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Energy policy regime change and advanced energy storage: A comparative analysis

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ABSTRACT

This paper employs a multi-level perspective approach to examine the development of policy frameworks around energy storage technologies. The paper focuses on the emerging encounter between existing social, technological, regulatory, and institutional regimes in electricity systems in Canada, the United States, and the European Union, and the niche level development of advanced energy storage technologies. The structure of electricity systems as vertically integrated monopolies, or liberalized or semi-liberalized markets, is found to provide different mechanisms for niche formation and niche to regime transition pathways for energy storage. Significant trade-offs among these pathways are identified. The overwhelming bulk of energy storage policy development activities are found to be taking place in liberalized or semi-liberalized markets. The key policy debates in these markets relate to technical barriers to market participation by storage resources, the ability of storage technologies to offer multiple services in markets simultaneously, the lack of clear rules related to the aggregation of distributed energy resources, and issues related to the meaning of "technological neutrality" in liberalized market systems. Landscape conditions, particularly jurisdictional commitments to pursue deliberate reconfigurations of their energy systems towards low-carbon energy sources, emerge as the most significant factor in the implementation of policy reforms in these areas.

1. Introduction

The large-scale electrification of transportation and other energy-based services are widely seen as important elements of efforts to reduce greenhouse gas (GHG) emissions from the combustion of fossil fuels (Bataille et al., 2015; Trottier Energy Futures Project, 2016). Major reductions in GHG emissions will be essential to meeting the requirements of the 2015 Paris climate change agreement.

The focus on electrification has emerged at a time of three major technological developments in the electricity industry. The past decade has seen declines in the costs of renewable energy technologies, particularly wind and photovoltaic (PV) and thermal solar systems, while the performance of these technologies has been improving (International Energy Agency, 2015; International Renewable Energy Agency, 2017). Secondly, the emergence of smart electricity grids, through the digitization of grid communications and control systems, has the potential to lead to more adaptive and resilient electricity systems. Such systems will be better able to coordinate intermittent, smaller-scale, and geographically distributed energy sources into reliable resources (Knight and Brownell, 2010; International Energy Agency, 2011; Navigant Research, 2012).

Finally, major developments have been occurring around energy storage technologies. Conventional energy storage technologies, including pumped or reservoir-based hydro-electric facilities, and lead-acid batteries, have existed for more than a century. The past decade has been marked by growing interest in both conventional and advanced energy storage technologies. Attention has been given to new mechanical systems based on compressed air and flywheels, advanced batteries (e.g. flow, lithium ion, NaS), and thermal and gas (i.e. hydrogen and methane) based storage technologies. These technologies are summarized in Fig. 1. They have become the focus of substantial government and private sector investments in technology development. These investments are expected to result in significant improvements in cost and performance (World Energy Council, 2016).

In addition to their potential role in managing the growing presence in electricity systems of intermittent renewable energy sources like wind and solar energy, energy storage technologies could also provide grid services as operating and ramping reserves, demand response resources, and ancillary service providers for frequency response and regulation. Storage resources may offer means of deferring transmission and distribution upgrades as well. Finally, storage technologies may facilitate the integration of distributed energy sources into grid-scale

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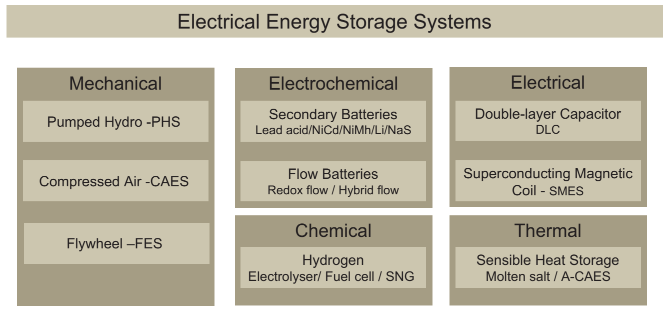

Fig. 1. Energy storage technologies classified based on their energy form. Figure adapted from (IEC, 2011).

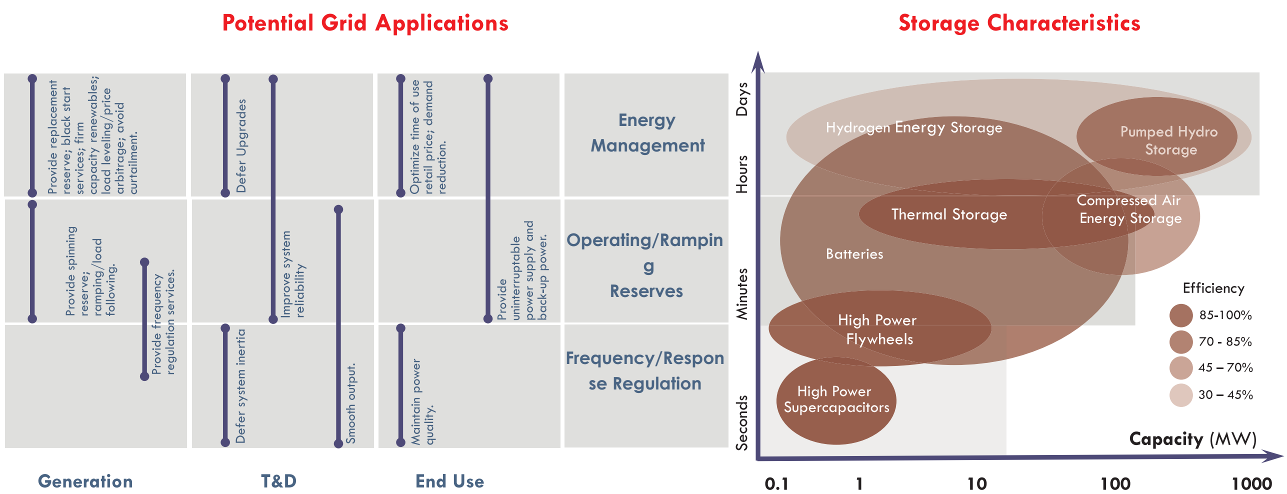

Fig. 2. Characteristics of energy storage technologies and the potential applications they can provide on the electric grid, adapted from (NREL, 2016).

resources. These applications are summarized in Fig. 2.

Taken together, the developments in renewable energy technologies, smart grids, and energy storage are seen to offer the potential to make energy systems more environmentally and economically sustainable than is currently the case. Specifically, they are expected to be able to:

- make better use of renewable low-carbon energy sources;
- be more reliable and resilient through expanded roles for distributed and technologically diverse energy sources;
- have improved ability to adapt to changing circumstances and needs; and
- have the potential to offer more control to consumers (Pepermans et al., 2005; US Department of Energy, 2007; Marsden, 2011).

This paper is focussed specifically on the new energy storage technology dimensions of these developments. Employing a multi-level perspective (MLP) approach (Geels et al., 2016), it examines the development of new energy storage technologies as an encounter between existing social, technological, regulatory, and institutional regimes in electricity systems in Canada, the United States, and European Union, and the niche level development of new energy storage technologies. The outcomes of these encounters are unknown at this stage. It is uncertain whether new energy storage technologies will remain relatively niche level developments, or if they will contribute to the transformation or even reconfiguration or realignment of energy systems in the direction of larger-scale deployment of intermittent renewable energy sources and significantly expanded roles for distributed generation.

Energy storage is not a substitute for existing energy generation technologies per se. Rather it is a potentially enabling technology for other new technologies, such as large-scale employment of distributed generation, and the expansion of behind-the-meter activity, which may disrupt conventional utility and generation models. These possibilities may prompt resistance from established actors within current regimes for these reasons. This may be especially the case in the current context of growing concerns about the stranding of conventional centralized generating, transmission and distribution assets in the reconfiguration or realignment of electricity systems (The Economist, 2013, 2017).

2. Methods and background materials

2.1. Theoretical approach

The MLP literature on socio-technical transitions is potentially helpful in understanding the processes of the development and adoption of new technologies and their impacts on existing institutional, regulatory, and technological systems. The MLP literature links three scales of analysis (Geels and Schot, 2007, 2010). The "socio-technical landscape" is defined as the exogenous environment of air quality, resource prices, lifestyles, and political, cultural and economic structures. The "socio-technical regime" consists of infrastructures, regulations, markets, and established technical knowledge. "Socio-technical niches" are smaller scale focal points of activity. The regimes are nested within and structured by landscapes, and niches are nested within and structured by regimes. The niche level is understood to be the key center for innovation in technology, practice, and policy. The MLP literature focuses on the transition processes that occur when landscape pressures on the regime create windows of opportunity for the adoption of niche-level innovations.

Three major variables are generally identified in socio-technical transitions (Geels, 2004). These are actors and social groups; rules and institutions; and changes in technologies and wider socio-technical and economic systems. Within the category of rules and institutions, Geels (2004) includes normative and cognitive rules as well as formal legislative, regulatory and policy regimes. Other authors have treated underlying ideas, norms and assumptions about energy systems, sustainability and the role of the state and markets in energy policy formulation and transitions as a separate category of variable (Doern and Toner, 1985; Dryzek, 2013; Winfield and Dolter, 2014).

Transitions are seen to follow one of four potential pathways (Geels et al., 2016). In the case of *technological substitutions*, existing regimes are overthrown by the deliberate introduction of new actors and technologies, through initiatives like Feed-in-Tariff (FIT) programs for renewable energy sources. In a *transformation,* incumbent regimes are gradually reoriented through adjustments by existing actors in the context of changing landscape conditions. The incorporation of smart grid technologies into electricity transmission and distribution systems by existing grid operators is an example of such a transition (International Energy Agency, 2011). In *reconfigurations*, the emergence of new technologies leads to more structural adjustments in regimes as a result of landscape pressures. The widespread replacement of coal-fired generation by combined cycle natural gas-fired technologies as intermediate and seasonal supply in North American electricity systems, facilitated in part by the availability of new low-cost natural gas supplies and the scalability and operational flexibility of gas-fired generation (Maher and Mikulska, 2016), illustrates such an outcome. *De-alignments and re-alignments*, where existing regimes are disrupted by external developments, and new niche level innovations and actors emerge and reconfigure the regime, are rare. The emerging convergence of smart grids, and the improving economic and technological performance of renewable energy sources and energy storage, around the expansion of distributed generation and behind-the-meter activities, may indicate the potential direction for future re-alignments in the electricity sector (Knight and Brownell, 2010).

As new technologies may not fit well with existing socio-technical regimes, niches are understood as spaces where developing technologies are protected from normal selection pressures embodied in dominant regimes (Smith and Raven, 2012). Niches provide a means of shielding, nurturing, eventually empowering new technologies. Shielding involves holding off selection pressures like industry structures, established technologies, infrastructures and knowledge bases, markets structures and dominant practices, existing public policies, and the political power of established actors. Nurturing entails supporting the development of new innovations within shielded spaces through the development of shared, positive expectations, social learning and actor network and constituency building. Empowering can involve processes that make niche innovations competitive within existing external selection environments. Alternatively, empowering can mean changing the existing selection environment in directions favourable to new innovations (Smith and Raven, 2012).

Much of the literature on socio-technical niches take their existence for granted (Smith and Raven, 2012; Kern et al., 2013). Niches may be protected from selection pressures of the regime either by design or by circumstance (Haley, 2015), although the specific understandings of their creation are less well developed (Smith and Raven, 2012). Where such research exists, it has tended to focus on the creation of niches through deliberate policy interventions, and less on other, more circumstantial, mechanisms through which they may emerge (Smith et al., 2010; Owaineh et al., 2015). The energy storage case offers examples of deliberate niche creation, but also opportunities to examine situations where niches may be more emergent, particularly in liberalized market electricity systems.

The empowerment stage of niche to regime transformations is generally considered the least developed aspect of the niche literature (Raven et al., 2016), even though it is the key location for niche to regime transitions. Energy storage, which is at a niche to regime cusp, provides opportunities to study this stage in monopoly utility and liberalized market electricity systems.

2.2. Methodology

The principal methodology for the study is a comparative public policy approach (Touhy, 1996). Specifically, energy storage policy development was examined in Canada (federal level and selected provinces including Ontario, Alberta, Québec, Manitoba, and British Columbia), the United States (federal level (Federal Energy Regulatory Commission (FERC)) and selected states, including California, New York, Hawaii, and Massachusetts), and member states of the European Union (principally Germany, the United Kingdom and Denmark). The jurisdictions reviewed were identified through a preliminary scan and then follow-up inquiries, as being active in energy storage policy or technology development.

The existing secondary literature on public policies around new energy storage technologies is very limited. As a result, the findings are principally based on the review of primary documents from governments, grid operators, regulators, and energy storage developers. The review of primary and secondary literatures was supplemented by attendance at energy storage technology and policy development conferences in North America and Europe. Follow-up inquiries with conference presenters were conducted as needed.

A review of each jurisdiction identified as a location for significant activity around energy storage development was conducted in terms of the following factors:

- articulated policies and goals around energy storage;
- key institutional and societal actors around energy storage;
- electricity system structure (e.g. liberalized or semi-liberalized markets vs. monopoly utility);
- specific policy initiatives intended to facilitate energy storage technology development (i.e. niche creation); and
- initiatives intended to facilitate commercial or grid-scale employment of energy storage technologies (i.e. niche to regime transitions).

In the following sections, the landscape-level drivers of a potential niche to regime transition for energy storage technologies are outlined, and the differences in transition pathways between monopoly utility and liberalized electricity markets systems are examined. The key barriers found across multiple jurisdictions in niche to regime transitions for energy storage are identified, and potential future policy directions discussed.

2.3. Landscape-level conditions and potential drivers of niche to regime transitions for advanced energy storage technologies

In an MLP context, the current status of advanced energy storage technologies is largely that of niche-level technological developments in the form of pilot projects, or relatively marginal operational roles in electricity systems, such as contributions to some categories of ancillary (i.e. voltage control and frequency regulation) or demand response services. A range of landscape-level developments are creating the potential for a greatly expanded role for energy storage technologies in electricity systems, with the potential to propel energy storage technologies from the niche to regime levels. These developments are examined within the four categories of key variables in socio-technical transitions identified earlier of rules and institutions; technological developments and changes in wider socio-economic structures; actors and social groups; and shifts in energy system discourses. The major developments are summarized as follows.

2.3.1. Legislation, policy, and institutional structures

The landscape with respect to energy storage is defined by two major developments of the past two decades. The first has been pursuit by governments of a variety of strategies intended to prompt the large-scale development of renewable energy sources, such as FIT programs, and renewables obligations and portfolio standards (World Energy Council, 2016; Fouquet, 2013; National Renewable Energy Laboratory, 2015). These initiatives have been driven by a combination of falling costs and improved technical performance for renewables, climate change policies focussed on de-carbonizing energy systems, and the high costs, technological challenges, and accident risks around nuclear energy (Jegen, 2014; Hand et al., 2012).

The second development has been the movement, beginning in the 1990s, of jurisdictions in North America and Western Europe away from monopoly or regulated utility models towards liberalized market models for their electricity systems (International Energy Agency, 2005). In monopoly systems a single vertically integrated entity provides generation, transmission and distribution services. In liberalized systems (sometimes referred to as "organized" markets) in contrast, electricity generation and related services are provided through a market, supported by independent market and transmission grid operators, into which third parties can bid their services. Electricity prices are set through the bidding process, rather than by a regulatory body overseeing a monopoly utility (Dewees, 2005). As such, liberalized markets are theoretically more open to new entrants than non-liberalized systems dominated by monopoly utilities.

Liberalized markets have been created principally for electricity generation and supply, although in some jurisdictions, markets have been established for other electricity system services as well, such as capacity (i.e. the availability of supply when needed immediately) ancillary services or demand response or conservation and demand management activities (Examples in (Federal Energy Regulatory Commission, 2016) and (The Federal Ministry for Economic Affairs and Energy, 2015)). Liberalized systems are also expected to be neutral in terms of the technologies included in their bidding processes (Dewees, 2005). Examples of liberalized market systems include FERC regulated interstate markets, like the Pennsylvania New Jersey Maryland (PJM) Interconnection LLC and the Midcontinent Independent System Operator (MISO), and some individual state markets, like California and New York, in the United States. Germany, Denmark, the United Kingdom, and the Canadian provinces of Ontario and Alberta, also operate under liberalized market structures. However, in some cases, like Ontario, liberalization has only been partial, and the resulting systems incorporate mixtures of market, planning and politically directed elements (Winfield, 2016).

These developments have major implications for the development of new technologies and their pathways from niches to incorporation into regimes. In MLP terms, monopoly utilities and liberalized markets are effectively different models for creating niches for technology development. The monopoly model largely relies on deliberate decisions by the monopoly utility to create, shield and nurture niches from regime level selective pressures until the targeted technology is developed and ready for deployment or commercialization. The liberalized market model, in contrast, relies principally on the *de facto* creation of multiple niches by private investors and technology developers, where they see opportunities for new innovations to provide services on a for-profit basis. Governments may also make specific policy interventions to create niches in both monopoly or liberalized market systems.

Liberalized and monopoly utility models embed different pathways for niche to regime transitions as well. Under the liberalized market model, the expectation is that the market will determine whether a technology or service moves from the niche to regime levels. Such outcomes would be indicated by successful commercialization resulting, for example, in sustained revenue streams for services off the rate base. Given the diverse range of services energy storage technologies can provide, commercialization may take the form of the acceptance and rate base funding of a series of different applications, as opposed to one dominant function. Market operators and regulators in liberalized markets are intended to play a facilitative role around market participation by actors and new technologies, rather than acting as gatekeepers in favour of established technologies and participants.

Under the utility shielded niche model, in contrast, the niche to regime transition is mainly in the hands of the monopoly utility. It can choose to initiate, support or terminate the development of a niche anytime it chooses. Such decisions may be functions of many factors – determinations of the usefulness of the technology to the utility itself (a *transformation*), preferences for existing technologies, a desire to maintain existing business models and avoid the risks of an unwanted *reconfiguration* or *de-alignment/realignment*, and politically influenced economic development considerations.

2.3.2. Technological developments and changes in socio-economic structures

The large-scale deployment of intermittent renewable technologies, such as wind and solar PV, is expected to continue to accelerate (International Energy Agency, 2015). The role of these technologies is likely to be to be reinforced by increased demand for low-carbon electricity as transportation and other energy based services are electrified in response to commitments to reduce GHG emissions (Bataille et al., 2015; Trottier Energy Futures Project, 2016). These developments have the potential to require substantial balancing resources to manage the intermittency of these technologies, as well as increased requirements for ancillary services such as voltage control and frequency regulation. The storage requirements needed to balance intermittent renewables in Germany, for example, are estimated to reach 3.5 TWh by 2025 and 40 TWh by 2040 (Rothacher, 2012).

In addition to requiring major expansions in the supply of high performance vehicle batteries, the large-scale electrification of transport will also change electricity consumption patterns, potentially presenting significant challenges at the distribution level in terms of charging load management. Storage resources may play a substantial role in managing these challenges (Zhang et al., 2017). In the longer-term, the growing prevalence of electric vehicles (EVs) may make large supplies of high-performance second-use batteries, which are potentially still useful in electricity grid applications, available at low cost (Jiao and Evans, 2016). Finally, rapid developments are taking place in energy storage technologies themselves, with expectations of continued improvements in performance and decreases in costs (World Energy Council, 2016).

2.3.3. Actors and social groups

Transition pathways can be shaped by struggles among interests (Rosenbloom and Meadowcroft, 2014). The capacity of supporters of new technologies to undertake socio-political advocacy work is, therefore, an important factor in the outcome of niche to regime transitions (Raven et al., 2016). The past five years have seen the emergence and maturation of an interest community around energy storage. Energy storage industry associations have been established in Canada and the United States, such as Energy Storage Canada, and the Energy Storage Association in the United States, respectively. At the subnational level, energy storage associations have formed advocacy coalitions/alliances with governments, utilities, and other non-state actors. Examples include the Alberta Storage Alliance, the Massachusetts Energy Storage Initiative, and the New York (state) Battery and Energy Storage Technology Consortium. Similar developments have been occurring in the European Union, with the emergence of the European Association for Storage of Energy and the Association of European Manufacturers of Automotive, Industrial and Energy Storage Batteries.

2.3.4. Energy discourses

These developments have occurred in the context of wider shifts in policy discourses regarding the structure of energy systems, especially among Organization for Economic Develop and Cooperation (OECD) countries. Energy policy discourses, particularly around electricity, have shifted from a focus on the development of large non-renewable generation (e.g. nuclear, coal, and natural gas) towards renewable generation technology based systems. These shifts have driven by a combination of concerns over climate change and other environmental impacts associated with non-renewable electricity sources, the geopolitical risks associated with fossil fuel supply chains and nuclear energy; and the cost, legacy and catastrophic accident risks associated with nuclear power (Jegen, 2014; Hand et al., 2012).

There has been a parallel shift in focus from centralized power systems towards more distributed systems. These are seen to be potentially more resilient and adaptive, and more amenable to local control. The development of renewable energy sources, along with smart grids and new energy storage technologies are seen to carry the potential for the development of new industries and services, and form part of the foundation for an ecological modernist vision for economic, social and environmental transitions (Dryzek, 2013; Winfield and Dolter, 2014). At the same time, there are growing concerns over how transmission and distribution infrastructure will be maintained as the traditional rate bases of utilities, rooted in the consumption of electricity from the grid, may be eroded by distributed generation and behind-the-meter activities (Navigant Research, 2012, 2017).

3. Results

3.1. The state of energy storage policy development

The state of energy storage policy development among the jurisdictions studied is summarized in Table 1 below.

3.2. Moving from niche to regime?

The changes in landscape conditions outlined in Section 2.3, including the need to integrate a growing portion of intermittent renewable energy sources into electricity systems, the maturation of the interest community around energy storage, and expanding interest in distributed generation, have created the conditions for a potential shift from niche level developments and deployment of energy storage technologies in the direction of deeper integration into electricity regimes.

These landscape-level developments have so far prompted investments in technology development and other forms of what can be seen as niche creation around energy storage by governments and some utilities. These have taken the form of one-off pilots/demonstration projects like Ontario distribution utility Alectra's PowerHouse project (Alectra Utilities, 2017) – a local energy network aggregating household level renewable energy generation and storage resources, the establishment of developmental or special markets (New York) and mandated procurements such as those in California and Ontario. New storage technologies are generally not being funded as regular services off the electricity rate bases, with the implication of acceptance as part of the regime. The exceptions tend to be relatively marginal functions, like ancillary services, deferrals of transmission and distribution system upgrades, and certain types of demand response services (Federal Energy Regulatory Commission, 2016; The Independent Electricity System Operator, 2016).

The movement of energy storage technologies from these niche level functions towards transformations or reconfigurations of the socio-technical regime is at this stage uncertain, with the implication that the potential contributions of storage technologies to energy systems may not be fully developed (Federal Energy Regulatory Commission, 2016). Private capital is increasingly interested in storage technology development and commercial scale investments, but is waiting for regulatory and policy frameworks which clarify how the services storage can provide will be remunerated through the energy services rate base or firm long-term contracts. This view has been consistently reflected in comments from venture capital providers at energy storage conferences in Canada (NRC 2016 (National Research Council Canada, 2016a), Panel 4 – "Follow the Money"), the United States (ESA 2017 (Energy Storage Association, 2017), including comments by FERC Chair Norman Bay) and Europe (IRES 2017 (IRES, 2017), Panel 3 – "Business and Finance").

3.3. Energy storage development strategies

Several of the jurisdictions studied have published energy storage development strategies or roadmaps over the past three years. These include California (California Independent System Operator, 2014), Massachusetts (Massachusetts Energy and Environmental Affairs, 2015), Germany (Federal Ministry of Economics and Technology BMWi, 2011) and Canada (National Research Council Canada, 2016b). These typically have been developed through industry-government collaborations and attempt to lay out institutional roles, identify key barriers to storage technology deployment and outline technology development strategies. In other cases, such as Ontario, (Ontario Ministry of Energy, 2013; Ontario Energy Board, 2013) storage is embedded in wider energy strategies (also (The Federal Ministry for Economic Affairs and Energy, 2015)), or is more emergent, as is the case at the federal level in the US.

3.4. Policy goals

The goals around the development and deployment of energy storage technologies vary considerably among the different jurisdictions studied. In some cases (e.g. Ontario) overall jurisdictional goals with respect to energy storage have yet to be fully articulated.

There is a considerable public discussion of the potential role of energy storage as a disruptive technology (Register, 2015), with the potential to lead to *de-alignments* and *realignments* in the energy sector, displacing existing actors and technologies and leading to the creation of new regimes. However, formal policy statements around energy storage generally avoid such framings. In some jurisdictions, like Germany and Ontario, this is a departure from the approaches taken with other new energy technologies, particularly renewable energy sources, where explicit strategies of *technological substitution*, designed to displace existing institutions and technologies with new entrants, were pursued through FIT programs and similar initiatives (Geels et al., 2016; Winfield, 2015).

Rather, some jurisdictions, such as Ontario (Ontario Ministry of Energy, 2013), and the US Federal Energy Regulatory Commission (Federal Energy Regulatory Commission, 2016), have framed energy storage as a useful technology to improve grid reliability, provide ancillary services, avoid or defer transmission and distribution system upgrades, and strengthen demand response strategies. These jurisdictions frame the entry of energy storage technologies from the niche to regime level as *transformative*. The development of their full potential may require incremental adjustments to existing regulatory and institutional arrangements, but they are unlikely to disrupt existing regimes. Indeed, in some cases, energy storage may be seen as a way to maintain existing technological regimes, particularly around the management of surplus baseload generation from large and inflexible (e.g. nuclear) generating facilities (The Independent Electricity System Operator, 2016).

Other jurisdictions see energy storage technologies as facilitating a larger *reconfiguration* of energy systems in a manner consistent with an overall structural adjustment towards low-carbon energy sources, particularly renewable energy. The US states of California and Hawaii, provide examples of such approaches. Germany also regards the development and deployment of energy storage technologies and an important element of its *energiewende*, or energy transformation (The Federal Ministry for Economic Affairs and Energy, 2015).

In some cases, economic development, through the commercialization and export of energy storage services and technologies emerges

Table 1
The summary of the findings of review of each jurisdiction in this research identified as a location for significant activity around energy storage development.

Jurisdiction	Articulated Policies & Goals	Key Institutional & Societal Actors	Electricity System Structure	Policy Initiatives – Niche Creation	Policy Initiatives – Niche to Regime Transition
Canada (Federal)	Technology and economic development (Niche creation)	National Research Council (NRC), Energy Storage Canada, Natural Resources Canada	Provincial dominance. Federal role in system planning, regulation, and operation very limited.	RD&D Funding (NRC, SDTC, NSERC); NRC Energy Storage Roadmap.	NRC ES Roadmap TOR published 2017
Ontario	Grid reliability, stabilization, ancillary services (Transformation)	IESO, OEB, LDCs (e.g. Toronto Hydro & Alectra), Energy Storage Canada (formerly Energy Storage Ontario), Electricity Distributors Association (EDA), Ministry of Energy	Semi-liberalized market	RD&D Funding, Pilot & Demonstration Projects; Procurement target (50 MW)	Storage referenced in Long-Term Energy Plans (2013, 2017); Included in OEB Canada's Energy Future, 2016; Energy Storage License introduced by OEB.
Quebec	Technology and economic development around batteries and EVs (Niche creation)	Hydro Quebec (IREQ), Association Quebec pour la Maitrise de L'Energie (AQME), Regie de l'energie,	Monopoly	RD&D Funding	Included in The 2030 Energy Policy, 2016.
Alberta	Potential role in large-scale renewables integration, ancillary services, economic diversification (Transformation, potential reconfiguration).	AESO, Alberta Storage Alliance (ASA), Ministry of Energy, Alberta Utilities Commission (AUC), Alberta Energy Regulator (AER), Alberta Innovates, Canadian Energy Systems Analysis Research Initiative (CESAR)	Liberalized market	AESO Energy Storage Initiative (2015); ISO Rule changes (502 Technical Requirements)	Discussed in AUC's Alberta Smart Grid Inquiry, 2011. Reviewing need for market rule changes: AESO Energy Storage Integration Discussion Paper, 2014; Energy Storage Integration Recommendation Paper, 2015
Manitoba	Economic development, applications in remote communities, EV infrastructure (Niche creation).	Manitoba Hydro, Public Utilities Commission	Monopoly	Secondary EV battery use for renewables integration; remote community applications.	
Germany	Facilitate large-scale RE integration/ engiewende; provide system flexibility (Reconfiguration, potential re-alignment).	BMWi, BNetzA, BMU, BMBF, EASE, EUROBAT, GT&I, German Association of Energy and Water Industries (BDEW), DSOs, TSOs, Fraunhofer ISE, Association of Transmission System Operators Gas (FNB Gas).	Liberalized markets	RD&D Funding: Energy Storage Initiative (BMWi/BMU/BMBF 2011); Market Incentive Program {MAP} (BMWi 2011); Combined Heat and Power Act {KWKG 2016}; Kopernikus Projects for the Energy Turnaround (Power-to-X); Energy System 2050 (Hydrogen research initiative).	Roadmap/Strategy published 2011, Residential solar + storage loan program (BMWi/KfW/ BMUB 2013–2018); Electricity System 2.0 elements re: aggregation, Renewable Energy Sources Act amendments (BMWi 2015).
Denmark	Facilitate RE integration/energy transition (Reconfiguration)	Ministry of Energy, Climate and Utilities, Danish Energy Agency (DEA), Danish Energy Regulatory Authority (DERA), Ministry of Transport, Building and Housing, Energenit.dk, DSOs (primarily DONG Energy & Vattenfall).	Liberalized markets	CHP focus (thermal storage) through funding for oil-to-electric conversions; ban on installation of oil-fired boilers, RD&D funding for RE-based CHP; batteries and hydrogen fuel-cells and associated infrastructure (primarily transport focused); EV incentives; RE-gas projects; funding for EVs as DR.	Assumed to be a central element of future electricity system as per Green Energy, 2010 & Energy Strategy 2050, 2011
United Kingdom	Grid flexibility, system balancing, renewables integration, ancillary services (Niche creation, transformation)	Ofgem, Electricity Storage Network, Association of Distributed Energy (ADE), Renewable Energy Association (REA), Energy UK, National Grid, Department of Business, Energy & Industrial Strategy (BEIS)	Liberalized markets	RD&D Funding (DECC, Innovate UK, BEIS, DfID, DfT, Defra); Energy Entrepreneurs Fund (EEF)	Key component of Smart Systems and Flexibility Plan, published 2017 Storage eligible under Renewables Obligation and Feed-in Tariff; Proposed final consumption levies (FCL) exemption (for grid exports); License exemptions for small capacity storage systems; Proposed modified generation license for large scale storage systems.
USA (Federal)		FERC, Sandia National Labs, NREL, ESA, USDOE, multi-state RTOs.		DOE Energy Storage Program; DOE Energy Storage Projects and Policy Database; NREL	FERC proposals re: wholesale market participation, bidding parameters, multiple

(*continued on next page*)

Table 1 (*continued*)

Jurisdiction	Articulated Policies & Goals	Key Institutional & Societal Actors	Electricity System Structure	Policy Initiatives – Niche Creation	Policy Initiatives – Niche to Regime Transition
	Was significant focus for RE integration and climate change, DR, ancillary services (Transformation). Now unclear.		Federal (FERC) interest in liberalized interstate markets.	initiatives; Lawrence Berkley Lab; Argonne National Lab Joint Center for Energy Storage Research; Oak Ridge National Laboratory; Pacific Northwest National Laboratory.	service market participation, and aggregation services.
New York	Economic development, DR, ancillary services, upgrade deferrals (Niche applications)	NYISO, ESA, NYBEST, NYSERDA, Utilities (Consolidated Edison Co., Central Hudson, …)	Liberalized markets with state ISO	New York State Public Service Commission's Initiative "Reforming the Energy Vision" (REV); NYSERDA Clean Energy Fund; Consolidated Edison's Clean Virtual Power Plant to showcase aggregate fleet of solar and storage; The NY Green Bank (NYGB) program to increase investments in the clean energy sector.	Energy Storage Roadmap by the NYBEST in 2012 with a ten-year plan of 1 GW of storage; new Roadmap published in 2016 updated to the goals of 2 GW in 2025, and 4 GW in 2035: Create new regulatory and market mechanisms to accelerate use of ES; Create standardized codes and regulations universally accepted by all jurisdictions across the State.
Massachusetts	Economic development, economic benefits to end-users, DR, environmental benefits, Transmission & Distribution upgrade deferrals.	Massachusetts Department of Energy Resources (DOER), Massachusetts Clean Energy Center (MassCEC), Department of Public Utilities (DPU), ISO-NE (a multistate RTO), Massachusetts Energy Storage Initiative, ESA.	Liberalized markets	DOER and the MassCEC programs; Energy Storage Initiative (ESI); Grant and rebate programs for business showcase projects and BTM activities; Launch commercial and industrial solar-storage feasibility grant programs.	2017 Launch of ESI's RFP for energy storage demonstration projects in different scales (BTM, distribution, utility); Roadmap/Strategy published 2015, integration of storage into State Portfolio Standards.
California	Facilitate RE integration/energy transition; (Reconfiguration, re-alignment)	California Public Utility Commission (CPUC), CAISO, California Energy Commission (CEC), California Energy Storage Alliance (CESA)	Liberalized markets with state ISO	Procurement target of 1.325 GW of ES in 2010 for the state's three IOUs by 2020; An updated procurement target in 2016 to add an extra capacity of 500 MW; Significant increase in the Self Generation Incentive Program (SGIP) funding; strong R&D funding to support ES ($100 million/yr for electricity generation research, and $100 million/yr for alternative fuel technologies and V2G), that scale-up new ES technologies.	California Energy Storage Roadmap published 2014; Several new legislations and rules that particularly create BTM and utility-scale energy storage markets, remove interconnection challenges, and ensure the role of bulk energy storage in the state's renewable energy landscape.
Hawai'i	Facilitate RE integration/energy transition (Reconfiguration).	ESA, Hawai'i State Energy Office, HPUC, The Hawaiian Electric Industries (responsible for 95% of the electricity. Utilities: HECO, HELCO, MECO); Kaua'i Island Utility Cooperative	Monopoly (regulated market; island-specific)	Solar and storage focus through R&D and pilot/demonstration projects (Solar City 52 MWh solar /storage project; The flywheel 4-h pilot project); and incentive programs: self-consumption policy for rooftop solar.	Central role of ES (along with solar) to achieve the new goal 100% RE in Hawaii by 2040 (HECO 2017); Distributed Energy Resource Programs (Customer Self-Supply and Customer Grid-Supply)

as an important sub-theme in energy storage strategies. Examples of such strategies are found in Massachusetts (Massachusetts Energy and Environmental Affairs, 2015), New York (New York Battery and Energy Storage Technology Consortium, 2016), the Canadian federal government (National Research Council Canada, 2016b), and Québec (Haley, 2015).

3.5. Niche formation and transition pathways in monopoly and liberalized market electricity systems

A defining consideration in the pathways for energy storage technology development and deployment is the underlying structure of jurisdictional electricity systems as utility monopolies or liberalized or semi-liberalized market regimes.

3.5.1. Monopoly systems

In monopoly systems, where a single vertically integrated entity provides generation, transmission, and distribution services, like the Canadian provinces of British Columbia, Manitoba or Québec, technology development tends to be sponsored directly by the utility, either through an in-house research arm or through direct funding of outside (typically university-based) research where the utility sees the potential for useful developments. In some cases, technologies that are perceived to have long-term economic development potential may also be sponsored. Hydro-Québec's research institute (IREQ) has, for example, maintained a longstanding research program on EVs and batteries (Haley, 2015). Manitoba Hydro has sponsored research on the use of secondary EV batteries for grid balancing purposes (Shokrzadeh and Bibeau, 2016). Although in some cases governments may make policy interventions to prompt the adoption of specific technologies, the determination regarding whether a technology or service moves beyond the niche level and is incorporated into the regime is predominantly in the hands of the monopoly utility.

3.5.2. Liberalized market systems

In theory, organized markets offer a more open landscape for technology developers than a simple monopoly utility model where niche to regime transitions are almost entirely at the discretion of the monopoly operator. This is particularly the case where an organized market incorporates multiple sub-markets, for example, for energy, capacity/reserves/balancing, demand response/peak shaving services, conservation and demand management, and ancillary services.

The initial model for storage service providers entering liberalized markets has been one of simple arbitrage - charging storage resources (e.g. charging batteries, storing compressed air, filling uphill reservoirs for pumped hydro) when demand and therefore market prices are low, and then discharging when demand and therefore electricity prices are higher.

Although some storage service providers consider this approach economically viable in the short-term (The Independent Electricity System Operator, 2016), the arbitrage model is increasingly regarded as inadequate for several reasons. The model is seen as potentially self-limiting, as the more successful storage service providers are - increasing demand during periods of normally low demand, and increasing supply when demand is high - the more they will reduce the difference between electricity prices at peak versus low demand (Shafiee et al., 2016; Zamani-Dehkordi et al., 2017). This problem may be reinforced as other demand response strategies are implemented by consumers and system operators, also reducing prices at peak demand.

More broadly, the simple arbitrage model is seen to fail to make full use of the potential contributions of storage technologies to electricity systems. Participation by storage resources in short-term energy markets may only make limited and incidental contributions, for example, to balancing intermittent renewable energy sources or capacity or reserve requirements more generally, or helping to manage the impact of behind-the-meter activities on transmission and distribution systems. Rather, the owner/operator of a storage resource is managing its operation to maximize their own revenues, and any contribution to other system needs is an ancillary benefit (McPherson and Karney, 2014; Kintner-Meyer et al., 2012).

The situation has prompted storage focussed policy development initiatives in several jurisdictions in North America and the European Union with liberalized or semi-liberalized electricity markets. In some cases, like the rule-making proposal published by the US FERC in November 2016, these initiatives are intended to enable better use of storage resources in liberalized markets - transformations in MLP terms. Federal Energy Regulatory Commission (2016).

The Canadian provinces of Ontario and Alberta - the only provinces with liberalized or semi-liberalized electricity markets - are following similar paths (The Independent Electricity System Operator, 2016; Ontario Energy Board, 2013; (AESO), 2015). In other jurisdictions, such as California (California Independent System Operator, 2014) and Germany (The Federal Ministry for Economic Affairs and Energy, 2015), storage is seen as an important element of larger *reconfigurations* of their energy systems. Reflecting these directions, Germany (Rothacher, 2012; KfW Group, 2016) and California (Energy Storage News, 2017a) encourage the embedding of storage resources with household level solar PV systems to support self-generation and consumption and thereby reduce stresses on grid resources in managing intermittent distributed resources.

Notwithstanding differences in landscape conditions in terms of the mixes of generation sources and long-term system orientations, across the different jurisdictions reviewed, several common themes emerge around the barriers to the development of energy storage technologies and services in liberalized markets. These themes are outlined in the following sections. In each case, the problem is summarized, supported by examples from the jurisdictions examined, and a brief discussion of responses that have been proposed within jurisdictions, provided.

3.5.2.1. Technical barriers/Bidding characteristics/parameters. In many cases market rules incorporate technical requirements which restrict the ability of storage resources to participate in markets. These may include such factors as minimum capacity requirements. In the Canadian province of Alberta, for example, only projects with a range of over 5 MW, 10 MW, and 15 MW can participate in the supplemental, spinning and regulating reserves ancillary service markets, respectively. For participation in the regulating reserve market, the continuous real power requirement is 60 min (ASA, 2016). Other examples identified by FERC among RTOs (multistate Regional Transmission Operators) and ISOs (generally single state Independent System Operators that may participate in interstate electricity markets) in the United States include issues related to minimum and maximum charge and run times, and charging and discharge rates (Federal Energy Regulatory Commission, 2016). In response, FERC has recommended that bidding parameters "reflect and account for the physical and operational characteristics of electric storage resources" (Federal Energy Regulatory Commission, 2016).

3.5.2.2. Participation in multiple markets. A key feature of energy storage resources is their ability to provide a much wider range of services than conventional generation resources (see Fig. 2, also (The Independent Electricity System Operator, 2016)). The possibility that a single facility or market participant might be able to provide services in multiple markets – energy, capacity, ancillary, and demand response – for example, was generally not contemplated when electricity systems were liberalized.

In addition to making full use of the potential contributions of energy storage resources to electricity systems, the ability to participate in multiple markets is seen as essential to the economic viability of storage services on a merchant or commercial, as opposed to pilot or one/off, basis. The ability to offer "bundles" of services is seen as important in attracting private capital investment in storage technologies (Wang and

Baker, 2017).

These types of limitations take different forms. In Alberta for example, wholesale market participants are not allowed to be both generators and consumers. In other cases, storage resources are limited to specific sub-markets, such as ancillary services or even sub-components of such markets (e.g. NYISO), or certain types of demand response markets (e.g. PJM, Ontario). Storage resources are excluded from some capacity, energy, ramp capability and contingency reserve markets (e.g. MISO). In other jurisdictions storage providers would have to participate in different markets virtually as separate entities, applying for status as market participants and paying licensing and other fees in each market they want to participate in. In some cases, markets do not exist for services storage resources can offer. The absence of capacity markets in Ontario and Alberta are examples of such situations. Capacity markets are seen to offer potentially large grid-scale applications for storage resources (Energy Storage News, 2017b; Brown, 2017; The Brattle Group, 2017).

Similar problems exist in Germany. As storage is considered final consumption and withdraw/output is considered energy generation, in principle a double EEG (*Erneuerbare-Energien-Gesetz* or Renewable Energy Sources Act) surcharge is due. Proposed amendments to the legislation would reduce the surcharge in the amount paid for electricity for storage.

Although there are concerns about the fairness of storage providers being paid to provide different services simultaneously, FERC in (Federal Energy Regulatory Commission, 2016) has recommended that storage resources be able to supply any capacity, energy, or ancillary services that they are able to provide in liberalized wholesale electricity markets.

3.5.2.3. Aggregation of distributed resources. One of the potential functions of storage resources that has garnered a great deal of attention has been their role in facilitating the management and integration of distributed energy resources. Generally, these types of resources, like household level solar PV systems, are too small to participate individually in wholesale electricity markets on a standalone basis (Federal Energy Regulatory Commission, 2016). They may also present grid management challenges at the distribution level given the intermittency of their output. The integration of these resources with distributed storage capacity resources could facilitate the use of these types of behind-the-meter resources for demand response purposes, and the aggregation their output into useful and more manageable resources at the distribution or transmission grid levels.

A major challenge around the aggregation of these types of distributed energy resources is the lack of clearly defined rules for aggregation services or significant limitations where they do exist (Federal Energy Regulatory Commission, 2016; The Federal Ministry for Economic Affairs and Energy, 2015; Navigant Research, 2017). The need for distributed generation aggregation services was generally not contemplated in the original design of wholesale electricity markets, with the result that there are no established models regarding who can provide aggregation services, and on what basis they should be paid for these services.

To the extent that distribution level electric storage and other distributed energy sources participate in wholesale electricity markets they tend to do so as behind-the-meter demand response resources. These demand response programs have reduced barriers to load curtailment resources. However, they can constrain the operation of other types of distributed energy resources, such as electric storage or distributed generation, and the services that such resources are able to offer (Federal Energy Regulatory Commission, 2016). In Ontario, for example, a market for behind-the-meter demand response resource aggregation exists but is very limited and is fragmented into a series of distinct niches or silos, some of which may be mutually exclusive (Ontario Energy Board, 2013). Potential aggregators of distributed resources may be limited in other ways. The municipally owned local distribution companies (LDCs) that provide distribution services in most of the province's towns and cities - potentially logical candidates to act as distributed resource aggregators - are not permitted to act as generators in the wholesale market above 10 MW (Navigant Research, 2017). In Germany aggregators of distributed resources are only permitted to participate in the tertiary balancing (15-min response) market (The Federal Ministry for Economic Affairs and Energy, 2015).

The situation has led to proposals for the recognition of aggregators of behind-the-meter storage and generation resources as a new form of market participant. FERC, for example, has proposed that RTOs/ISOs permit distributed energy resource aggregators to participate in wholesale energy, capacity, and ancillary services markets in a way that “best accommodates the physical and operational characteristics of its distributed energy resource aggregation.” This would include setting appropriate rules regarding location, bidding parameters, information, and data and metering requirements, for distributed energy resource aggregators, as well as coordination mechanisms between aggregators and grid and distribution system operators (Federal Energy Regulatory Commission, 2016).

In Germany, the federal ministry of Economic Affairs and Energy's White Paper (The Federal Ministry for Economic Affairs and Energy, 2015) on the future of electricity system proposed to expand the range of services aggregators of small and medium-sized consumers can provide, particularly participation in secondary balancing markets (available within 5 min of demand). The intention is to enable the aggregation of small-scale battery systems such as the household level systems being incentivized through loan programs to accompany household level solar PV systems (KfW Group, 2016).

In Ontario, the province's LDCs have proposed that they function as behind-the-meter generation and storage resources aggregators, under the concept of being Fully Integrated Network Operators (FINOs). As such they would enable diverse distributed energy resource integration, and facilitate and potentially operate distributed energy resources markets within their distribution systems (Navigant Research, 2017). Recently issued rules around licencing energy storage providers as market participants in Ontario seem to limit such status to non-utility third parties, specifically excluding transmission and distribution grid owners, like LDCs, from such status (Ontario Energy Board, 2017).

3.5.2.4. “Technological neutrality” and market integrity. In many jurisdictions, a significant feature of the discussions about how to incorporate energy storage resources into liberalized electricity markets has been debates about the need to maintain the “technological neutrality” of markets. However, the concept of technological neutrality means different things to different constituencies. For renewable energy advocates and storage developers, the existing market regimes are not regarded as technologically neutral, as the current market rules are seen to present barriers to new technologies. Technological neutrality is therefore understood to mean that the current market rules need to be adjusted to enable to the participation of new technologies on a “level playing field” with existing technologies (for example, (Chen, 2014; AESO, 2016; Fürstenwerth and Waldmann, 2014)).

Established network operators and suppliers, on the other hand, tend to interpret “technological neutrality” meaning that deliberate *technological substitution* strategies in favour of new technologies, like the FIT program under Germany's EEG, should not be pursued in support of new technologies. These concerns may flow from the disruptive impacts of such strategies on the economic viability of established utilities (The Economist, 2013, 2017), and the risks that such strategies may introduce price distortions and cross-subsidization (International Energy Agency, 2014; European Network of Transmission System Operatorsfor Electricity, 2016).

There are also ongoing debates about the extent to which storage resources should be owned directly by utilities and grid operators versus provided through third party providers on a market basis.

Developers tend to prefer market-based models, as they are theoretically more open to new entrants, and offer the potential for ongoing revenue streams as opposed to one-time sales of technologies. In practice, many jurisdictions with liberalized wholesale markets place limits on transmission or distribution utility ownership of distributed energy resources (e.g. California, New York, and Ontario).

There is an underlying issue of the extent to which jurisdictions wish to run system elements like ancillary services and balancing on a market basis, as opposed to having these services provided directly by utilities and grid operators. There are concerns over potential conflicts of interest in utilities owning the enabling platforms for potentially competing services and technologies as well (Navigant Research, 2017). Utility control would also return the niche to regime transition question to the hands of the utility rather than the market.

4. Discussion

The appearance of advanced energy storage technologies, and the resurgence of interest in existing technologies like pumped hydro, over the past decade, presents an important opportunity to study niche formation and niche to regime socio-technical transitions.

Niches for energy storage technology development have emerged through multiple mechanisms. In some cases, they have been deliberately created by governments through initiatives like research and development funding, and procurement mandates. In other cases, utilities have consciously created and sheltered niches for their own technology development purposes. Finally, in liberalized market systems third party investors have been creating niches for the development of new services and technologies that might be offered on a commercial, for-profit basis. The latter pathway for niche creation has been relatively less theorized or studied than deliberate efforts by utilities and governments.

While multiple mechanisms for niche creation for energy storage have emerged in monopoly and liberalized market electricity systems, the niche to regime transition stages emerge as more complex and uncertain. Monopoly utility and liberalized market systems offer different niche to regime transition pathways. In monopoly utility regimes, the niche to regime transition lies chiefly in the hands of the utility. This may make movement beyond relatively niche-level applications like ancillary services support, and infrastructure investment deferral, challenging. Although such regimes may undertake internally initiated transitions (see (Rosenbloom and Meadowcroft, 2014)) monopoly utilities are unlikely to be interested in enabling technologies that may result in the reconfiguration or realignment of their systems unless propelled there by overwhelming landscape level developments. The US State of Hawaii provides an example of a deliberate reconfiguration of a monopoly utility, mandated by the state legislature. These considerations explain in part the concentration of private sector interest in energy storage development in liberalized or semi-liberalized market systems.

In theory, within such systems, the empowerment stage of niche to regime transitions for new technologies depend on choices made by the market. In practice, energy storage developers are finding that the empowerment pathways in liberalized and semi-liberalized market systems are much more complicated than the underlying theory, grounded in assumptions of free entry and technological neutrality, would suggest. Numerous barriers to new technologies turn out to be embedded in market rules largely designed before new storage technologies existed. The result has been to push storage resources towards sub-optimal applications like arbitrage in energy markets, and marginal applications in other markets, where they exist.

In effect, the key strengths of liberalized markets around the empowerment stage of niche to regime transitions for new technologies turn out to be their key weaknesses as well. The complexity of liberalized markets offers the potential for the emergence of multiple niches. This complexity also provides many potential pathways from niches to incorporation into regimes. In practice, however, these empowerment pathways turn out to be very complicated. They are subject to highly complex sets of rules which, consciously or unconsciously, favour or were designed around existing technologies and institutional arrangements.

Consequently, the final empowerment stages of the niche to regime transition turn out to be very challenging. Empowerment may require adjustments to regime rules around which new actors or entrants may or not be able to assemble the necessary support. The utility monopoly model, in contrast, is potentially less creative and offers fewer opportunities for niches to emerge, but its pathways from niche to regime are simpler and clearer, if more arbitrary in terms of the interests of existing institutions and actors. These trade-offs lie at the core of the differences between monopoly utility and liberalized market models as structures for the development and adoption of new technologies and practices. In the storage case, the attention of private sector investors and technology developers is strongly focussed on liberalized or semi-liberalized market systems.

Within these types of systems, the need for adjustments to existing market rules and structures to address the barriers to the full utilization of energy storage resources they present is now the focus of major discussions in the United States, Canada and EU. The specific issues that have been identified as needing attention include:

- the removal of technical barriers to market participation by storage resources;
- the facilitation of the simultaneous participation of storage resources in multiple markets; and
- the establishment of new categories of market participants, like aggregators of behind-the-meter resources, including energy storage, that were not anticipated when organized markets were originally designed.

It remains an open question whether the maturing interest community of storage developers and advocates has the capacity to advance these types of changes to existing regulatory regimes. The sensitivity of established actors to risks of further reconfigurations or realignments, which may present additional challenges to existing business models and technologies, is particularly important in this regard. The prospects for the implementation of significant policy changes are likely to be strongest in jurisdictions, like California and Germany, that are engaged in wider deliberate reconfigurations of their energy systems towards low-carbon energy sources. Storage resources are expected to play central roles in these processes.

A further factor influencing the likelihood of changes to market rules and structures to make better use of energy storage resources relates to the jurisdictional complexity of those markets. The most active jurisdictions around energy storage policy development tend to operate on a liberalized or semi-liberalized market system model and have a principally single-jurisdiction grid operator or ISO. Examples of the combination of a (in some cases semi) liberalized market and a single-jurisdiction system operator include California, Texas, New York, Ontario and Alberta. Institutional coordination tends to be much simpler where the system involves organizations from the same jurisdiction, all operating under mandates from a single legislature.

The next steps for energy storage policy among the jurisdictions examined are likely to be determined by the combination the existence of liberalized or semi-liberalized electricity markets, the presence of a single jurisdiction system operator, and a jurisdictional commitment to the low-carbon reconfiguration of electricity systems.

At the federal level in the United States, the direction of the Trump administration on the regulatory issues raised by FERC in its November 2016 proposed rule-making, and energy storage more broadly, is unknown. It is unlikely, however, to pursue deliberate low carbon reconfigurations of electricity systems. Activity at the individual state level, in contrast, is far more likely continue to move forward.

Jurisdictions like California and Hawaii, who by virtue of their single jurisdiction system operators, are less affected by developments at the federal level, and who are committed to the low-carbon reconfiguration of their electricity systems, seem positioned to continue their leads in regulatory and policy development around energy storage.

In Germany, the landscape-level need to manage the low-carbon reconfiguration of the electricity system towards the large-scale integration of intermittent renewable energy sources will continue to propel the development of storage resources and their integration into the existing energy regime. That said, there are ongoing debates about regime technological neutrality and desirability of further realignments of electricity systems.

In Canada, the absence of a significant federal institutional and regulatory role around electricity, and dominance of single-jurisdiction system operators, means that determinations of niche to regime transitions for energy storage technologies will take place at the provincial level. Among the provinces with (semi) liberalized electricity markets, further significant reconfigurations of Ontario's electricity system, and an accompanying growth in the grid scale deployment of intermittent renewables or distributed generation activities, are not anticipated (Ontario's Ministry of Energy, 2017). This may limit energy storage applications to their current, relatively niche-level applications, such as ancillary services. In Alberta, the need for a significantly expanded role for storage resources depends in large part on whether the province's planned wider low-carbon reconfiguration of its electricity system, including a coal phase-out and transition towards an expanded role for intermittent renewable energy sources (Government of Alberta, 2017) survives the next provincial election, expected in 2019.

5. Conclusions and policy implications

The emergence of advanced energy storage technologies, and the revival in interest in existing technologies, provides the opportunity to study a niche to regime transition in progress. The creation of niches emerges as a relatively straightforward process. A variety of mechanisms for niche creation have been employed or have emerged in the storage case, in both monopoly and liberalized market systems.

The niche to regime transition is much more difficult. Here the monopoly and liberalized market system models offer significantly different pathways for the empowerment of niche level developments. Both have the potential to provide routes for niche to regime transitions, but there are substantial trade-offs between the two. In monopoly regimes, the pathway to adoption into a regime is relatively direct, but largely at the discretion of the monopoly utility. Such utilities may be unenthusiastic about the adoption of technologies which may disrupt their existing operational models. In liberalized systems, there may be multiple transition pathways, but these pathways are grounded in complex rules, which have largely been designed around existing technologies and actors, who may be resistant to change to accommodate new technologies and entrants.

The ability of the maturing interest community of energy storage developers and advocates to advance significant regime change in favour of the full utilization of the potential energy storage technologies will be strongly influenced by the landscape-level features of the availability of liberalized or semi-liberalized market system configurations, the simplifying presence of a (principally) single jurisdiction system operator, and most importantly, a jurisdictional commitment to a low-carbon reconfiguration of electricity and energy systems. These factors are well established in some of the jurisdictions studied, such as California. In other jurisdictions they remain unresolved, particularly with respect to commitments to low-carbon system reconfigurations. In the result, the path forward for energy policy regime change around energy storage will remain jurisdictionally uneven until commitments to energy system de-carbonization are deepened and become more prevalent.

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