effectiveness be monitored
	d	Constraints	Do constraints on battery applications result in optimal outcomes?

Source: Adapted from Dovers and Hussey, (2013, pp.134–135)

5.4 Policy analysis

5.4.1 Cost and efficiency in terms of achieving outcomes

The NGRP uses an innovative funding mechanism that avoids any government budgetary issues: by sourcing funding from winners of reverse auctions, as well as much of the capital cost being borne by consumers, the costs to government, other than administrative costs, are avoided. This is a major benefit of the program. However, recent figures show only 290 battery systems have been installed (ACT Government, 2017), yet the installation target for 2020 is 5,000 systems. This suggests the subsidy may not be high enough to incentivise consumers, or interactions with other policy mechanisms like feed-in tariffs, are hindering installations. The stated claim of the program is that \$61–\$221 million in network benefit will result. This benefit is based on a reduction in peak demand resulting in a deferral or removal of transmission and distribution network upgrade costs (Sue et al., 2014). Assuming \$25 million in funding will result in the range above, the NGRP represents a very high return on investment. There are, however, three main issues that may hinder this value being realised.

The first relates to the operation of batteries and the values different actors place on different applications. Batteries' inability to deliver multiple applications simultaneously results in a conflict between applications. In this case peak shaving would conflict with a consumer selling onto the grid to enjoy the high spot prices possible during peak demand times. Consumers are unlikely then to choose to use electricity stored in their battery for home use.

The second involves concurrent discharge of batteries. A total reduction in peak demand of 36 MW would require every individual battery to be discharged concurrently (Franklin et al., 2016). Hau and Lim (2016) have suggested a novel control method to maximise peak demand reduction, but it would require each of the 5,000 batteries to be externally orchestrated or coordinated, or be optimised for peak demand reduction.

Finally, the calculation of the savings from peak demand reduction is problematic. Using CME's (2012) calculation, ACT Government policy-makers found demand response induced reductions in peak demand could result in savings of \$1.7–\$6.1 million per MW of reduction. The lower end of this range is higher than previous calculations for the NEM, which estimated \$0.63–\$1.63 million per MWh (Sue et al., 2014). The range of savings would be \$23.3–\$95.6 million, resulting in a much lower cost to benefit ratio. This does, however, ignore that other benefits are possible. One caveat is that the two estimates use different units – CME estimate load reduction (MW), whereas Sue et al. (2014) estimate consumption reduction (MWh).

5.4.2 Complexity and cross-sectoral influence

Consumer subsidies for technology promotion are a common tool and the basic principles that structure them are uncomplicated: demand is created for a technology in an immature market (Grubb et al., 2014). However, the policy analysis highlights that the complexity of battery operation, and the system into which they are installed, raises concerns once again around the use of an untargeted subsidy. This is particularly the case with the NGRP as there is no way of optimising outcomes by directing installations. Since several applications need specific spatial distribution to produce optimal outcomes, the policy is unlikely to result in the most value possible, or it could potentially even challenge the stated goals in terms of peak demand reduction.

Another aspect of this category relates to the interaction with other policy instruments. The NGRP has a specific rule of only subsidising new systems, or retrofits, to avoid conflicts with the previous feed-in tariff program. However, this has a double effect, whereby only new-build solar connected to a battery will be well integrated into the system, so the application of integrating current renewable capacity may be hindered by this decision. Until such a time as prices decrease to the extent where current solar PV consumers install batteries, much of the solar capacity in the ACT will remain without back up.

5.4.3 Equity implications

One of the most common criticisms of consumer subsidies surrounds equity and the possible concerns that occur due to particular individuals enjoying subsidies and others not (see Freiburg, 2010). The program as it currently stands does not feature any mechanism for targeting low income areas or households, resulting in less than equitable outcomes.

5.4.4 Monitoring requirements

As outlined above, battery systems installed under the program need to have a sophisticated control system, and send data to a central register at five minute intervals. Monitoring of the behaviour and performance of individual batteries will occur and will likely lead to positive outcomes in the research sector when the data is made available. Less clear is whether the program's goals, in particular the 36 MW reductions in peak demand, are being monitored. Whether monitoring is linked back to the flexibility of the instrument is also questionable.

5.4.5 Dependability

It is currently unclear whether the current policy instrument can be depended on to meet all goals of the program. This relates chiefly to the inclusion of system security goals. If the program was limited to increasing installation of batteries, promoting an industry in the ACT, and creating data for research then it would likely be a success. However, the complexities outlined in the previous section cast doubt on whether or not the peak demand reductions will occur. There are also possible further negative impacts on other system actors as a result of the discharging of batteries in an uncontrolled manner or when responding to regional price signals. A possible emissions increase is also particularly concerning.

5.4.6 Flexibility in space and time

It is unknown whether the design of the program can or will be augmented in line with developments in knowledge or understanding. This is perhaps the category of highest importance as we have shown above how the constraints around battery applications, and the various impacts on actors and organisations, result in a number of concerns. It is also the most contentious in light of the difficulties that exist around targeting subsidies to particular consumers. Though the subsidies are generous, the program requires a large capital investment by consumers. This is both a positive and a negative aspect of such an instrument. Targeting of investment to promote a particular outcome, reduced network investment cost, will require a willing consumer to be located in an area of need. Ausgrid (2017, p.12) suggested "the widespread installation of batteries, at unconstrained network locations will not deliver a network capital deferment benefit." This casts doubt on the network upgrade deferral claims of the program.

6 Discussions

The analysis above has shown it is questionable whether the program will meet its stated goals. The poor likelihood of peak demand reduction occurs because there is currently no method of targeting installations to the most beneficial areas, combined with a lack of coordination or orchestration between systems. The slow rate of take-up by consumers and possible emissions increases are also sub-optimal. Finally, by subsidising only those consumers voluntarily installing batteries, the program leads to inequitable outcomes for consumers lacking capital to enjoy the subsidy. The program does however use a novel funding mechanism and one which would be promising for future renewable energy developments. The requirement for 'smart batteries' to be installed, and the data created are positive outcomes.

The analysis does however provide an opportunity to learn from the policy's shortcomings. To distil those lessons, we have sought to identify policy learning across four domains using the following typology developed by Dovers and Hussey (2013):

- Instrumental: design of better policy instruments.
- Governmental: improved outcomes for administrative structures and bureaucratic processes.
- Social: change in the construction of policies and goals that flow into the broader policy community resulting in reframing of problems and goals.
- Political: leading to change in or defence of current agendas by actors that may not have previously been involved – the result being an expanded policy network (stakeholders and actors involved in the policy making process).

Perhaps the starkest shortcoming of consumer subsidies is the inability for policy makers to direct those subsidies to where consumer cost-sharing is desired. If installations occur at random, the possible benefits from targeting areas of high peak demand or those in need of network upgrades could be fewer than would be possible if installations could be more 'spatially directed'. However, this represents perhaps the most significant challenge for policy making in this space – there is a considerable trade-off accepted when providing consumer subsidies. Positively, a major portion of capital costs are borne by the consumers installing systems, and thus the cost/benefit ratio for the implementing jurisdiction is high. This is compounded in the ACT because funding was obtained from winners of reverse auctions and costs are reduced further still. This could entail a condemnation of governments taking a larger role in the augmentation of the electricity sector. It instead highlights that consumer subsidies of the kind analysed here may no longer be capable of promoting the change in markets needed to meet the current security requirements of electricity sectors. Therefore, policy instrument design needs to change.

Subsidies provide opportunities for leveraging consumers. The ACT has capitalised on this by including requirements for consumers to provide data. We suggest this could be extended to limiting operations to avoid emissions increase or allowing orchestration or coordination by actors such as the recently suggested distribution system operator (DSO). DSOs would then play a much greater role in distribution system security and performance (see ENA, 2016). This already occurs in Germany and California (Moore and Shabani, 2016), and considering the possible *increase* in network upgrades would ultimately increase the cost of the system for all consumers, batteries need to be carefully monitored and coordinated in situations that could result in system security issues. Considering the value consumers enjoy from subsidised batteries, it is reasonable to expect those same consumers to have some limits or expectations associated with that subsidy. This is particularly relevant in light of the benefits consumers enjoy in comparison with the questionable benefits to the grid that batteries provide if they are installed randomly.

Another option for improving outcomes is an expansion of the policy network to include DNSPs or other stakeholders. More effective placement of installations could result, by various means. First, DNSPs are already implementing programs that address demand reductions using batteries and other storage technologies, so they know about grid upgrade requirements, and could be leveraged to increase installations in areas of need (ISF, 2017). Second, DNSP program funding could be combined with government subsidies to incentivise customers in areas of need, who would not otherwise have the capital. Cooperation between actors has been suggested in the recent review into Australian electricity security, which suggests the Council of Australian Governments Energy Council should consult with state, territory and local governments to improve outcomes for distributed generation and storage (Finkel et al., 2016).

7 Conclusions and policy recommendations

This paper, using the ACT's Next Generation Renewable Energy Program as a case study, has explored the efficacy of consumer subsidies for the deployment of batteries. The program has several benefits, including the enhancement of the battery market in the ACT and Australia, and creating a large, growing body of data that can improve battery system operation and grid integration. However, in the context of the Australian grid, these benefits could in the future be outweighed by negative impacts from concentrated clusters of installations and the un-orchestrated functioning of batteries. No doubt, the difficulties faced by policy makers in promoting renewable energy are many, and there is an inevitable trade-off between capacity additions and benefit when subsidising consumers, and policy can never be perfect, but it can be improved. Our purpose here was to analyse where those improvements could be made and as the ACT's program is the first of its kind in Australia, it has proved to be a very valuable test case to improve market and system conditions for batteries.

Several significant policy recommendations can be drawn, categorised by the four types of policy learning above:

1 Instrumental: Consumer subsidies for batteries should be targeted and coordinated so as to avoid system security issues, which can be best achieved through the implementation of virtual power plants.

2 Governmental: In designing policy instruments, governments need to account for the changing context, needs and complexity of the electricity sector, which means engaging power systems engineers in the design of the policy.

3 Social: Augmenting markets should not be the dominant paradigm in addressing the security or emissions of the electricity sector. Policy makers need to reframe problems toward addressing multiple issues simultaneously, including social-equity considerations, which means involving a broader range of stakeholders.

4 Political: Decision making needs to include the actors affected by policy actions, but also those with better knowledge of the problems being addressed, including market and/or distribution network operators. Expanding policy networks and including actors already addressing the same issues is likely to improve outcomes.

Moreover, our analysis suggests the theory of 'technology neutrality' and the avoidance of 'picking winners' is outdated. Given governments are promoting specific technologies, rather than neutrality, stronger emphasis needs to be given to technology integration by policy makers and there is precedent in the literature. Most notably, the way technology interacts with the electricity system, as well as how it is acted on by, and impacts upon, the different actors within the system, matters. This is particularly the case in behind-the-meter batteries with mixed value streams, and the different priorities various actors place on those values.

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Notes

1 This is made possible by envisioning the grid as a hierarchical structure – transmission above distribution above end consumers – and if batteries are installed at the lowest level, the possible applications flow upward. If they are installed above this level, the lower applications are removed from the picture.

2 Research into the software optimisation of different value streams is currently being undertaken by the CONSORT group and the Bruny Island Battery Trial. It is unknown at this time whether these issues have been overcome.

Appendix

Table A1 Interviewee details

Coded interview number	*Date of interview*	*Background*
1	11/11/2016	Academic/consultant
2	16/11/2016	Commissioner – regulatory body
3	14/11/2016	Consultant – various roles in sector
4	9/12/2016	Senior frameworks and regulation specialist, distribution network service provider (DNSP)
5	9/12/2016	Team leader, market strategy and compliance – DNSP
6	25/1/2017	Anonymous – DNSP
7	25/1/2017	Strategic asset engineer – DNSP
8	2/2/2017	Technical visionary – DNSP
9	24/1/2017	Director – battery and solar PV installer
10	30/1/2017	Energy efficiency and renewable energy program manager – electricity retailer
11	14/11/2017	Consultant, prior industry participant
12	11/1/2017	Policy adviser – industry body
13	Multiple interactions	Anonymous state government official

Table A2 Australian government review submissions

Review	*Timeline*
Senate select committee on the resilience of electricity infrastructure in a warming climate	Created 12 October 2016 – submissions closed 3 February 2017
Standing committee on the environment and energy – inquiry into modernising Australia's electricity grid	Referred 27 February 2017
Council of Australian governments energy council independent review into the future security of the national electricity market	Launched 7 October 2016
Council of Australian governments energy council energy market transformation public consultation: battery storage; stand-alone systems; and consumer protections consultation	August–October 2016