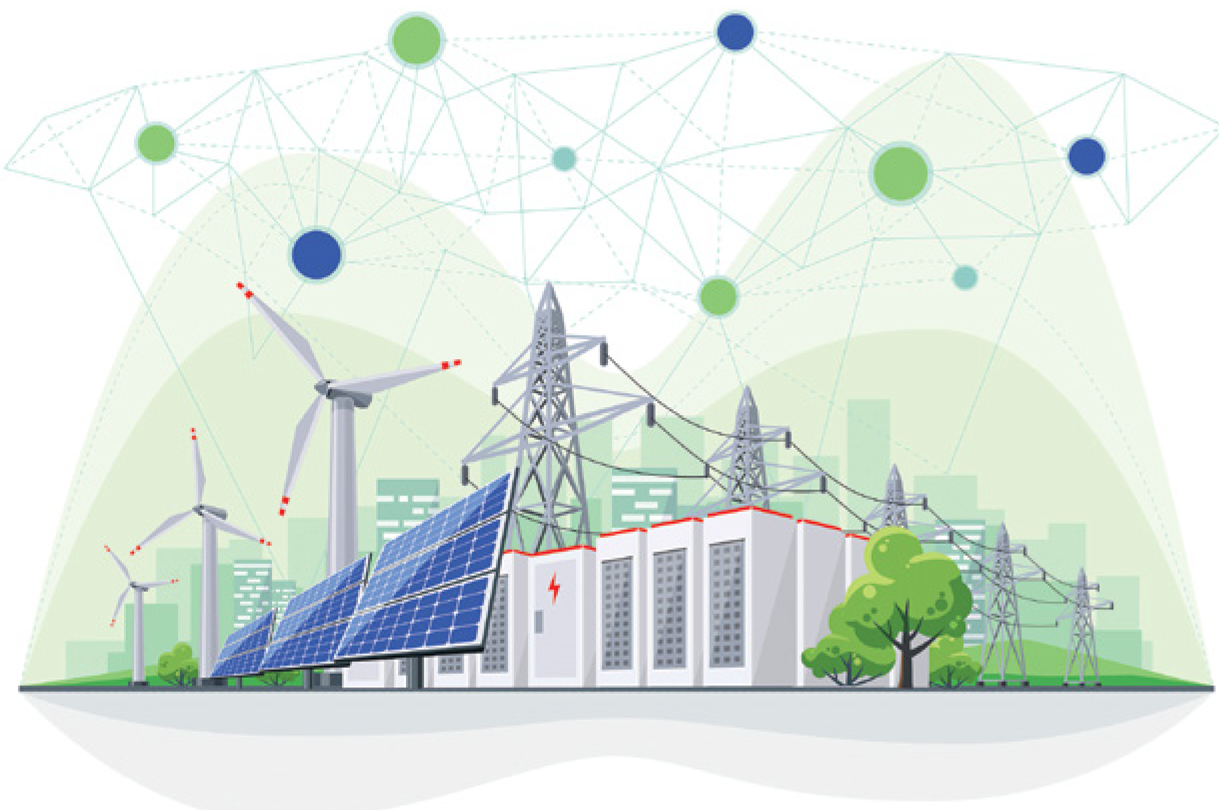
NARUC
National Association of Regulatory Utility Commissioners

Battery Energy Storage Technology Adoption & Electric Utility Structure

Analyzing factors driving storage deployment across utility ownership structures



Sara Mulhauser

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Disclaimer

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Acronyms

ACES
Advancing Commonwealth Energy Storage (Massachusetts)

AMI
Advanced Metering Infrastructure

BES
Battery Energy Storage

BTM
Behind the (electricity) Meter

CPUC
California Public Utility Commission

C&I
Commercial and Industrial (retail customers)

CCA
Community Choice Aggregator

DSIRE
Database of State Incentives for Renewables & Efficiency

DOE
Department of Energy

DER
Distributed Energy Resource

DRP
Distribution Resources Plan

eGRID
Emissions & Generation Resource Integrated Database

EIA
Energy Information Administration

EPA
Environmental Protection Agency

FERC
Federal Energy Regulatory Commission

GHG
Greenhouse Gas

GMI
Grid Modernization Index

IPP
Independent Power Producer

ISO
Independent System Operator

IRP
Integrated Resource Planning

IOU
Investor Owned Utility

LCOS
Levelized Cost of Storage

NETL
National Energy Technology Laboratory

NEM
Net Energy Metering

NERC
North American Electric Reliability Corporation

PJM
Pennsylvania-Jersey-Maryland Interconnection

PV
Photovoltaic Cells (solar generation)

PPA
Power Purchase Agreement

POU
Publicly Owned Utility

PURPA
Public Utility Regulatory Policies Act

RTO
Regional Transmission Organization

RPS
Renewable Portfolio Standard

SGIP
Self-Generation Incentive Program

SEPA
Smart Electric Power Alliance

SAIDI
System Average Interruption Duration Index

SAIFI
System Average Interruption Frequency Index

TOU
Time of Use (rates)

VRE
Variable Renewable Energy

Executive Summary

Changing customer loads, externalities from fossil fuel generators, and rapid innovation of new technologies have contributed to a large-scale, ongoing transformation of the electric grid. Successful commercialization and integration of additional new technologies will be critical to meeting further challenges.

Electric utility structure has potential to impact how new technologies are adopted. Electric utilities are often a gatekeeper for new grid-connected technologies. Because of their regulated monopoly status, utilities (especially vertically integrated ones) often have a wide range of discretion about whether or not it is in their interest to adopt new technologies, potentially creating bottlenecks. Electric utilities can be major purchasers of new technologies or they may choose to be competitors by developing their own offerings. The regulatory environment within which electric utilities operate also influences utility behavior – vertically integrated utilities have a different relationship to the supply chain of the electric power industry than restructured ones, and may have different incentives impacting their engagement with new technologies. The nature of these interactions is an important consideration for the viability of any new technology's commercialization.

Any decision-makers contemplating policy interventions or market mechanisms to encourage commercialization of new technologies need to consider the impact of the electric utility structure in their process. Even seemingly unrelated rate design or legal designations[1] can have an impact on the viability of technologies or their path to market.

This paper begins an exploration of the extent to which the structure of investor-owned utilities (IOUs) (i.e., in vertically integrated and restructured states) may influence the commercialization of the critical new technologies needed to transform the electric grid into a system that emits far less carbon for the electricity it produces. The analysis focuses on the interaction between the growth of battery energy storage (BES) in vertically integrated and restructured states as a relevant test of the hypothesis.

BES growth has been nearly exponential, with 148.8 MW installed in the first quarter of 2019, representing a 232 percent increase over first quarter 2018 (Morehouse, 2019b). The increased adoption of battery energy storage technology is due in part to technological advancement both of batteries and newer intermittent renewable generation sources, in part due to utility rate designs that purposefully or inadvertently encourage arbitrage, and in part due to federal and state policies that encourage deeper penetration of renewable energy. In addition to shifting loads and storing renewable energy for use at different times, BES can provide a range of grid services that might be beneficial to the grid.

This report identifies barriers to adoption of BES, including cost, externalities, institutional barriers associated with a monopoly utility, market designs, innovation barriers, regulatory uncertainty, and political feasibility. Due to some of these barriers, BES technology has historically been largely dependent on some sort of policy or subsidy support, though future projections indicate that this situation might rapidly change. This report also categorizes and summarizes government interventions directed at utilities, independent power producers, and retail customers.

The analysis shared in this report aims to identify the policy and market drivers of adoption, and the extent to which those differ depending on IOU structure. The specific questions this paper attempts to answer are:

- To date, has battery adoption been higher in territories served by vertically integrated or restructured IOUs?

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1 One example of a legal designation impacting technology path-to-market is classification of battery energy storage. Since this technology provides services at times like a generator, at others like a load, and still others like a transmission or distribution management asset, it does not easily fit into traditional legal definitions. If a restructured utility is precluded from procuring new generation assets, for example, technology providers cannot access the market through the utilities, and may not be able to sell as many services as the technology could provide.

- To date, have battery service offerings (i.e., grid support services beyond energy and capacity) been more widely used in territories served by vertically integrated or restructured IOUs?
- Which policy mechanisms have been used and effective at spurring battery adoption, and how is that different in states with vertically integrated or restructured IOUs?

This research demonstrates, quantitatively, that in battery energy storage adoption to date:

- States with vertically integrated IOUs have the **same normalized adoption of battery capacity** (rated capacity relative to state size) in their IOU territory as states with restructured IOUs.
- Battery adoption is positively correlated with **renewable portfolio goals and standards**, and **higher system reliability** (fewer minutes of outages) in states with vertically integrated IOUs.
- Battery adoption is positively correlated with **higher penetration of renewable energy generation, storage mandates**, and **markets for capacity** and **demand response** in states with restructured IOUs.
- Battery storage projects developed in a vertically integrated IOU territory are observed to provide **more grid services** (services directly benefiting the bulk power system), whereas those in a restructured IOU territory are observed to provide **more behind-the-meter (BTM) services** – this is suggestive of the potential to value-stack.
- States with restructured IOUs are observed to adopt **more unique battery services overall**, which suggests a higher willingness to experiment with the technology's capabilities.

For states interested in increasing BES battery energy storage adoption, the following recommendations follow from the analysis:

States with Vertically Integrated IOUs	States with Restructured IOUs
• Consider expanding policies that encourage value stacking of BTM services (third-party asset ownership of BES assets is particularly effective) • Consider developing policies that encourage a wider range of BES services at the grid scale • Evaluate integrated resource planning (IRP) requirements for opportunities to encourage BES consideration • Consider adopting BES targets or mandates, and/or expanding renewable energy targets	• Consider developing policies that encourage value stacking of BES services at the grid scale • Consider adopting BES targets or mandates • Work with wholesale market organizations to enable competition for grid services that BES can qualify to provide

Introduction

The electric industry, and the grid itself, is undergoing rapid transformation. Technological advancements are being developed and commercialized by companies within and outside the traditional electric industry orbit, aimed at offering new services for utilities and for customers. The nature of some of these new technologies now interacting with the grid allows new entrants to market directly to electricity customers (e.g., rooftop photovoltaics, smart home controls, Internet-of-Things devices). Reaching true scale of commercialization with these new technologies nonetheless requires interface with the other dominant electric industry stakeholder: the electric utility.

This paper examines one recent technological innovation and its adoption thus far: battery energy storage (BES). BES is interesting for several reasons:

- BES is one technological solution to the challenges posed by intermittent renewable generation, and notably emits zero carbon dioxide emissions during use;
- BES has become more financially viable recently because of innovation spillovers from other industries, namely lithium ion battery technology developed for personal computing, smart phones, and electric vehicles;
- BES can be classified as a generation asset, a load source, or a transmission/distribution asset, which creates challenges for traditional regulatory models; and
- BES is attracting a good deal of investment with sizable projections for future growth.

This paper will not engage in any of the interesting debates about whether BES is a meritorious technological solution to intermittency challenges, or who should be allowed to sell, own, or operate BES assets. This paper instead seeks to understand factors influencing the adoption of this technology. The paper focuses on investor-owned utilities (IOUs)[2] in the United States and seeks to understand if the variation in the structure and regulatory environment of these IOUs (vertically integrated versus restructured) has any observable correlation with variable BES technology adoption outcomes. This analysis also seeks to better understand the policy and market drivers of adoption and the extent to which those differ depending on IOU structure. The specific questions this paper attempts to answer are:

- To date, has battery adoption been higher in territories served by vertically integrated or restructured IOUs?
- To date, have battery service offerings (i.e., grid support services beyond energy and capacity) been more widely used in territories served by vertically integrated or restructured IOUs?
- Which policy mechanisms have been used and effective at spurring battery adoption, and how is that different in states with vertically integrated or restructured IOUs?

2 Nearly three-quarters of utility customers get their electricity from investor-owned utilities.

Reverse Salients

Thomas Hughes chronicles the evolution of the electric industry in several books. One important concept he discusses in these works is that of the **reverse salient** – a subsystem of a larger system that experiences growth or development at a lower rate than surrounding subsystems, eventually slowing the growth or development of the system as a whole. Because of the subsystem's negative impact on the system, the subsystem becomes a focus of effort to overcome whatever is hampering that subsystem's advancement. Hughes points the readers' attention to various engineering problems that were, in hindsight, reverse salients for the development of the electric grid, and therefore the industry. The physical limitations of electrical distribution in the early direct current generation and distribution system were a reverse salient that spurred the invention of the alternating current generation and distribution system, which was able to grow very quickly (Hughes, 1983).

When physical reverse salients are identified in a physical subsystem, the nature of their limitations are quantified, new operational parameters defined, designed, and prototyped. Eventually, trial-and-error experimentation with new subsystem designs is performed until a new, and sometimes revolutionary, solution results.

A reverse salient can also be organizational in nature. This paper begins an exploration of the extent to which the structure of IOUs may be a reverse salient, of sorts, to the commercialization of the critical new technologies needed to transform the electric grid into a system that emits far less carbon for the electricity it produces.

How this Paper is Organized

This report starts with a background of utility structure types and their historical context, regulatory frameworks, the demand for BES technology, and a brief background on the technology itself. The report then outlines the economic theory behind barriers to adoption of BES technology, and the type of interventions that currently exist to overcome those barriers to adoption (including some unintentional drivers of adoption). This report then outlines the findings of the analysis and concludes with recommendations for regulators. Detailed descriptions of data gathering and analysis methodologies are provided in Appendix A. Appendix B contains more detailed descriptions of the findings, with regression tables.

The State of Energy Storage

Utility Structures & Regulatory Jurisdiction

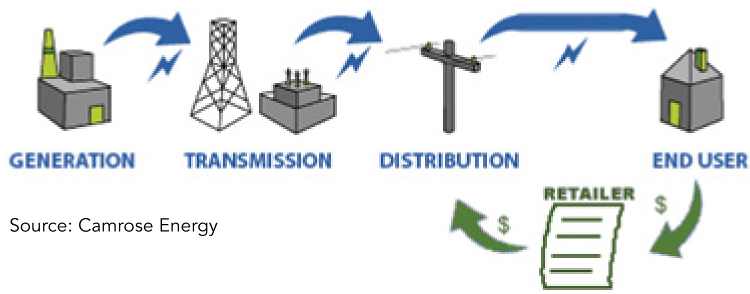
Electric utility operations generally fall into four high level categories:

Generation: Transforming fuel into electricity for sale. Large generation facilities have traditionally been located away from urban centers.

Transmission: High voltage capacity lines transport electricity from generation facilities to urban centers, or load centers.

Distribution: At the load centers, high voltage electricity is stepped down to a lower, safer voltage, and distributed to the point of connection on an end user's property, frequently referred to as "the meter." Electricity can also be generated "behind the meter" at a user's property (e.g., solar photovoltaic panels), where it is called distributed generation.

Figure 1: Electric Utility Operations



Source: Camrose Energy

Retailing: This refers to the operations associated with selling electricity as a commodity to end users, which include selling retail power to customers, invoicing, etc.

Electric utilities may be owned by public entities (such as a federal or local government), by its customers (rural cooperatives are the common form of this type of ownership in the United States), or by shareholders as for-profit corporations. This last type is known as the investor-owned utility (IOU).

IOUs serve the majority of customers in the United States (72 percent in 2017; EIA August 19, 2019), and are the focus of this study. Traditional IOUs are vertically integrated, meaning they hold monopoly franchises for power generation, transmission, distribution, and retailing services for their territory. In exchange, these utilities are required to provide service at "just and reasonable rates" to all customers in their territory. The rates they are allowed to charge ("retail rates") are regulated by a state public utility commission, and the opportunity to earn revenue, while limited by this body, is guaranteed (R. Hirsh, 1999).

Starting with the enactment of the federal Public Utility Regulatory Policies Act of 1978 (PURPA), the widespread consensus that electricity generation was a natural monopoly began to erode (R. Hirsh, 1999). In line with unbundling of services in the natural gas and telecom industries, starting in the late 1990s, many states began a restructuring effort for the electric industry, which had three basic elements (see *Figure 2*):

1. Competition for generation services
2. Competition for retailing services
3. Independent operation of transmission resources

The first two elements were intended to reduce the cost of electricity for customers, and the third was thought to be necessary to ensure fair competition by lowering barriers to entry (Borenstein & Bushnell, 2015).

In traditional rate of return calculation, the price for electricity allowed is set by calculating the amount of revenue a utility must receive in order to cover their costs and return the allowable profit. The formula for calculation typically looks like this: (Jamison, 2007)

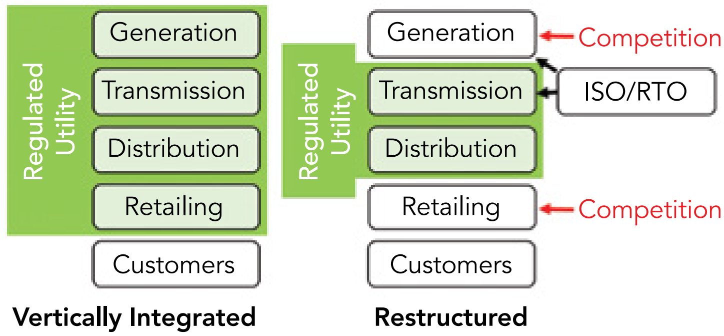
$$RR = B*r+E+d+T$$

Where:

RR = revenue requirement
B = rate base, or the amount of capital/assets dedicated to providing service
r = allowed rate of return (profit)
E = operating expenses
d = annual depreciation
T = taxes

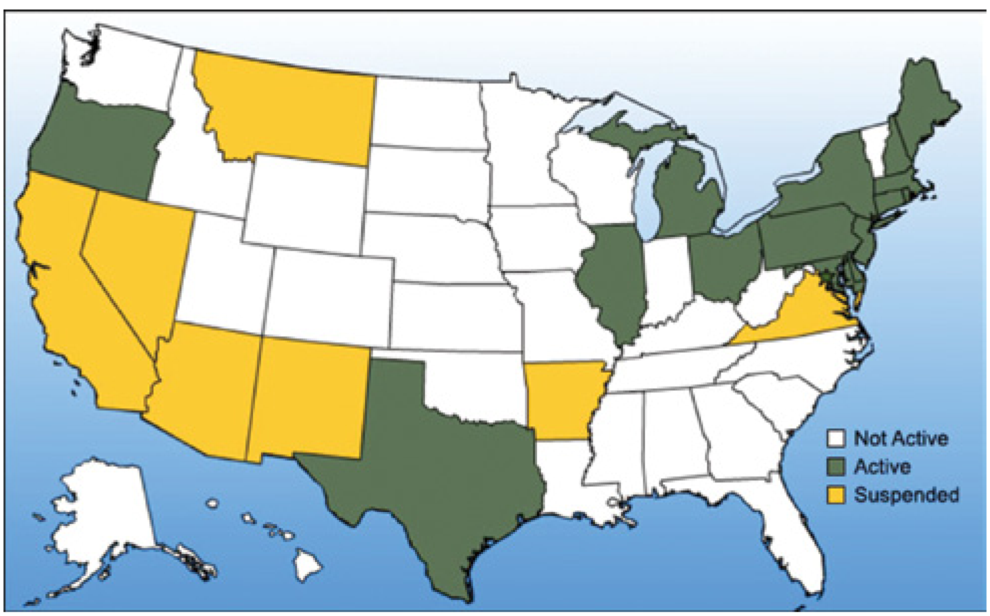
Some states successfully implemented all three elements and today have competitive retail electricity markets, competitively owned and operated generation, and transmission-owning utilities that are members of a Regional Transmission Organization (RTO) (sometimes referred to as an Independent System Operator, or ISO). The RTO/ISO manages – but does not own – transmission resources, dispatches generation assets to align supply and demand, and, in most cases, runs wholesale markets for electricity and some important grid services (Borenstein & Bushnell, 2015). IOUs still operate in these states, but they are "restructured" and only operate the distribution grid plus some retailing. They are no longer vertically integrated in the way IOUs were traditionally across all four categories of utility operations.

Figure 2: Regulated Components of Vertically Integrated vs. Restructured Utilities



Some states tried to restructure, but experienced difficulty. California's electricity crisis of 2000 and 2001, due in part to market manipulations following the initial restructuring effort, caused that state to reverse some of its actions, which slowed or stopped the restructuring progress of other states (R. Hirsh, 2017). Nonetheless, some of these states today do still experience some competition for wholesale electricity generation, as well as for retail service. Some states have IOUs that are members of RTOs. In California, the ISO plays a similar role as the RTOs for other regions. It may not be accurate to call the IOUs in these states restructured, but neither is it accurate to describe them as vertically integrated in the same way IOUs were before the 1990s.[3]

Figure 3: Electricity Restructuring by State

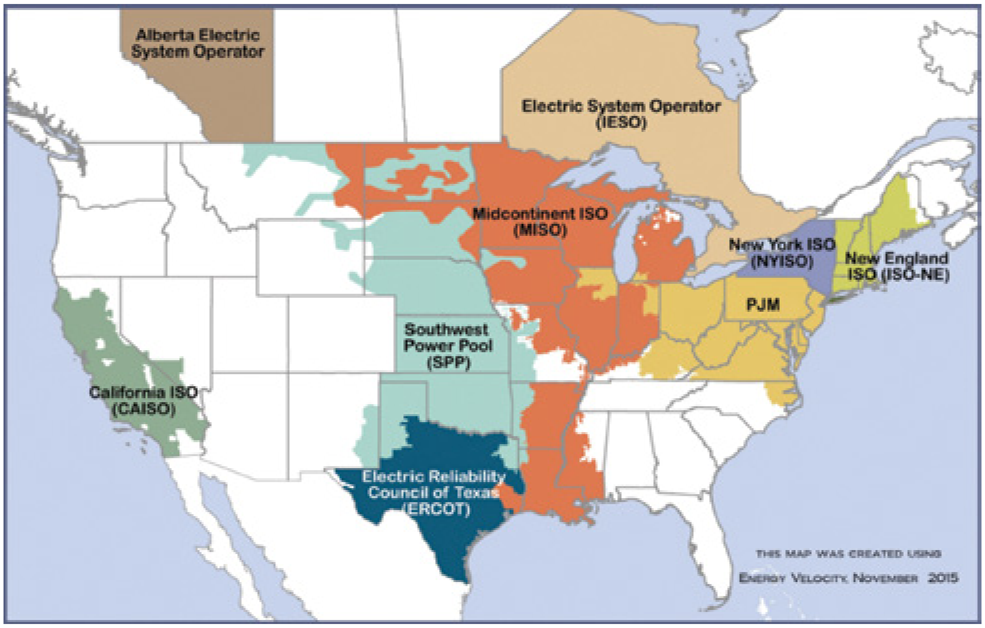


Source: Brattle Group & EIA

As shown in *Figure 3*, some states made no changes to the structure of their IOUs. And although the IOUs in these states are accurately referred to as vertically integrated, some of the IOUs are nonetheless members of RTOs (see *Figure 4*).

3 See Appendix A: Methodology – Data Sources: Utility Restructuring Status by State for further discussion on data sources and methods used in this analysis to determine whether the regulatory environment of a particular state is vertically integrated or restructured. See Table 4 in Appendix A for a complete list of designations by state.

Figure 4: Regional Transmission Organizations



Source: FERC

In the United States, the Federal Energy Regulatory Commission's (FERC) jurisdiction over the electricity grid is mostly limited to oversight of interstate trade. This jurisdiction stems from Article 1, Section 8, Clause 3 of the U.S. Constitution, which gives Congress the power to "regulate commerce…among the several states," commonly referred to as the Commerce Clause. Congress created the agency that exercises that power in the Federal Water Power Act of 1920. FERC has thus mostly been involved in issues related to wholesale markets, large-scale generators, and transmission lines. FERC is also occasionally involved in issues associated with the Dormant Commerce Clause, which relates to states enacting rules that discriminate against interstate commerce.

With the federal government's jurisdiction narrowly defined, states have the ability to regulate intrastate activity, which in practice translates to distribution and retail sales in restructured states and all four categories of utility operation in vertically integrated states. This explains why there is such variety in the structure of IOUs from state to state, even within the same regional transmission footprint, and in the nature of energy policies within states.

What is Driving the Growth of Energy Storage?

Technological Advances

Due to the fundamental nature of electricity, generation and supply of electricity delivered to customers must match demand at all times, within a small margin of error. Since the grid's inception, direct storage of electricity has been cost-prohibitive compared to precise control of generation. Due to this limitation, the grid was built with significant reserve generation capacity such that new generation could be dispatched to meet rising demand, and curtailed when demand waned. When supply does not meet demand, the grid's alternating current frequency is disrupted. Frequency disruption can lead to reduced efficiency of power generation, or, in the case of extreme low or high frequency, damaged equipment (von Meier, 2006).

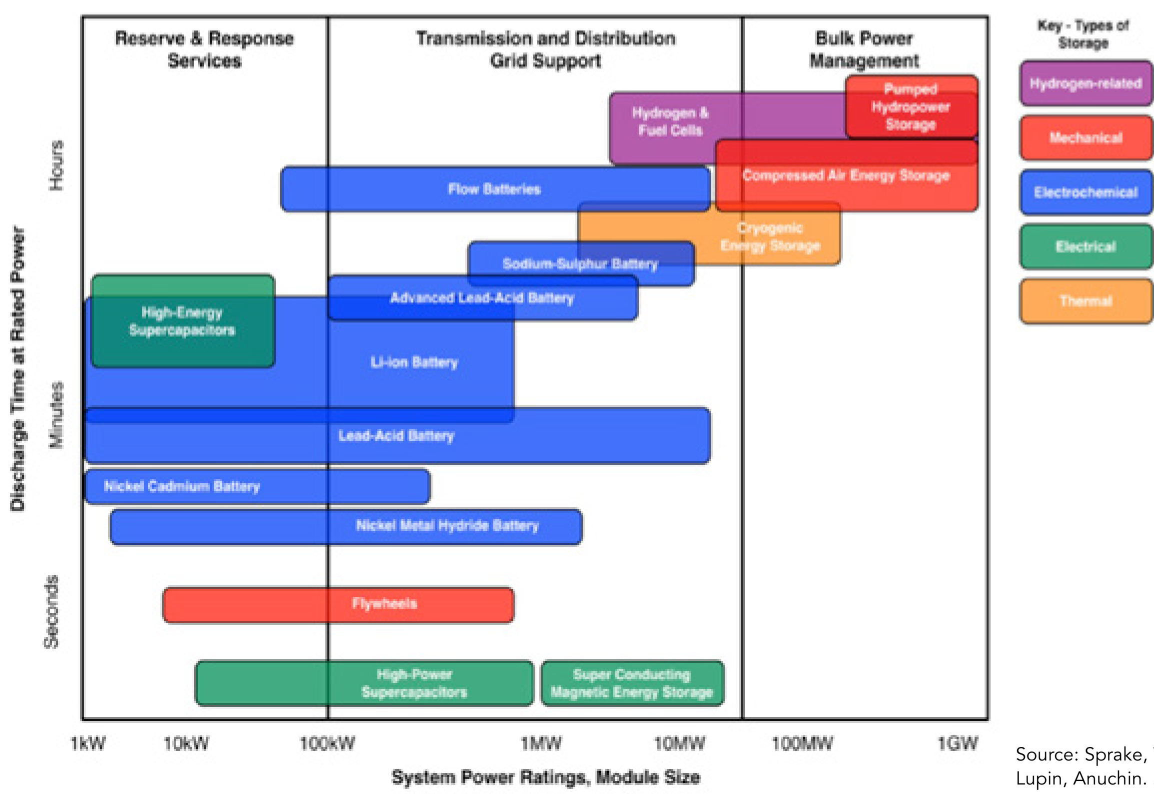
Recently, energy storage technology has improved, such that the old paradigm of building excess generation capacity may no longer be the most economically efficient way to ensure balance of supply and demand. Energy storage technologies reaching viability today include[4]:

4 Installed capacity estimates for these technologies accessed from the DOE Energy Storage Database.

- Mechanical & Thermal Storage – kinetic energy is energy associated with motion. Storage applications require bi-directional conversion of energy (creation of kinetic potential energy, conversion of kinetic energy to electricity). Examples of kinetic energy storage are:
    - Pumped storage hydropower (the vast majority of existing storage, over 90 percent of installed capacity, ~25GW)
    - Flywheels (~87MW installed capacity)
    - Compressed air energy storage (CAES) (~114MW installed capacity)
    - Thermal storage (~669MW installed capacity)
- Electrochemical Storage – electrochemical reactions convert chemical energy to electrical energy. Storage applications require bi-directional conversion of energy (charging electrolytes by adding electricity, or discharging electrolytes and supplying electricity). Examples of electrochemical energy storage are:
    - Batteries – provide storage through charge and discharge of a fixed reservoir of reactants. Lithium ion battery technology breakthroughs associated with consumer electronics have spilled over to electricity and transportation (electric vehicle) applications. (~800MW installed capacity)
    - Flow batteries – provide storage through a charge and discharge of a non-fixed reservoir of reactants. (~8MW installed capacity)
- Electrical Storage (~3MW installed capacity)
    - Superconducting magnetic energy storage (SMES)
    - Capacitors

These energy storage technologies have unique characteristics that offer different benefits to the grid. In *Figure 5*, they are characterized by their range of system power rating (rated power output, or capacity)

Figure 5: Energy Storage Technology Power and Discharge Ranges



Source: Sprake, Vagapov, Lupin, Anuchin. 2017 and discharge time at rated power (run time of the battery at the rated power output). Other performance characteristics vary among technology types as well.

This report focuses only on battery energy storage (BES), not including flow batteries.

As the share of electricity generated by intermittent, non-dispatchable renewable sources (such as wind and solar) increases, the value of energy storage to the grid increases (von Meier, 2006). Research shows that increased penetration of wind and solar in competitive wholesale markets leads to a "cannibalization effect," whereby revenues of new wind and solar installations cannot support investment due to downward price impacts of other installed wind and solar generation (Prol, Steininger, & Zilberman, 2018). Batteries, and other energy storage technologies, have the potential to mitigate this issue by allowing wind and solar generation to be stored and sold into wholesale markets at higher marginal cost times of the day. Furthermore, storage— such as renewables — does not create emissions (e.g., carbon dioxide, particulate matter) during its use.

Customer Adoption

To date, much customer investment in customer-sited energy storage, often referred to as behind-the-meter (BTM) storage, has been influenced by rate design structures that facilitate sufficiently attractive pay-back periods and / or customer reliability or resilience goals.

Rate Design: End-use customers pay different types of rates for their electricity service. How those rates are designed can create incentives or disincentives to invest in BES. Most customers face some combination of fixed and volumetric charges. Fixed charges ideally represent the customer's share of the utility's fixed costs, whereas volumetric charges change with the amount of electricity used (Aznar, 2015).

Demand charges are additional to fixed or volumetric charges, and are typically applied only to commercial and industrial (C&I) customers. This is an additional charge associated with the customer's peak electricity demand, and may or may not also be related to the peak demand the utility experiences for its customers in aggregate. Demand charges can be quite high for some C&I customers, and BES is proving to be one investment these customers can make to reduce their long run costs. BES allows a customer to reduce their peak demand by charging the battery system during a non-peak period, and discharging it during peak hours.

Time-of-Use (TOU) rates are a kind of volumetric charge. When volumetric charges use TOU rates, the volumetric rate a customer pays varies not only with the amount of electricity consumed, but also with the time of day the electricity is consumed. Because the cost of wholesale electricity varies over the course of the day, incorporating TOU rates encourages customers to consume more electricity when it is cheaper for the utility to produce and/or procure, and consume less when it is more expensive (with the caveat that not all customers have the flexibility to change their time of consumption). TOU rates are becoming more widely used as smart meter infrastructure allows utilities to have greater visibility into the exact time of consumption (Borenstein & Bushnell, 2015). TOU rates also provide an opportunity for customers to invest in BES and arbitrage between the different rates —that is, charging the battery when rates are low and discharging the battery when rates are high.

Global Adjustment Demand Charge:

The government of Ontario, Canada, established a charge known as the Global Adjustment (GA) in 2005. This charge is intended to allow the electric utility to make up the cost difference between the market-clearing wholesale electricity cost, and the additional costs imposed by other contracted generation sources (such as nuclear, natural gas, and renewables). Most customers see this charge rolled into their normal marginal cost, but industrial customers experience the GA as a demand charge determined by their usage on five top peak demand days. Because of this unique pricing structure, industrial customers see 50-70 percent of their bill expressed as a GA charge (Maloney, 2018c), which can drive these customers to install BTM BES in order to reduce their apparent demand on peak days. These customers see low marginal costs for consumption, generally, so arbitrage is not a compelling driver of BTM storage adoption.

Reliability and Resilience: Some customers require or desire higher reliability or resilience around electricity than the utility provides. Traditionally, these customers used stand-alone diesel generators as a backup power supply. These onsite generators require a large capital investment for equipment that is rarely utilized, a supply of diesel fuel, regular maintenance, and sometimes pairing with an uninterruptible power supply, to allow ride-through until the generator begins operation. BES now has the potential to replace diesel generator backup power supplies, especially when the BES can offer additional savings through reduction of demand charges and TOU arbitrage. Furthermore, BES paired with onsite renewable generation can theoretically hedge against extended outages where diesel fuel supply could be challenging to maintain.

State and Federal Policies

The federal government and many state governments have encouraged the growth of renewable power generation technologies through a range of policies. The purpose of these policies is to reduce the emission intensity of power generation, both for greenhouse gas emissions, as well as for pollutants that have localized health and other environmental impacts (such as nitrogen oxides and sulfur dioxide). The success of these policies in driving ever greater shares of generation by renewable generation—specifically, intermittent, non-dispatchable renewables, or variable renewable energy (VRE) like wind and solar—has increased the demand for BES to help avoid VRE curtailment in times of oversupply. As a result, BES can be seen as a way to facilitate a cleaner electricity grid. Some policies that drive BES adoption are not driven purely by environmental concerns, but also nominally pursue increased economic development.[5] To the extent BES represents a new industry, policies encouraging its adoption potentially encourage company investment, economic activity, and job creation.[6]

Federal Renewable Energy Policies:

PURPA's Section 210 required regulated utilities to pay "Cogeneration and Small Power Producers" meeting certain qualifications for excess power they produced and exported to the grid. They were required to pay the producer's cost of production, provided it did not exceed the utility's avoided cost for not[RD3] generating/procuring the electricity themselves. While this legislation was intended to encourage cogeneration facilities, it also became a pathway for renewable generation facility developers to sell power (R. Hirsh, 1999).[7]

Investment Tax Credits encouraged development and commercialization of solar generation (and can also be applied to storage of solar-generated electricity).[8]

Production Tax Credits encouraged development and commercialization of wind generation.

State Renewable Energy Policies:

Renewable Portfolio Standards (RPS) have been adopted by more than 50 percent of states and required regulated utilities to procure a share of electricity from renewable or clean sources (Rule, 2018).

Rebates are offered as direct cash transfers to some developers of renewable generation projects.

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5 There are many examples of a close link between VRE policies/procurements and job expansion goals, such as New Jersey's offshore wind procurement results and new, in-state factory development (Stromsta, 2019).

6 Although many economists argue that justifying specific industry or technology encouragement by potential economic development gains is problematic (Borenstein, 2015).

7 Subsequent to completing the research for this paper, FERC issued new guidance on PURPA on July 16, 2020. See: https://www.ferc.gov/news-events/news/ferc-modernizes-purpa-rules-ensure-compliance-reflect-todays-markets and https://www.ferc.gov/sites/default/files/2020-07/07-2020-E-1.pdf.

8 The ITC also applies to energy storage devices that are charged exclusively by the associated solar PV panels, even if the storage is placed in service in a subsequent tax year to when the solar energy system is installed. See: https://www.energy.gov/eere/solar/downloads/residential-and-commercial-itc-factsheets.

About Battery Energy Storage

Range of Services

BES technology offers a wide range of services directly to customers in BTM installations and to the distribution and transmission system[9] when installed at grid scale. EIA's 2018 U.S. Battery Storage Market Trends offers the following summary definitions of the most common services sought by BES adopters:[10]

- **Frequency regulation** helps balance momentary differences between demand and supply, often in response to deviations in the interconnection frequency from 60 Hertz. All ISO/RTOs have a market for frequency response or regulation services and FERC Order 755 requires that markets pay more for faster responding units.
- **Spinning reserve** provides synchronized capacity for grid frequency management, which may be available to use during a significant frequency disturbance. For example, during an unexpected unavailability of generation capacity. This reserve ensures system operation and availability. Every ISO/RTO has an operating reserve market, which includes spinning reserves.
- **Voltage or reactive power** support ensures the quality of power delivered by maintaining the local voltage within specified limits by serving as a source or sink of reactive power. Some, but not all, ISO/RTOs offer compensation for voltage control and reactive supply.
- **Load following** supplies (discharges) or absorbs (charges) power to compensate for load variations—this a power balancing application, also known as a form of ramp rate control. There is no specific wholesale market for this service.
- **System peak shaving** reduces or defers the need to build new central station generation capacity or purchase capacity in the wholesale electricity market, often in times of high (peak) demand. Demand response markets, where available, do provide value for system peak shaving.
- **Load management** provides a customer-related service, such as power quality, power reliability (grid-connected or microgrid operation), retail electrical energy time-shift, demand charge management, or renewable power consumption maximization.
- S**toring excess wind and solar generation** reduces the rate of change of the power output from a non-dispatchable generator (e.g., wind or solar) to comply with local grid codes related to grid stability or prevent over production or over-production penalties.
- **Arbitrage** occurs when batteries charge with inexpensive electrical energy and discharge when prices for electricity are high, also referred to as electrical energy time-shift.
- **Backup power for black start** after a catastrophic failure of a grid; provides an active reserve of power and energy that can be used to energize transmission and distribution lines, provides start-up power for generators, or provides a reference frequency. Black start services to the grid are represented in the market for only a couple of ISO/RTOs.
- **Transmission and distribution deferral** keeps the loading of the transmission or distribution system equipment lower than a specified maximum. This allows for delays or completely avoids the need to upgrade a transmission system or avoids congestion-related costs and charges. ISOs/RTOs often reflect this value to the grid through programs such as financial transmission rights, congestion revenue rights, or locational marginal pricing.

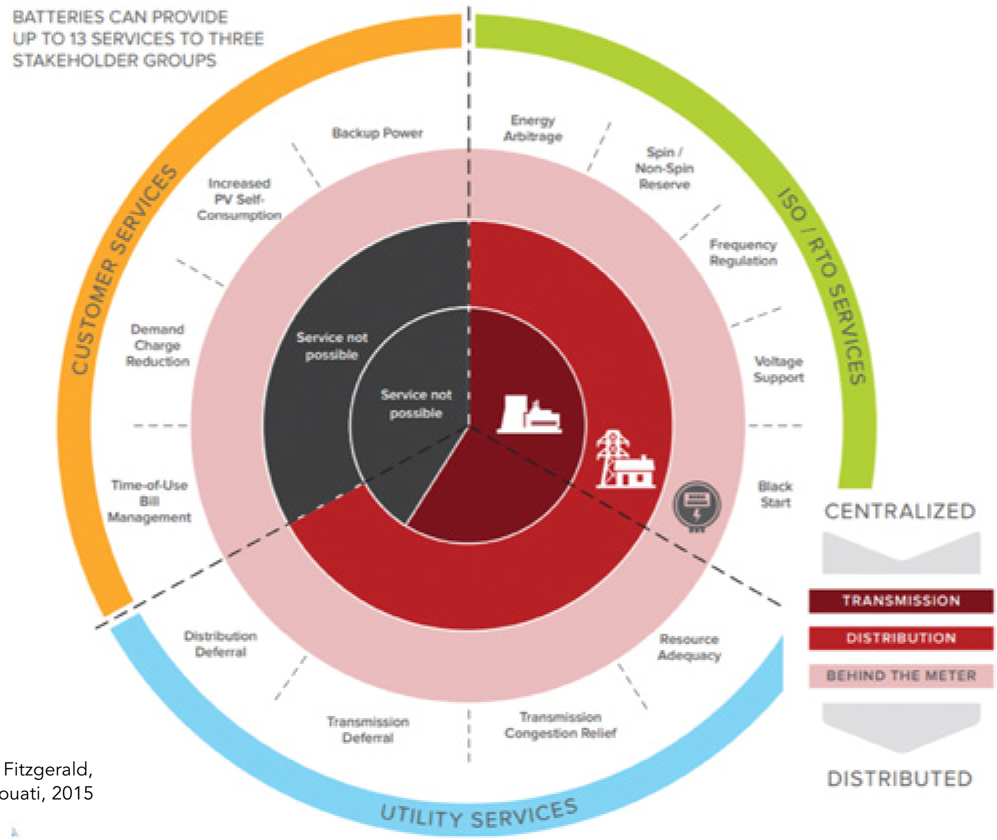
9 Transmission and distribution services from BES can either come from centralized installations interconnecting along the transmission or distribution network or from aggregating many BTM BES assets.

10 BES service definitions taken verbatim from the referenced EIA report; references to wholesale markets are provided by this author. See https://www.eia.gov/analysis/studies/electricity/batterystorage/archive/2018/pdf/battery_storage.pdf.

- **Co-located generator firming** provides *constant output power* over a certain period of a combined generator and energy storage system. Often the generator in this case is a non-dispatchable renewable generator (e.g., wind or solar). (EIA, 2018)

See *Figure 6* for an illustration of a broad range of BES services and their likely installation location.

Figure 6: BES Range of Services and Installation Locations



Source: K Y Mou N, Fitzgerald, Mandel, Morris, & Touati, 2015

This paper focuses on two primary measures for BES adoption: Power Capacity and Energy Availability.

- **Power capacity** is the power rating, which is measured in watts, and reflects how many watts can instantaneously flow in or out of the BES.
- **Energy availability** is the energy rating (sometimes called battery capacity), which is measured in units of watt-hours, and reflects how much energy the battery can store, or how much power can be delivered over a given period of time (McLaren, 2016).

To make meaningful comparisons between states with vastly different populations and loads, power capacity values are normalized by each state's summer peak load, and energy availability values are normalized by each state's retail sales. Normalization of power capacity and energy availability outcomes are primarily examined here, since the question of interest is not how much overall BES adoption is happening, but rather how meaningful is that BES adoption to the region? Hawaii's adoption of 31MW/42MWh is more meaningful to that state than Arizona's 35MW or Texas' 58MWh. This is primarily due to the intended audience of this research being state level decision makers.[11]

A count of unique services provided by BES projects is a third measure of BES adoption used in this analysis.

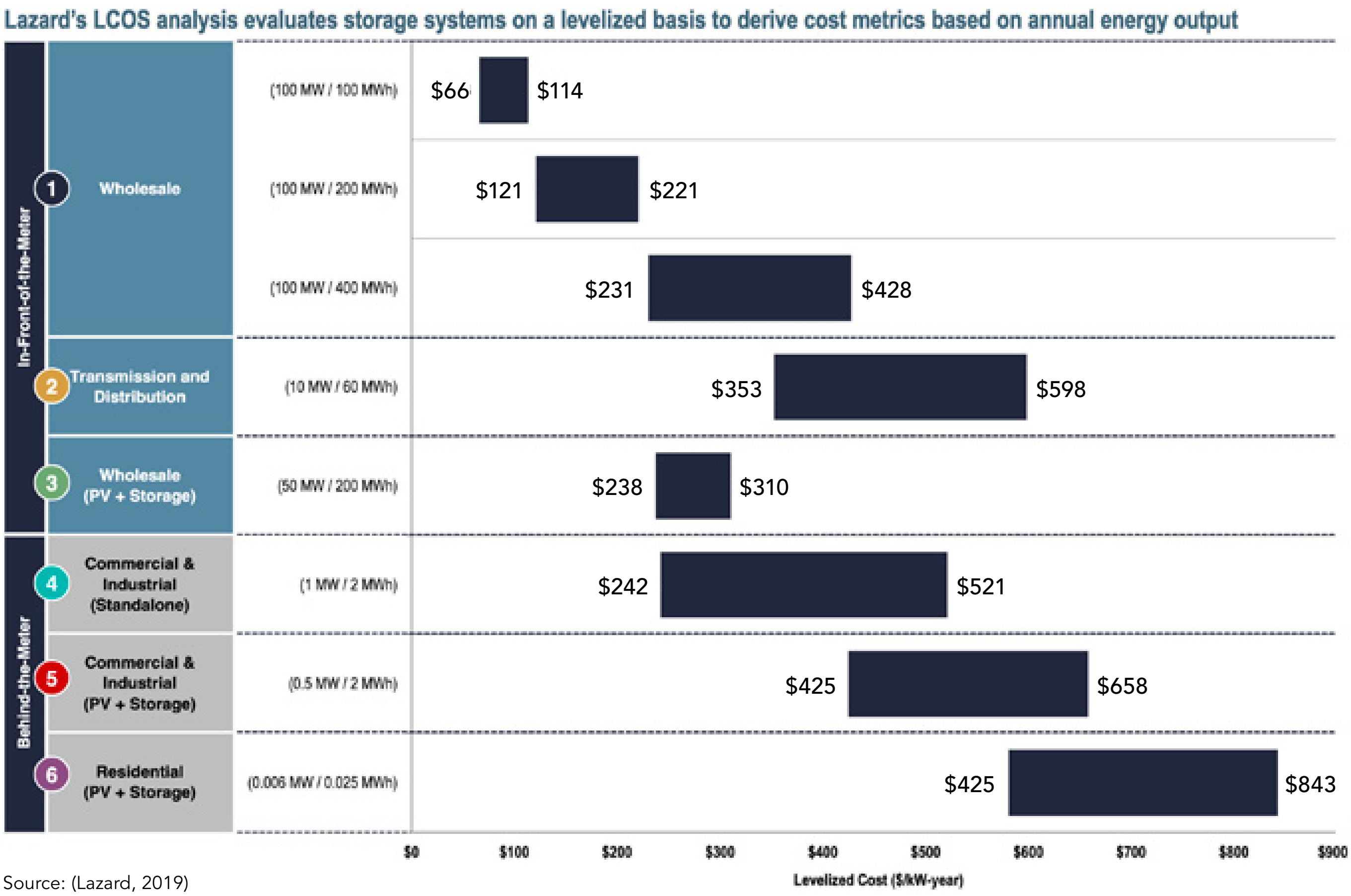
11 From the perspective of technology developers, overall scale of BES adoption is a greater concern.

Cost and Value

Costs for BES have been decreasing each year since 2010, due to technological advancements and economies of scale associated with growing adoption. Unlike some other industries, however, a downward-sloping cost curve is not guaranteed for BES. Material supply constraints may trigger scarcity pricing that offsets the cost reductions (Lazard, 2018).

The unsubsidized Levelized Cost of Storage (LCOS), the means by which different energy storage technologies are compared against one another and legacy providers of services, for BES is not yet consistently lower than legacy alternatives. Lazard's most recent (2019) comparative study of LCOS found that lithium ion and other BES technologies are frequently more expensive than the fossil fuel alternative for the same service, but that some of these technologies are rapidly becoming cost competitive with costs falling year-over-year (Levelized Cost of Storage Analysis - Version 5.0, 2019). See *Figure 7* for the most recent LCOS for BES.

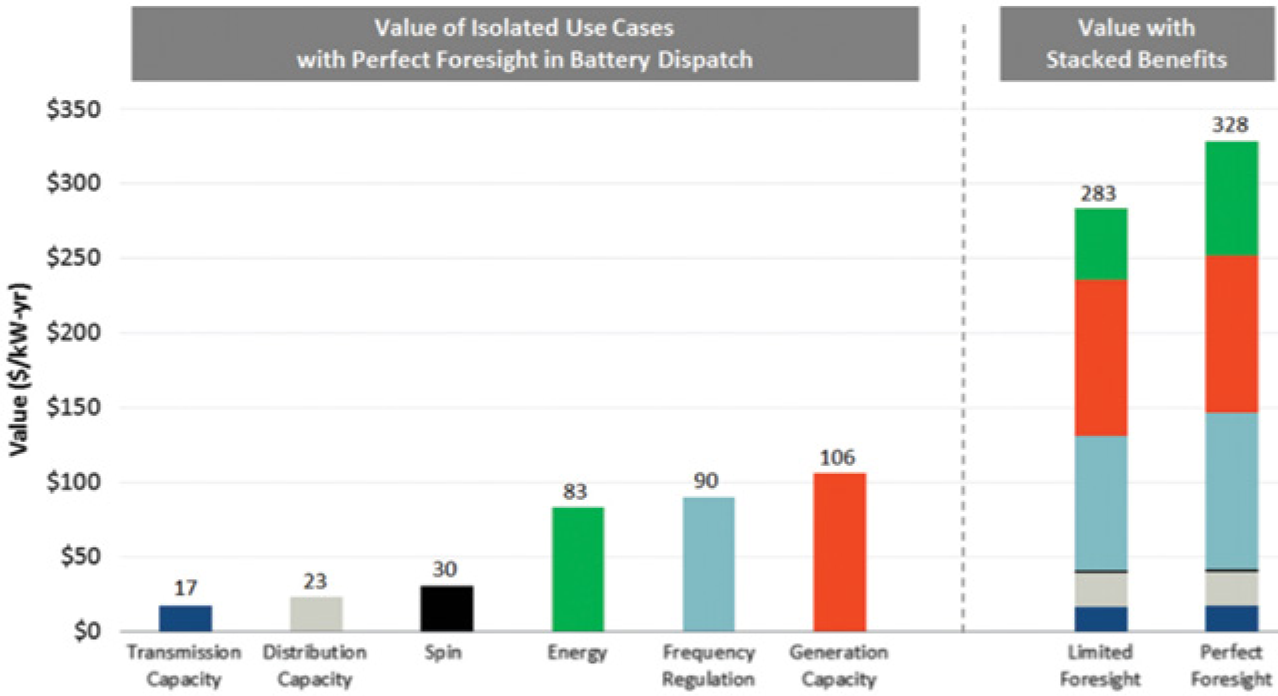
Figure 7: Levelized Cost of Storage by Illustrative Use, Unsubsidized



Source: (Lazard, 2019)

Many BES projects can offer multiple services in the same installation. This is called value stacking. Not only does it represent an efficient deployment of capital, but also the potential stacking of revenue streams that, when allowed, can make BES projects viable or profitable more quickly. See *Figure 8* for a graphic example of how value stacking increases revenue potential.

Figure 8: Illustration of Value Stacking in a California Grid-Scale BES Project



Source: Hledik, Lueken, Mcintyre, & Bishop, 2017

When comparing the individual values shown in *Figure 8* to the 2019 levelized cost of storage in *Figure 7*, it becomes clear why value stacking is necessary to make projects financially viable. This figure represents value stacking of wholesale energy services. Value stacking can also be found for retail services, as well as for a combination of wholesale and retail services.

Barriers to Adoption

Now that we have established several drivers for demand for BES, this section examines the barriers to adoption of BES, in addition to cost. This section primarily outlines market failures but also discusses some other barriers to adoption.

The principle market failure that leads battery energy storage to face a higher LCOS than legacy alternatives is missing markets. The nature of missing markets differs by BES application but can be summarized relatively simply.

Missing Markets – Positive Externalities

Value stacking is the term used for recognizing and monetizing the actual value streams (multiple) that a technology offers in its operation or existence across various services that provide benefits to customers and/or the grid. Currently, there are inadequate means to monetize most of the benefits that BES provides, and certainly to sum the ones that can be offered concurrently.

Wholesale electricity markets, designed as they were for legacy technologies, impose "operation obstacles for value stacking" of grid scale energy storage. Rigid storage charging requirements limit opportunities for project optimization, and inadequate market operational limitations increase the cost of financing energy storage, due to risks associated with the battery's useful life (Lee, 2017b). And some of the definitions built into the rules preclude some forms of battery energy storage from competing on a level playing field with legacy technologies. For example, battery energy storage installed on the distribution grid is often charged a retail rate for the electricity consumed during charging, but BES owners can only sell electricity back at a wholesale rate (Canada, 2018).

Retail electricity rates rarely reflect the marginal cost of electricity at the exact time the electricity is consumed. Many customers see a flat marginal rate, which includes some marginal costs, and some fixed costs. Some customers see increasing block pricing for that marginal cost, if their consumption exceeds thresholds within a billing period. Marginal pricing is challenging for utilities to accomplish for a number of different reasons, but TOU rates have been one method to achieve pricing that more closely matches marginal pricing. TOU rates charge more for marginal electricity used during periods of the day that, historically, have higher marginal wholesale costs, and lower at other times. This rate structure allows for more efficient market signals to electricity consumers, but is not widely adopted. Industrial and commercial retail customers are often subject to TOU rates, but residential retail customers rarely are. California is rolling out the nation's largest residential TOU rate program across its three major IOUs (Trabish, 2019), whereas utilities in twenty-eight other states[12] are in various phases of trials of new TOU residential rate structures. Without TOU rates, or other marginal cost pricing structures, the arbitrage value function of BES would not be available to would-be behind-the-meter adopters.

Missing Markets – Negative Externalities

The negative externalities for fossil fuel powered generation are well documented. The social cost of CO2 as well as the economic value of health co-benefits for reduced SO_2 and NO_X emissions have been calculated by the U.S. Environmental Protection Agency (United States Environmental Protection Agency, 2015). The federal government has regulations on many of these emissions, but it is largely left to state policies to incorporate the cost of externalities of GHG emissions into the price of electricity generation. California's Cap-and-Trade program is one example of a state policy that does this. The marginal price of electricity across the nation still does not appear to reflect the totality of these externalities, and is often lower than the social marginal cost (Borenstein & Bushnell, 2018).

Moreover, since the early 2000s, advances in hydraulic fracturing extraction techniques revealed many new sources of domestic natural gas. With these new supplies, natural gas prices plummeted in 2009 to a fraction of its cost earlier in the decade, and have since remained low. Ample supply is not the only reason natural gas prices are persistently low. Environmental regulation of fracking has not kept pace with the technology advances, and has yet to internalize the costs to the environment of that extraction technique. Natural gas generators are a substitute provider of a number of the services that BES solutions can provide, most notably frequency regulation. The persistent low input fuel price for natural gas (where negative externalities are excluded from pricing) is one driver of limited success of many energy storage technologies at large scale adoption (Hittinger & Lueken, 2015). This challenge persists for all non-renewable fuels (e.g., coal mining) where environmental externalities are excluded from pricing.

Monopoly Utility Institutional Barriers

Whether BES technology is installed at the distribution or transmission (grid scale) level, or behind a retail customer's meter, there are transaction costs associated with garnering the necessary approval for interconnection and operation. Some utilities do not have a formalized method for these interconnection agreements for BTM storage. For those that do, there are often fees and waiting periods. Grid-scale projects must pass rigorous review with utilities, and, sometimes, with regional grid operators or federal regulators. Time, in project development, is money.

Battery energy storage project developers who wish to monetize stacked values associated with their product often do not have visibility into which parts of the grid might realize the most benefit from those services. Utilities possess information about congestion and age of infrastructure within the distribution grid they own,

12 Arizona, Colorado, Connecticut, Florida, Georgia, Hawaii, Iowa, Idaho, Illinois, Indiana, Louisiana, Maryland, Maine, Michigan, Minnesota, North Carolina, North Dakota, New Jersey, Nevada, New York, Ohio, Oklahoma, Oregon, South Carolina, South Dakota, Texas, Vermont, and Wisconsin. Source: Form EIA-861

but very little of that information is made available to market players. Locational marginal pricing is publicly available in some regions, but data on congestion is not always available. Absent regulatory action, there is little incentive for utilities to share detailed distribution-level data with potential competitors, and the information asymmetry that results exacerbates the missing markets failure.

Innovation Barriers

Rational consumers of new technology are often skeptical of making procurement decisions while the technology is early in its learning curve. This is the early adopter problem. Early adopters presumably get some value out of adopting newer technologies (such as building an innovative culture, or teaching staff how to use the technology), but they also face trade-offs associated with purchasing technologies that may become obsolete, or whose costs will be higher than what might be available if procurement decisions are delayed. At the utility level, because there is little-to-no competition within the ownership structure, there is little incentive to overcome the early adopter problem.

The Maryland Public Service Commission (MDPSC) initiated Public Conference 44 (PC44) in 2016 to review a wide range of issues related to the modernization of its distribution grid, including DERs. In 2019, Maryland passed legislation to establish an energy storage pilot program.

The Energy Storage Working Group, created as part of PC44, issued a draft proposal in 2019 for a proof of regulatory concept program to "test innovative regulatory and business models for energy storage that have the potential to reduce ratepayer costs and provide benefits to customers, utilities, competitive storage providers, and the electric grid."

Project Type	Storage Ownership	Storage Control for Grid Reliability	Storage Operation in Wholesale Markets	Direct Effect on Ratepayer Revenue Requirements
Multiple-Use 1: utility only	Utility	Utility	Utility	Coverage of storage investment less revenue from wholesale market transactions
Multiple-Use 2: utility and 3rd party	Utility	Utility	3rd party	Coverage of storage investment less 3rd party lease or contract for wholesale transactions
3rd Party Ownership	3rd party	Utility	3rd party	Utility payment to 3rd party for priority access to storage for grid reliability
Virtual Power Plant	Customer or 3rd party	Utility via aggregator; utility as aggregator	Utility and/or 3rd party as aggregator, if at all	Utility payment to aggregator for priority access for grid reliability; Utility payment to storage owner if utility is aggregator

The proposed program involves a three-year pilot for planning, development, and operation of BES assets under four distinct models, shown below. These pilots will be evaluated across a range of metrics aimed to determine which model(s) produces better outcomes for customers, utilities, competitive storage providers, and the electric grid. (EnergyStorageWorkingGroup, 2019) By Order No. 89240, issued on August 23, 2019, the MDPSC established the energy storage proof of concept pilot program.[13]

Utilities are last in research and development spending among all industries, allocating merely 0.2 percent of sales on R&D.[14] Due to technological spillover, it is thought the wider market, in general, under-invests in technological development. The federal government intervenes to offset some of this market failure through programs administered by agencies within the Department of Energy, such as the Advanced Research Projects Agency-Energy (ARPA-E).

13 *In the Matter of Transforming Maryland's Electric Distribution Systems to Ensure That Electric Service is Customer-Centered, Affordable, Reliable and Environmentally Sustainable in Maryland*, Public Conference 44 (PC44), Order No. 89240 (Aug. 23, 2019).

14 Cyril Yee, Rocky Mountain Institute, presentation on NARUC webinar, "Dream Machine: The U.S. Energy Research & Development (R&D) Ecosystem," December 19, 2019.

Regulatory Uncertainty

Financing new technology start-up ventures, as well as financing energy development projects, relies on funding partners who have some level of confidence their investment will return profitably in the future. When regulatory bodies introduce uncertainty into revenue capture by shifting policies, the cost of financing goes up, and sometimes becomes unaffordable entirely.

Political Feasibility

Policies that appear to favor specific technologies (e.g., installation targets) are sometimes discussed by critics as "picking winners and losers," which is a framing intended to decry this policy approach. This rhetoric often intentionally over-simplifies the issue by ignoring the advantage enjoyed by incumbency and legacy technologies, while failing to acknowledge the importance of addressing the missing markets issues outlined above.

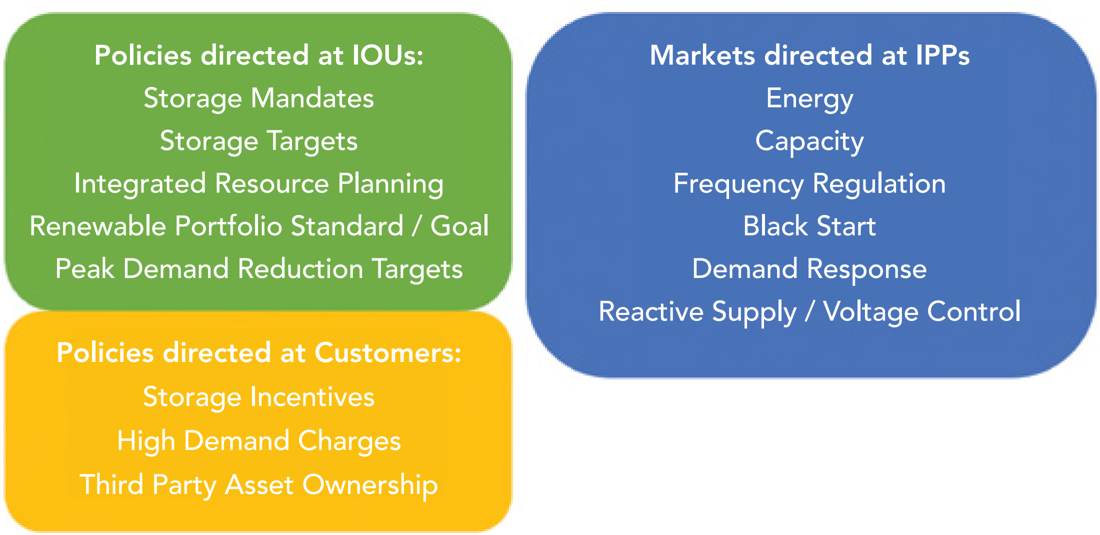
Conversely, a compelling case has been made in some cases that new technologies bring an opportunity to grow economic activity and job opportunities that don't currently exist within a region. As a result, it sometimes becomes politically feasible to set goals or targets that encourage certain technologies to bring some part of their value chain within a jurisdiction's borders.

> Arkansas passed legislation in March 2019 allowing third-party ownership and financing of BTM generation. This legislation does not allow PPAs, but does allow lease arrangements. IOUs were against the legislation, and solar developers in favor. One of the major factors in the legislation's favor was the strong support given to it by Walmart, which is headquartered in Arkansas, and seeks to install solar on many of its stores' rooftops. In states reticent to fight the strong influence of established, vertically integrated IOUs, it is clear the influence of other major economic players within the state can be leveraged to achieve changes that push utilities to newer technologies. (Morehouse, 2019a).

Intervention Options

This section outlines policies and other interventions that, either purposely or incidentally, may encourage BES adoption. These interventions can be broadly categorized by who is targeted, as shown in *Figure 9*:

Figure 9: Interventions Driving BES Adoption and Their Targeted Audience



15 IPP refers to Independent Power Producer.

Storage mandates, targets, and incentives are all policies aimed at having a direct impact on the adoption of BES (or other storage technologies). Integrated Resource Planning, Renewable Portfolio Standards, Renewable Portfolio Goals, and High Demand Charges are policies or rate mechanisms that have an indirect impact on BES adoption through their potential to increase demand for BES. Third-party (generation) asset ownership (whether it is permitted in a state) is less a policy and more a matter of legal standing. And all the wholesale markets listed on the right side of *Figure 9* are a reflection of grid operation requirements, each with its own potential indirect impact on demand for BES adoption. Some of these are discussed in more detail below.

Storage Mandates

One direct enticement policy approach is to direct electric utilities to procure BES projects. California did just this with AB 2154 and AB 2868 (Esch & Keller, 2018). In response to this legislation, in 2013, the California Public Utilities Commission (CPUC) directed the state's three IOUs to procure a total of 1,325MW of energy storage by 2024 (Maloney, 2018a). In 2017, the legislature added 500MW of distribution-connected storage to this target (Maloney, 2017a). The energy storage targets are divided into requirements for transmission-connected projects, distribution-connected projects, and BTM projects. IOUs are free to use any combination of potential grid services that energy storage may offer, and are limited to owning up to 50 percent of the assets procured (Kintner-Meyer, 2014). The CPUC rulings allow IOUs to include theoretical social value when they calculate energy storage procurement cost effectiveness (such as social benefit of emissions avoided), instead of only including traditionally monetized values. If actual costs do exceed actual benefits (not including social benefits), the utility is eligible to recover the costs (Lee, 2017b). Massachusetts, New York, Oregon, and Nevada also have storage targets or mandates, ranging from 10MWh by 2020 to 3,000MW by 2030.[16]

This analysis examines correlations between BES adoption and enticement policies in effect, well ahead of the end of the observation period (observation period 2010 through 2018). Based on the success of early states' mandates and targets, similar policies are being considered in other states (Maloney, 2018b). These are likely to increase BES adoption in meaningful ways for these states, while also driving down the cost of BES technologies. A question remains: for states with targets or mandates within an RTO/ISO subject to FERC Order 841 (discussed further below), can BES that satisfies those mandates or targets also compete in wholesale markets for services?

Incentives

Another policy approach is to provide cash incentives to developers of BES projects. Sometimes these incentives can take the form of grants for pilot projects, as in the case of Massachusetts's Advancing Commonwealth Energy Storage (ACES) demonstration program. ACES provides grant and matching funds for 26 BES projects of various scales and applications.

California has another kind of incentive program. California created the Self-Generation Incentive Program (SGIP) in 2001 to provide subsidies to BTM electricity generation projects, targeting technologies that would help California increase its renewable energy production, or otherwise further the state's GHG emissions reduction efforts. In 2017, the CPUC directed IOUs to collect $83 million from ratepayers (2017 to 2019) to fund SGIP subsidies that would be divided between renewable energy projects (15 percent) and energy storage projects (85 percent). By statute, 90 percent of those energy storage funds will go toward projects that are likely to be C&I scale (greater than 10kW in size), whereas 10 percent will go toward residential scale projects (lower than 10kW in size) (Cohn, 2017). These subsidies will be given to project developers as a rebate on a capped percentage of the energy storage project development cost.

16 Energy Storage Association, https://energystorage.org/energy-storage-goals-targets-and-mandates-whats-the-difference/.

Markets

BES adoption can be spurred by setting up a competitive market for some of the grid-level services which the technology can provide. Resource adequacy, reserves, and frequency regulation are some of the services for which wholesale markets have been created in some RTOs.

PJM Interconnection LLC's (PJM[17]) response to FERC orders on frequency regulation markets[18] yielded fast response through high volume adoption of BES (EIA, 2018), and is a good example of a market driver of BES. PJM's Frequency Market design in 2012 shifted to consist of two frequency regulation components: slow and fast. Slow components make up what traditionally provided frequency response services: existing turbine power plants which can provide frequency support for extended durations. Fast components can ramp quicker to meet immediate frequency support demands, but have shorter duration. Fast component frequency regulation demand is well suited to battery energy storage technology (Lee, 2017a). Before to this change, BES was unable to be competitively bid into the frequency regulation market.

In 2018, FERC issued Order 841, which requires RTO/ISOs to

> *"establish a participation model consisting of market rules that, recognizing the physical and operational characteristics of electric storage resources (ESRs), facilitates their participation in the regional transmission organization (RTO) and independent system operator (ISO) markets."* (Esch & Keller, 2018)

RTO/ISOs submitted their plans in December 2018 and are expected to complete implementation by December 2019.[19] FERC and industry groups have been unsatisfied with some provisions in each RTO/ISO submission, and negotiations continue to determine the final format of each participation model (St. John, 2019b).

Some states and RTO/ISOs are concerned about the speed of implementation required in the FERC order, especially as FERC recently ruled states may not opt-out of FERC 841 paradigm if they have an RTO/ISO within their jurisdiction (Gheorghiu, 2019b).

This order and the participation model design of each RTO/ISO is likely to have a dramatic impact on BES adoption in the years to come.

Retail Rate Structure

Retail rate structures are discussed above as a driver of BES adoption (Retail Customer Interest). To the extent retail rates are designed to reimburse utilities in a fair and equitable manner, as well as encourage economically efficient consumption of electricity, they are not specifically considered a policy mechanism for BES adoption. Recognizing rate design can impact BES adoption, however, may spur some policy makers and regulators to consider actively pursuing retail rate structural changes for the purpose of achieving a more optimal level of BES adoption.

In a forthcoming report, Satchwell, Cappers, and Barbose[20] outline five trends in retail rate design, and all but one of the five trends have the potential to accelerate the adoption of BES. To tie the table below to concepts outlined previously:

17 PJM stands for Pennsylvania-Jersey-Maryland and refers to the PJM Interconnection regional transmission organization.

18 In particular, FERC orders 755 and order 784. "Frequency Regulation Compensation in the Organized Wholesale Power Markets, Order No. 755, 76 FR. 67260 (Oct. 31, 2011), FERC Stats. & Regs. ¶ 31,324 (2011)," https://www.ferc.gov/sites/default/files/2020-06/OrderNo.755.pdf and "Third-Party Provision of Ancillary Services; Accounting and Financial Reporting for New Electric Storage Technologies, Order No. 784, 18 CFR Parts 35, 101, and 141 (July 18, 2013), FERC Stats. & Regs. ¶ 61,056 (2013)," https://www.ferc.gov/sites/default/files/2020-06/OrderNo.784_0.pdf.

19 Since research was completed for this paper, the U.S. Court of Appeals for the DC Circuit ruled on a suit filed by NARUC and others, Nat'l Assoc. of Regulatory v. FERC, contesting FERC's authority in asserting that states may not "broadly prohibit" local, state regulated electric storage resources on the distribution system from participating in federally regulated wholesale markets. On July 10, 2020, the Court ruled that FERC was within its authority in issuing Order No. 841; see: https://www.cadc.uscourts.gov/internet/opinions.nsf/E12B1903B0477E21852585A1005264D7/$file/19-1142-1851001.pdf.

20 Satchwell et al., 2019

- Time-Based Rates are equivalent to TOU rates
- Load Building Rates are TOU rates specifically designed to encourage demand at certain times of the day
- 3-Part Rates are the addition of demand charges to fixed and volumetric charges for residential customers
- NEM Alternatives are changes to the mechanism of reimbursement for renewable generation exported to the grid from behind a customer's meter
- EV-Specific Rates are intended to increase demand of EVs, but often also have a time-based or load building component to them to encourage EV charging behavior which benefits the grid

Table 1: Potential Impacts on Near-Term DER Deployment Levels.

Rate Design Trend	PV	Energy Efficiency	EV and Electrification	Storage and Demand Response
Time-Based Rates	Highly constrained, Slightly constrained, No impact, Slightly accelerated	Slightly constrained, No impact, Slightly accelerated	Slightly accelerated	Slightly accelerated
Load Building Rates	Highly constrained, Slightly constrained, No impact	Slightly constrained, No impact	No impact, Slightly accelerated, Highly accelerated	Slightly accelerated, Highly accelerated
3-Part Rates	Highly constrained, Slightly constrained	Slightly constrained	Highly constrained, Slightly constrained, No impact, Slightly accelerated	Slightly accelerated, Highly accelerated
NEM Alternatives	Highly constrained, Slightly constrained, No impact	Slightly constrained, No impact	No impact, Slightly accelerated, Highly accelerated	No impact, Slightly accelerated, Highly accelerated
EV-Specific Rates	No impact	No impact	Slightly accelerated, Highly accelerated	No impact

● Highly constrained ● Slightly constrained ● No impact ● Slightly accelerated ● Highly accelerated

Source: Satchwell, Cappers, & Barbose, 2019

The authors note that the trends are in some cases in response to DER adoption; in large part, the trends are a result of:

> *"widespread adoption of advanced metering infrastructure (AMI), increased customer investment in solar and other distributed energy resources (DERs), concerns about utilities' fixed cost recovery and revenue sufficiency in an era of flat or declining load growth, and significant changes to utilities' hourly net load profiles and operational needs as greater amounts of variable renewable energy (VRE) resources connect to the grid."*

And further note the importance of the following details in rate design trends in the magnitude and directionality of impact on DERs:

> *"the timing and peak-to-off-peak pricing differential under time-based rates, the choice between intermittent vs. continuous incentives to increase midday load, the use of coincident vs. non-coincident demand charges, the specific price paid for grid exports under net billing rates, and whether or not EV-specific rates are sub-metered vs. applied on a whole-house basis"*

IRP & DRP

Integrated Resource Planning (IRP) and Distributed Resources Plans (DRP) are tools utilities use to plan and communicate to state regulators what services their customers will demand for a future period, and how they plan on satisfying that demand (what resources need to be procured, upgraded, etc.). Increasingly these planning tools are incorporating evaluation of BES technologies, both at the transmission and distribution levels, and some states are requiring consideration of DERs generally, BES specifically (Esch & Keller, 2018). Logic suggests that a utility that explicitly evaluates the costs and benefits of any newer technology is more likely to adopt that technology (provided benefits outweigh costs along some timeline) than a utility that does not conduct a cost and benefit assessment. Because values of BES to the transmission and distribution system can be stacked, and are more easily quantified by and accrued to the owner of transmission and distribution assets, states where IRPs and/or DRPs are required may see faster adoption of BES technology if they incorporate up-to-date cost and performance data.

Third-Party Asset Ownership

As with BTM solar, third-party financing can make BES adoption by retail customers a more attractive option. For some, it may be the only affordable method of achieving BES adoption. The solar industry encountered some obstacles to third-party financing, in that third parties are disallowed from owning generation assets. This barrier was resolved in some states, but not all. The extent to which state policy has evolved to accommodate third-party asset ownership and financing, and that evolution allows participation of BES technology, will likely impact the rate of adoption of BES.

Findings

To understand better the relationship between the adoption of BES technology and regulated utility structure (vertically integrated versus restructured), this analysis focuses on IOUs in the United States and seeks to understand if the variation in IOU structure has any observable correlation with BES adoption. This analysis also seeks to understand the policy and market drivers of adoption and the extent to which those drivers differ depending on IOU structure.

In absolute numbers, the data show higher overall BES adoption (cumulative power capacity) in restructured IOU territory. However, as explained earlier, the normalized adoption of battery capacity (cumulative rated capacity relative to state size, for both power and energy measurements) is more important for conducting analysis of the effectiveness of interventions.

A summary of the findings around **normalized** adoption follows:

- States with vertically integrated IOUs have seen essentially the same effective adoption of battery capacity in their IOU territory as states with restructured IOUs.
- For states with vertically integrated IOUs:
    - Battery adoption is positively correlated with **renewable portfolio goals and standards**, and **higher system reliability** (fewer minutes of outages);
    - Battery storage projects are observed to provide more grid services.
- For states with restructured IOUs:
    - Battery adoption is positively correlated with **higher penetration of renewable energy generation**, **storage mandates**, and **markets for capacity and demand response**;
    - Battery storage projects are observed to provide more BTM services (suggestive of the potential to value stack) and adopt more unique battery services overall, which suggests a higher willingness to experiment with the technology's capabilities.
- **Higher penetration of VRE generation, higher grid modernization indices, allowance of third-party asset ownership**, policies such as **storage mandates, targets, incentives**, as well as **markets for demand response services** are all positively correlated with more numerous battery services.

None of these findings create a clear case for IOU structure itself being an impediment to adoption of BES.

Several points should be noted, however:

- Given the clear findings that more raw power capacity of BES adoption happens in restructured IOU territory, technology developers can reasonably view vertically integrated IOU structure as a barrier to adoption at this point in time. Many of the policy and market drivers included in the quantitative analysis are distilled to binary variables, when the nuances of the policies and markets likely have considerable impact on adoption outcomes. Further research that adds nuance to measures of policies and markets may yield more meaningful findings of correlation than this research uncovers.
- These findings are not generalizable for other kinds of electric industry technologies.

The following pages show findings for each of the three specific questions analyzed.

Question 1: Has battery adoption been higher in territories served by vertically integrated or restructured IOUs?

BES adoption is analyzed here primarily using two ratings for BES projects: Power Capacity and Energy Availability.

- **Power capacity** is the power rating, which is measured in watts, and reflects how many watts can instantaneously flow in or out of the BES.
- **Energy availability** is the energy rating (sometimes called battery capacity), which is measured in units of watt-hours, and reflects how much energy the battery can store, or how much power can be delivered over a given period of time (McLaren, 2016).

The total rated power capacity and energy availability of BES observed is greater in restructured IOUs. When analyzed with linear regression, this finding is statistically significant for rated power capacity only.21 (See Appendix A for methodology details and Appendix B for detailed findings.)

To make meaningful comparisons between states with vastly different populations and loads, power capacity values are normalized by each state's summer peak load, and energy availability values are normalized by each state's retail sales. Normalization of power capacity and energy availability outcomes are primarily examined here, since the question of interest is not how much overall BES adoption is happening, but rather how meaningful is that BES adoption to the region? Hawaii's adoption of 31MW/42MWh is more meaningful to that state than Arizona's 35MW or Texas' 58MWh. This is primarily due to the intended audience of this research being state level decision makers.

Below are plots of the aggregated rated power capacity (MW - *Figure 10*) and energy availability (MWh - *Figure 11*) operational in IOU territory in each state, along with the normalized values.[22] These figures show the importance of normalizing power and energy availability. On the basis of volume alone, California's BES adoption far outweighs all other states, but when the size of each state is used in the denominator to normalize the power and energy availability, the relative importance of that state's BES adoption can be more easily understood.

Figure 10: Top 15 States by Normalized BES Power Capacity

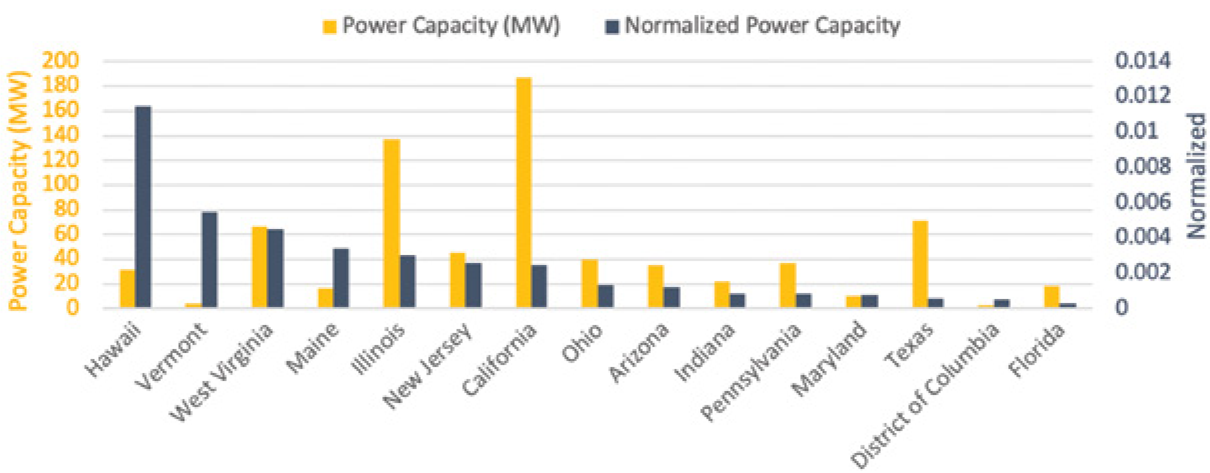
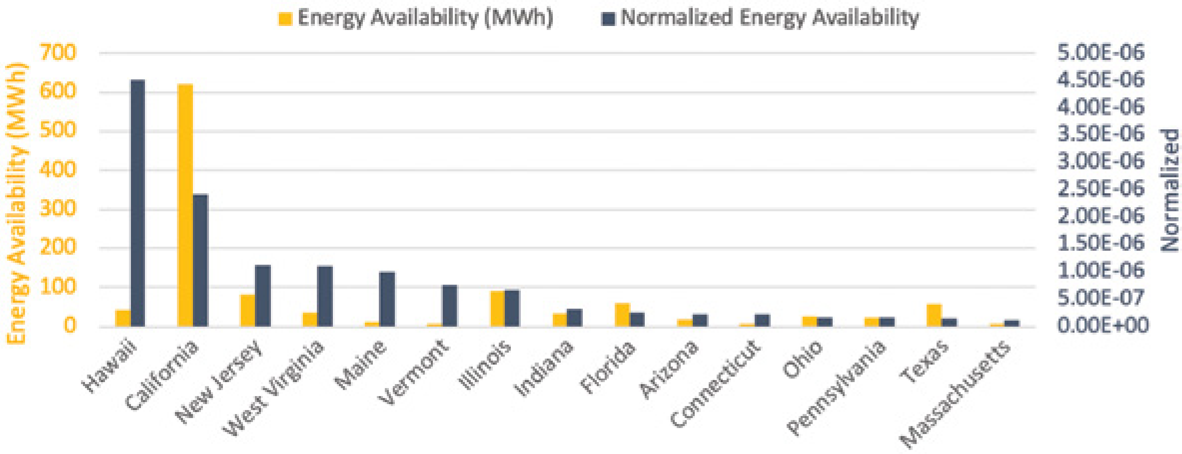


Figure 11: Top 15 States by Normalized BES Energy Availability



The normalized power capacity and energy availability is only marginally greater in restructured IOUs. When analyzed with linear regression, no statistically significant difference between vertically integrated and restructured IOUs is found for normalized power capacity or normalized energy availability measures. Control variables added are not significantly correlated to BES adoption outcomes, except that there is a strong, statistically significant positive correlation on an interaction between restructured IOUs and VRE penetration. This suggests that, for normalized measures of power capacity and energy availability, battery adoption is positively correlated with high VRE penetration in restructured IOUs, but not in vertically integrated IOUs. There is a similarly significant, though lower magnitude, interaction relationship between the presence of a demand response market in restructured IOUs.

Question 2: Have battery service offerings (i.e., grid support services beyond energy and capacity) been more widely used in territories served by vertically integrated or restructured IOUs?

BES adoption is analyzed in this question by looking at the range of services provided by BES projects, both at the project level, as well as aggregated at the state level. BES services are further categorized in this analysis as either grid services, or BTM services. Question 2 is split in two unique parts:

1. Is a project expected to have more service offerings if it is located within a vertically integrated IOU, or a restructured IOU?
2. Is a state expected to observe more unique service offerings from its aggregated BES projects if its IOUs are vertically integrated or restructured?

Figure 12 and *Figure 13* show the range of values for unique service offerings that occur in BES projects in vertically integrated and restructured states, respectively. Higher values suggest more experimentation with and learning about the range of services BES potentially offers, either at the grid scale or BTM. (See Appendix A for additional details.)

Figure 12: Unique BES Service Offerings in Vertically Integrated IOUs

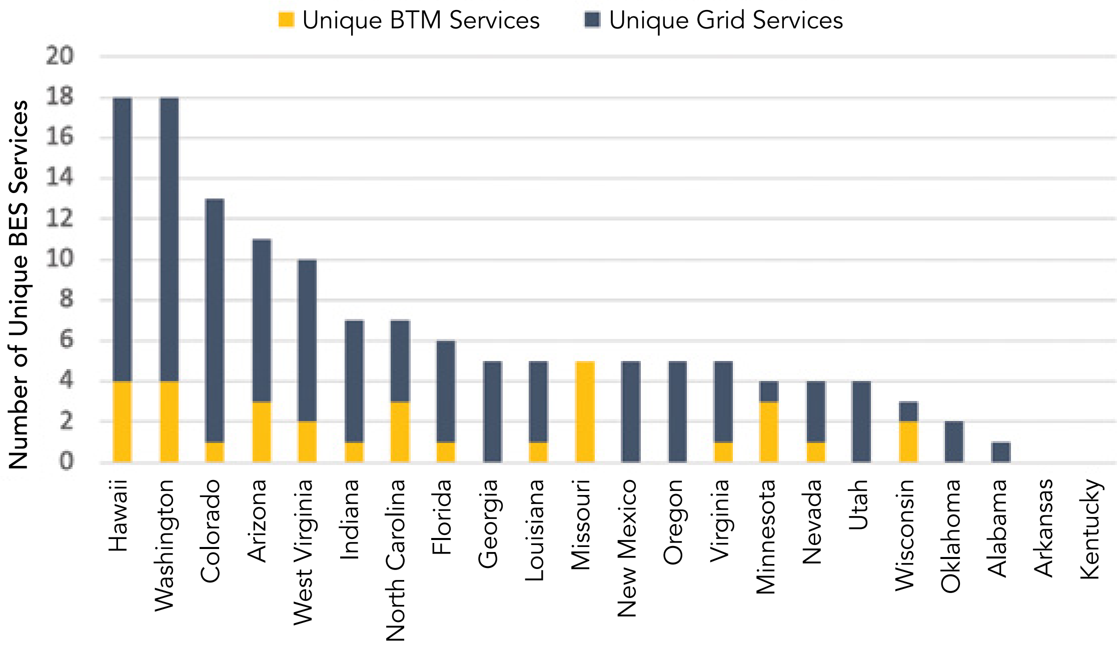
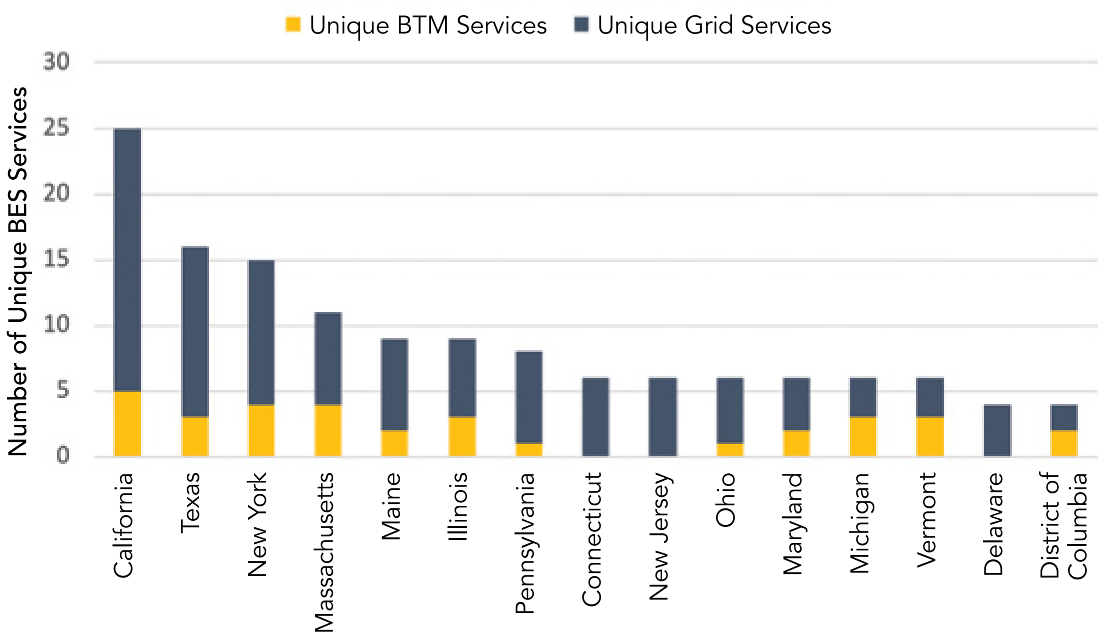


Figure 13: Unique BES Service Offerings in Restructured IOUs



1. Is a **project** expected to have more service offerings if it is located within a vertically integrated IOU, or a restructured IOU?

This question looks at project-level BES services. Regression analysis of all completed BES projects within the United States estimates **a project is likely to have more services if installed in** vertically integrated utility territory, though that appears to be driven largely by a higher number of **grid-level services** offered, rather than BTM services. These findings hold when control variables and variables related to policy and market mechanisms are considered.

In both vertically integrated and restructured IOUs, high demand charges are negatively correlated with the number of unique grid services, and this negative correlation is stronger in vertically integrated IOUs. This means fewer grid services are observed where demand charges are higher and the magnitude of that difference is higher in vertically integrated IOUs than restructured. Third-party asset ownership is positively correlated with more **grid service**s in both vertically integrated and restructured IOUs, and the positive correlation is stronger in restructured IOUs. This means more grid services are observed where third-party asset ownership is allowed and that effect is higher in restructured IOUs than vertically integrated.

In vertically integrated IOUs, analysis shows a strong positive correlation between VRE penetration and the number of unique BTM services. This means more unique BTM services are observed in vertically integrated IOUs, where more renewable energy operates.

In restructured IOUs, analysis shows a strong positive correlation between VRE penetration and the number of unique BTM services, as well as a strong interaction between VRE penetration and restructured utility territory. Projects in restructured utility territories with high penetrations of VRE have far greater number of **BTM services** than those in vertically integrated utility territories of similar VRE penetration.

Similar positive correlations and interactions with restructured utilities is observed for storage mandate policies, high demand charges, and where third-party asset ownership is allowed. When wholesale market status is considered, the finding of more services for BTM projects in restructured utility territory becomes stronger and statistically significant. Greater numbers of BTM services are positively correlated with the existence of demand response markets, and negatively correlated with the existence of capacity, storage-friendly frequency regulation, and black start markets. This means more unique BTM services are observed when a demand response market is present, and fewer services are observed in the presence of the other markets listed. All of the correlations outlined in this paragraph are statistically significant.

2. Is a **state** expected to observe more unique service offerings from its aggregated BES projects if its IOUs are vertically integrated or restructured?

This question examines aggregated BES services at the state level. When analyzed with linear regression, **no statistically significant difference** is found between vertically integrated and restructured IOUs in the number of unique service offerings.

In vertically integrated IOUs, capacity markets are strongly, negatively correlated with range of services. Third-party asset ownership is strongly correlated to and interacts with IOU structure, such that, where third-party asset ownership is not allowed, vertically integrated IOUs see a wider range of services than restructured IOUs. Conversely, where third-party asset ownership is allowed, restructured IOUs see a wider range of battery services. In basic terms, for vertically integrated IOUs, a wider range of services is observed at the state level when capacity markets are not present and when third-party asset ownership is not allowed.

In restructured IOUs, there is a strong, positive correlation and interaction between VRE penetration and range of services, and a similar strong, positive correlation and interaction between storage mandate policies and range of services. There are strong, positive correlations between the range of services and storage target policies, as well as demand response markets. In other words, for restructured IOUs, a wider range of services is observed where there is more renewable energy, where storage mandates and targets exist, and where there is a demand response market.

Question 3: Which policy mechanisms have been utilized and effective at spurring battery adoption, and how is that different in states with vertically integrated or restructured IOUs?

To perform this analysis, measures of BES adoption (normalized power capacity and energy availability ratings) in vertically integrated states are separated from those in restructured states. Linear regressions include variables for observed interventions (both policies and markets) as well as physical grid attributes (such as grid reliability measures, VRE penetration, etc.) which show correlations between interventions and BES adoption. (See Appendix A for methodology details and Appendix B for detailed statistical findings.)

In vertically integrated states, BES adoption in IOU territory is positively correlated with better reliability performance in the state (fewer minutes of outages), as well as existence of renewable portfolio goals, and negatively correlated with the existence of IRP requirements. There is a strong, positive interaction and correlation between renewable portfolio standards and goals, as they relate to BES adoption, though the correlation of BES adoption to actual VRE penetration, and the interaction between renewable penetration and policies which encourage renewable penetration are not statistically significant. This means that, **in states with vertically integrated IOUs, more BES adoption is observed where the grid is more reliable, and where renewable portfolio goals and standards are adopted (even if VRE penetration is not yet achieved)**. Also, for some reason, less BES adoption is observed where IRP requirements exist.

In restructured states, BES adoption in IOU territory is positively correlated with higher VRE penetration, storage mandates, as well as markets for capacity and demand response. This means **more BES adoption is observed in states with restructured IOUs that also have higher VRE penetration, storage mandates, and the specific wholesale markets for capacity and demand response.**

All correlations and interactions listed above are statistically significant, unless otherwise noted. Please note that all findings are based on relatively small sample sizes, and the measures of fit suggest many factors that have a stronger correlation are still not observed.

Recommendations

In spite of the limited conclusions that can be drawn from the data analysis, there are still some implications for consideration of regulators. The recommendations below are aimed at states interested in increasing BES adoption within the IOU service territories in their state, and stem from an important basic assumption about BES:

- BES value stacking is generally a preferable outcome to single-purpose BES because it facilitates greater project revenues (this may not be true for all projects, but is a fair assumption for BES adoption on the whole). Greater revenues increases the likelihood of private market entrance and capital investments in BES projects that don't need to be subsidized or mandated in the future. Also, getting more services from the same hardware investment increases overall societal efficiency.

The following recommendations regarding value stacking follow from the findings:

- States with restructured IOUs may wish to consider policy or market modifications to encourage more value stacking of grid services, since the data suggests vertically integrated IOUs are likely to see projects with a greater number of grid services in their territory.[23]
- States with vertically integrated IOUs may wish to consider policy modifications to encourage more value stacking of BTM services, since the data suggests restructured IOUs are likely to see projects with a greater number of BTM services in their territory.[24]
- Third-party asset ownership can be an enabler of value stacking in retail markets, wholesale markets, and even across the two; clarification or modification of rules on this topic can be improved in many states and some ISO/RTOs.[25]

The following state policy recommendations are suggested by the findings:

- Given the surprising negative correlation between IRP requirements and adoption of BES in vertically integrated IOUs (and less significantly so in restructured IOUs), regulators in states with vertically integrated IOUs may wish to evaluate whether their IRP requirements are robust enough to truly encourage the evaluation of newer technologies by their IOUs. Regulators may wish to consider explicitly requiring BES and other technologies be evaluated, and require metrics of evaluation from restructured IOUs (or, more generally, from states with higher penetration of BES) be used in their evaluation.[26]
- States with vertically integrated IOUs appear to get traction with BES adoption when they make a commitment to VRE generation, through renewable portfolio standards or goals. BES adoption in these states is not yet strongly correlated with actual renewable energy penetration. It is reasonable to expect

23 For example, California's storage mandate program encourages IOUs to experiment with value stacking of grid services.

24 Modifications to encourage value stacking of BTM services may not be generalizable. If one BES service dominates BTM installations in a state that may inform what policy modifications could be effective. For example, if commercial & industrial (C&I) BTM storage projects are primarily utilized for emergency backup or demand charge avoidance, encouragement of pairing solar and storage through incentives may result in more value-stacking by giving C&I customers a path to reducing their payback period.

25 To provide an example of an opportunity for improvement, in a recent report, Advanced Energy Economy outlined in greater detail barriers to wholesale market adoption of advanced technologies, such as BES, and noted an additional barrier related to third-party asset ownership: who is allowed to bid the services of the asset into wholesale markets. Even if third parties own assets, if they are not permitted, as is the case in PJM's proposed program, to bid the services of the asset into wholesale markets, financing and creating value from those assets becomes more difficult. (Economy, 2019)

26 Note that some states (including Arizona, California, Indiana, New Mexico, North Carolina, Oregon, and Washington) now explicitly require energy storage consideration in IRPs, with California and New Mexico specifically using new modeling methodologies to appropriately value storage (Maloney, 2017b). Meanwhile other states are beginning to, for the first time, push back on IRPs that do not consider storage, or appear to under value storage, such as Virginia (Spector, 2018; Merchant, 2018) and North Carolina (Walton, 2019). In some cases, utility customers themselves are providing the pressure to reconsider storage and other newer technology values in IRPs (Gheorghiu, 2019a). Further, NARUC Resolution EL-4/ERE-1, adopted in 2018, recommends principles for energy storage modeling within resource planning.

the states will achieve these goals, and this dynamic may shift, but it is also an indication that the intention to integrate renewable energy may be enough to encourage meaningful adoption of BES. Adoption of more ambitious renewable portfolio standards and goals could be pursued at the state or utility level to encourage greater BES.

- Storage mandates have yet to be adopted widely in states with vertically integrated IOUs, but regulatory structure does not preclude their use. If a state wants to encourage BES adoption, this is an effective policy. Whether the capital investment by an IOU for BES (in response to a storage mandate) is permitted to see rate-of-return profits, or is a straight pass-through to retail customers, is up to regulators – California is experimenting with both.[27] Allowing utilities to earn a rate-of-return on BES investments will encourage more speedy adoption by IOUs, but may impact the political feasibility of the policy, depending on dynamics within the state. This recommendation for expanded use of storage mandate or target policies is not limited to states with vertically integrated IOUs – these have also proven effective in states with restructured IOUs.[28]

These market-related recommendations are suggested by the findings:

- Frequency regulation markets, if they are to be served by and support the growth of BES technology, may have to be re-designed. PJM's fast response market should be reviewed for lessons learned.[29] Both its initial success and its eventual saturation offer important feedback for other markets.
- Demand response markets have the strongest correlation to meaningful BES adoption, as compared to other wholesale markets. Most ISO/RTOs have demand response markets of some kind (except ERCOT), but further improvements should be pursued to allow aggregators better access to these markets. Changes that increase access to newer technologies, while remaining technologically neutral, and standardization of communication requirements can increase BES adoption (among other technologies). Demand response services allow for more private investment in technologies which for services to grid operators, which can increase beneficial competition and lighten technological risks to utilities and their customers.
- This analysis found no statistically significant correlation between BES adoption and other wholesale markets. These findings provide some quantitative support to the concerns expressed in recent literature, and by stakeholders in interviews, that most wholesale market designs may not permit fair valuation of BES services. In fact, markets for demand response interact with many of the other wholesale markets (energy, capacity, other ancillary services) (Neukomm, Nubbe, & Fares, 2019). Advanced Energy Economy issued a report recently outlining wholesale market barriers to many new energy technologies (Economy, 2019), and many of the barriers identified speak to potential improvements to both capacity and ancillary markets, which can level the playing field for competition between incumbent and new technologies and create more opportunities for BES adoption. Its recommendations focus on dismantling the advantages to incumbent technologies built into existing markets (such as valuation of technology-specific fuel security attributes, real-time communication requirements, or processes that favor large, centralized installations), as well as expanding the revenue potential for grid services offered by BES and other technologies (such as valuation for more discrete grid services, avoiding derating capacity value of newer technologies, and communication and bidding policies that facilitate aggregation).

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27 California's storage mandates require a significant portion of BES projects built to satisfy the mandate be done so (and operated) by third parties. These costs will be passed through to rate payers, whereas projects developed and owned by utilities will become part of the rate base. (St. John, 2019a)

28 See page 22 for a description of successful mandate program, and pages 31 and 51 for findings of positive correlation between storage mandates and BES adoption.

29 See Lee, 2017a, for some lessons learned.

Appendix A: Methodology

Existing Literature

Although the bibliography outlines many sources of information used in this research, there are three main types of literature that most importantly inform this exploration and deserve highlighting.

The first are two market reports, EIA's 2018 *U.S. Battery Storage Market Trends Report* (EIA, 2018) and SEPA's 2018 Utility Storage Market Snapshot Report (Esch & Keller, 2018), which were the most recent versions available at the time of this research.[30, 31] EIA's report aggregates overall storage trends at the ISO/RTO level, whereas SEPA aggregates at the state level. Both present actual power capacity (MW) and energy availability (MWh) ratings, disaggregate into interesting subsections for other exploration, and present case studies of interesting actions and developments within various states or wholesale markets. This research provides unique layering to these market reports by normalizing BES outcomes, and by exploring the correlation to IOU structure.

The second is the body of academic literature that attempts to quantify the impact of restructuring on generator operations (Fabrizio, Rose, & Wolfram, 2007), (Davis & Wolfram, 2012) and retail rates (Borenstein & Bushnell, 2015). This research follows some methodologies developed in this body of academic literature.

The third literature that informs this research is the body of historical study of the electric utility industry, utility and regulatory structures, and technological innovation. Richard Hirsh has focused many works on this subject (R. F. Hirsh, 1989; R. Hirsh, 1999; and R. Hirsh, 2017), but Thomas Hughes' historical look at western electrification is also critical (Hughes, 1983). These works provide the required historical context to understand the origins of the industry, why its regulatory and market structures are the way they are, and how technological innovation has happened in decades past. In this age of rapid innovation and vast quantities of data, the electric industry's pace of innovation can frustrate and confuse those unfamiliar with the industry's history. The highest aspiration of this research is that it can apply some theoretical aspects of the work of these authors to new technologies and expand the learnings these authors provide.

Hypothesis

One potential a priori hypothesis for the expected outcome of this research is that innovative technology is more likely to be adopted earlier in territory served by restructured IOUs, because a more competitive environment will create demand among electricity service providers for the newest and most efficient services[32]. An alternative hypothesis considers the fact that BES adoption **at large scale** offers values across different parts of the generation, transmission, and/or distribution network, and those values are more likely to be recognized by a vertically integrated utility. This author hypothesizes that BES technology, which was not yet cost competitive with alternative services at the time of this analysis,[33] is dependent on policy interventions for adoption. The author further hypothesizes the adoption will be greater where a regulatory body, motivated to intervene through policy set by a legislative body, has more leverage with which to achieve outcomes. IOUs in vertically integrated states have a monopoly franchise over a greater share of the electric service supply chain; thus, the regulatory bodies that oversee them have greater leverage in these states.

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30 SEPA issued its 2019 *Utility Storage Market Snapshot & Report* in August 2019, accessible at: https://sepapower.org/2019-utility-market-snapshot-series/.

31 Since the research for this publication was completed, EIA issued a July 2020 publication, *Battery Storage in the United States: An Update on Market Trends*, accessible at: https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage.pdf.

32 Technological stasis in the industry was an important driver of restructuring (R. F. Hirsh, 1989).

33 Referring to the range of services BES can offer and the range of different incumbent technologies that currently offer those services. Examples include pumped hydrological energy storage for bulk power management, transmission and distribution equipment upgrades to ease congestion constraints, diesel backup generators for behind-the-meter outage ride through, etc.

In spite of the intuition and hypothesis posited above, where actual hypothesis testing is performed in this research, the null hypothesis is that neither structure is expected to have greater adoption. Alternative hypothesis is that either structure has greater adoption.

Methods

This research combines qualitative and quantitative analysis. Qualitative analysis was performed early to help target information to gather for quantitative analysis.

Qualitative Analysis

Qualitative analysis methods primarily involve interviewing industry stakeholders (regulatory officials, representatives from trade organizations, and BES technology and project developers). These stakeholders are asked which policies and markets they see affecting the adoption of BES, and how their organization views the recent developments within the industry.

Information from stakeholders was provided in confidence, so qualitative findings is shared in aggregated and summarized form in the Stakeholders Perspective section above.

Quantitative Analysis

Quantitative analysis methods vary depending on the question we aim to answer, so each question is considered sequentially:

Question 1: Has BES adoption been greater in territories served by vertically integrated or restructured IOUs?

This question is analyzed with a simple regression using the following formula:

$$Y_i = \alpha + \beta D_i + \delta X_i + \varepsilon_i$$

Where:
Y_i : BES adoption in state i
D_i : Treatment of vertically integrated or restructured in state i
X_i : Control variables for state i

The outcome or dependent variable, Y_i, is actually two separate measurements: the normalized power capacity of operational BES in IOU territory in state i, and the normalized energy availability of operational BES in IOU territory in state i.

Y_i : BES adoption in state i = $\dfrac{\sum \textit{BES Power Capacity (MW)}}{\sum \textit{BES Max Peak (MW)}}$ and

Y_i : BES adoption in state i = $\dfrac{\sum \textit{BES Energy Capacity (MWh)}}{\sum \textit{Retail Electricity Sales (MWh)}}$

The treatment or independent variable, D_i, will be considered in the range of binary and categorical variables outlined in the Sources section above. Note that publicly owned utilities (POUs) are included in the observations, as they are subject to some of the same drivers in state i.

The regression is first run excluding any control variables (a difference in means test), and then adding the policy, market, and other control variables. In all cases, the null hypothesis is there is no difference in the BES adoption based on utility structure. The alternative hypothesis is that there is a difference in BES adoption based on utility structure. Where D_i is a binary variable, we reject the null hypothesis when ? is non-zero, and zero is not within the 95 percent confidence interval for that estimated coefficient.

Question 2: Have BES service offerings (i.e., grid support services beyond energy and capacity) been more widely used in territories served by vertically integrated or restructured IOUs?

This question is explored analytically in two ways:

1. Is a project expected to have more service offerings if it is located within a vertically integrated IOU, or a restructured IOU?
2. Is a state expected to observe more unique service offerings from its aggregated BES projects if its IOUs are vertically integrated or restructured?

The first question uncovers which utility structure is correlated with more value-stacking at the project level. The following regression is used to analyze this:

$$Y_i = \alpha + \beta D_i + \varepsilon_i$$

Where:
Y_i : Count of service offerings for project i located within IOU territory (see Appendix B for data sources)
D_i : Treatment of vertically integrated or restructured for the state of installation of project i

Service offerings are also classified into BTM and grid services, so additional analysis, run using the same method above, uncover whether the finding changes for either of these disaggregate categories of services.

The second question uncovers which utility structure is correlated with wider experimentation with different services, aggregated at the state level.

The following regression is used to analyze this:

$$Y_i = \alpha + \beta D_i + \varepsilon_i$$

Where:
Y_i : Cumulative count of unique service offerings for BES within IOU territory in state i
D_i : Treatment of vertically integrated or restructured in state i

Question 3: Which policy mechanisms have been used and effective at spurring BES adoption, and how is that different in states with vertically integrated or restructured IOUs?

This question is analyzed with a simple regression using the following formula:

$$Y_{ia} = \alpha + \beta Z_i + \delta X_i + \varepsilon_i$$

Where:
Y_{ia} : BES adoption in state i, which is in restructured category a
Z_i : Independent variables for policy status in state i, or for market status in the RTO in which the BES is installed
X_i : Control variables for state i

Y_{ia} will be the same normalized BES adoption in IOU territory (power and energy availability), but this regression is run separately for each category of restructuring (a).

X_i will be control variables such as VRE share of generation mix, GMI, and reliability measures.

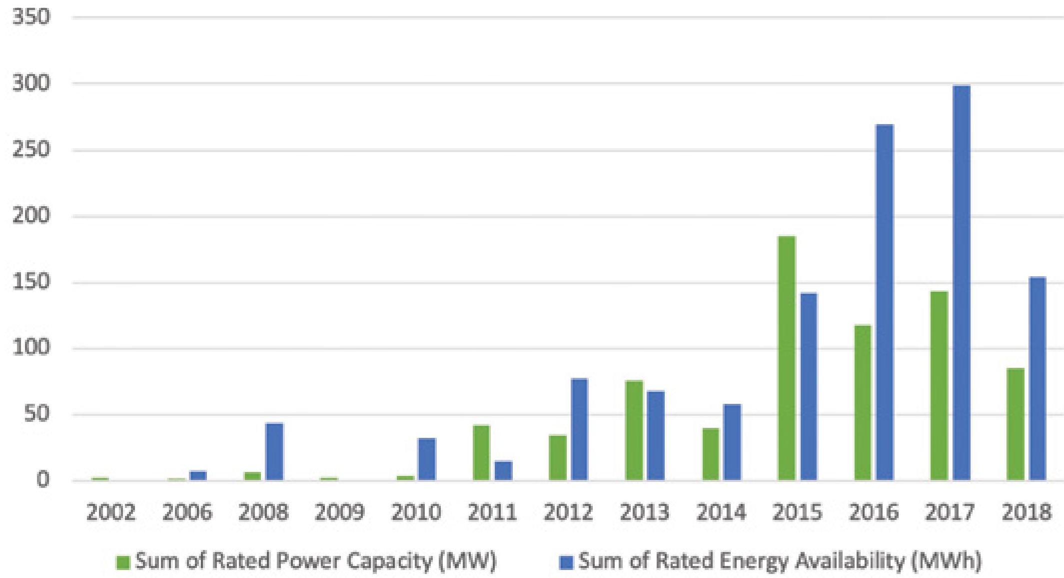
The vector of coefficients β (since there will multiple independent variables) will suggest the correlation of specific policies or markets to the outcome of BES adoption.

Data Sources

This section outlines the sources of data for this study, and, where necessary, explains any steps taken to improve the quality of the data.

Where available, data is gathered for the year in which the project, policy, or market is enacted. Due to the inconsequential volume of BES systems before 2000, that is the earliest year for which time-dependent data are observed (see *Figure 14*).

Figure 14: BES Adoption in IOU Territory, by Year



Battery Energy Storage Adoption & Applications

The DOE and Sandia National Laboratory hosts a **Global Energy Storage Database**. This database captures a wide range of volunteered information on energy storage projects of all size, technology, and operational status. Due to the voluntary input nature of this database, the completeness of the aggregated values from this database cannot be assured (developers and BTM customers may not know or desire to announce their projects), and there are many gaps in the project data for the projects that are on the list. Notwithstanding these limitations, the database does offer the potential for excellent examination of volume of adoption, power and energy availability, multiple BES applications, ownership of assets, utility territory in which projects are installed, and more. Given these advantages, this database will be the launching point for battery adoption and application information.

Two other sources, however, offer additional information that is used to improve the accuracy of the DOE Global Energy Storage Database. The first is the annual results of **EIA's survey form 860**. One output from this survey is annual information from electric utilities and independent power producers (IPPs) on the energy storage plants in their portfolio that were operational and retired. While this database represents a snapshot of a subsector of the total BES technology adoption picture, and does not hold as complete project information as the DOE Global Energy Storage Database (less than 1/3 the total sites), it does serve as a helpful verification tool. Because the DOE database is updated periodically and voluntarily, projects that may have been completed and become operational since database entry may not be actively updated. The EIA 860 data are used to verify BES projects operational status, check for missing projects, verify rated power, energy availability, applications, and fill in other missing data fields.

The second source is aggregated survey information from the **Smart Electric Power Alliance (SEPA)**, which has, for several years, collected survey data from electric utilities about energy storage deployment within their territory. SEPA uses this data to inform their annual Utility Energy Storage Market Snapshot (Esch & Keller, 2018). This survey data include all BES that is visible to the electric utility (including BTM BES) and it represents a more complete total than EIA's database. Additionally, this data provide summary by sector (residential, commercial & industrial, and grid-scale). This data are used to check the likelihood that the DOE Global Energy Storage Database is complete, as well as to add a range of outcome values to include for uncertainty analysis. The projects least likely to be entered into the DOE Global Energy Storage Database are residential and small C&I BTM projects. To the extent these projects are visible to the utilities, and the utilities report the aggregate rating of these projects to SEPA's survey, that can be helpful to account for possible measurement error. Because of the aggregated nature of the data, it is not used to change any project or utility specific values in the DOE Global Energy Storage Database.

Additional steps taken to improve the quality of the data within the base DOE Global Energy Storage Database, include, but are not limited to:

- Removing observations outside the scope of research (international, non-BES, non-operational);
- Removing duplicate observations, often located by finding projects with matching latitude and longitude (note, some projects with matching latitude and longitude data were legitimate, such as in instances where new projects were installed on an existing project site or actual location is likely masked to protect anonymity);
- Corrected projects incorrectly listed as operational, but that are still in development. This was an especially meaningful change for projects in California, for which there were 350MW capacity worth of projects that were not operational as of the end of the 2018 observation period; and
- Conducted additional web-based research to support this cleaning effort.

Table 2: BES Database Adoption Modifications after Data Cleaning Effort

Aggregate Power Capacity	Change as a result of:
+98MW	Status changed to Operational (now within observation group)
-33MW	Duplicate projects removed
+112MW	Missing projects found by comparison to other databases
-350MW	Corrected an Operational status (now outside observation group)

Another important step in quantifying BES adoption is to normalize the aggregate power capacity and energy availability values, by state. The normalization process allows for more meaningful comparisons between states with vastly different populations and loads. Normalization values are obtained from annual results of **EIA's survey form 861**, which gathers detailed information on many aspects of utility (and other related entity) operations in each state. The variables of interest for normalization are state level summer peak load and total retail sales. Summer peak load (in MW) normalizes the power capacity (also MW), whereas retail sales (MWh) normalizes the energy availability (MWh).

Utility Restructuring Status by State

The simplest designation for status of restructuring is a binary designation of vertically integrated (not restructured) or restructured. For reasons discussed in the State of Energy Storage section, this binary designation falls short of representing the complexity of the actual status of many states.

Advanced Energy Economy's Power Portal contains information on each state's regulatory commission, utilities, energy policies, executive brand and state legislature, as well as summary energy data. This is one source for binary restructuring status. This site also categorizes each state's approach to retail competition in a non-binary fashion:

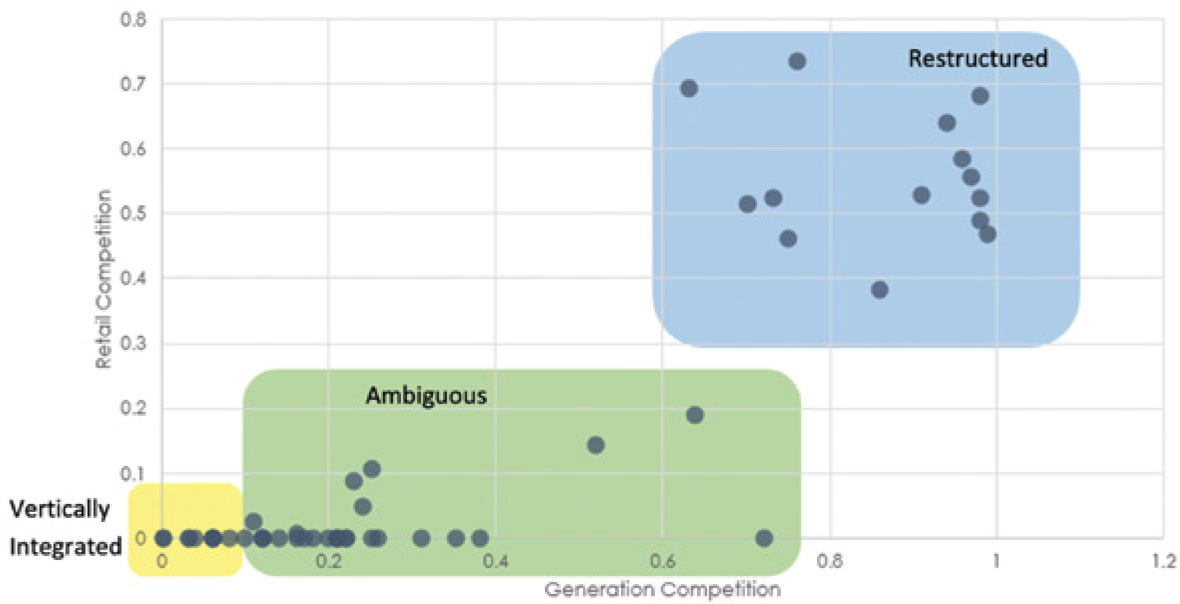
Borenstein & Bushnell, in their 2015 paper, discuss two methods for binary designation, one based on share of competition for generation services, and, the one they prefer, based on competition for retail services (Borenstein & Bushnell, 2015).

This analysis uses both generation and retail competition status to determine binary treatment of utility structure. Retail sales competition share is determined using **EIA's survey form 861**; specifically, the retail sales by non-utility entities, by state. Generation competition is determined by taking the 5-year average of share of generation by non-utility generators, per state, from **EIA's Net Generation by State by Type of Producer by Energy Source report**.

Using this information I characterize states into three categories:

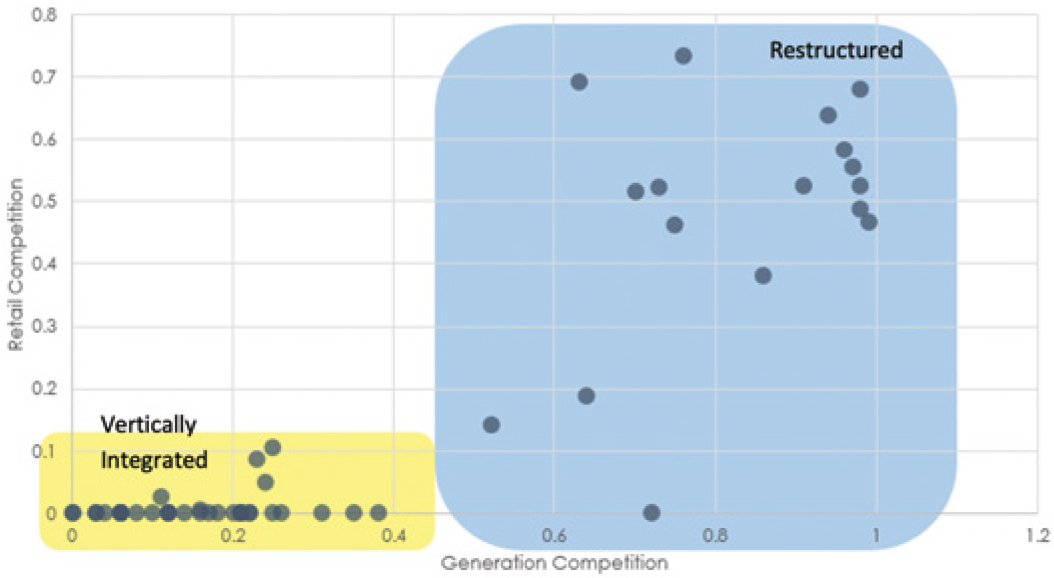
The unambiguous categories are ones in which the AEE portal listed above designates as vertically integrated or restructured, and the behavior suggested by their actual recent retail and generation competition percentages matches that designation. States where the generation or retail competition shares do not closely hew to the binary designations of AEE, or states where the retail competition category of AEE is in the third or fourth category, fall into the middle **ambiguous** category. See *Figure 15* for a plot of each state and visualization of the three categories.

Figure 15: Share of Competition for Retail and Generation, by State – 3 Categories



The bulk of the analysis performed for this study, however, utilizes a binary designation that is primarily based on the 5-year average generation competition share. Any state with greater than 40 percent generation competition, regardless of status of retail competition, is designated as restructured. See *Figure 16* for a graphic depiction of this designation.

Figure 16: Share of Competition for Retail and Generation, by State - 2 Categories



See *Table 3* for the range of designations gathered by state and the final binary designation used for analysis.

Policy Status by State

The primary source for data on energy and energy storage policy by state is the **Database of State Incentives for Renewables & Efficiency (DSIRE)**, which aggregates state level policy information and is hosted by the North Carolina Clean Energy Technology Center. Binary variables for the existence of a renewable portfolio standard (RPS) and renewable portfolio goals (non-binding) are created from this source. DSIRE also has a 2018 catalog of states that specifically allow, disallow, or have unclear regulations on third-party ownership of solar PV. An ability to own, and finance, renewable generation assets by a third party is suggestive of a similar ability for BES assets.

State-level status of policies related to BES mandates and targets, which target IOUs, are obtained from the EIA's *2018 US Battery Storage Market Trends Report* (EIA, 2018). State-level status of BES incentives, which target customers of electricity for BTM development, are obtained from SEPA's 2018 *Utility Energy Storage Market Snapshot* (Esch & Keller, 2018).

The **Advanced Energy Economy's Power Portal** is a source for state-level information about requirements for IRP and DRP, each of which is included as a binary variable. This site includes no indication of whether IRP or DRP requirements include direction to consider VRE or BES. Some states have different nomenclature for DRPs: forward-looking maintenance and reliability plan requirement are treated as a DRP, but backward-looking reliability reports are excluded.

Electricity customer rate structures are not technically state-level policies, but rather compensation mechanisms imposed on customers by the electric utilities. They are, nonetheless, a potential factor in the adoption of BTM BES. Since state regulators are responsible for approving rate structures, variables representing possible factors are used in this analysis at the state level. TOU rates are a potential driver of BES adoption, since arbitrage between expensive and inexpensive retail electricity is a possible service. This analysis, however, does not include any variable for TOU rates, because there is not an easily available clean metric to differentiate TOU rates between states. Most IOUs charge TOU rates to C&I customers, and few charge TOU rates to residential customers (though residential TOU rates are in development now).

Demand charges are another rate structure variable that is a potential factor in the adoption of BTM BES. Similar to TOU rates, demand charges are commonly charged to C&I customers, rarely to residential customers. In a recent NREL study, it was determined demand charges in excess of $15/kWh are necessary to make BES attractive to C&I customers (McLaren, Mullendore, Laws, & Anderson, n.d.). States with significant populations of C&I customers facing at least $15/kWh demand charges are obtained from this study, and converted into a binary "High Demand Charge" variable.

Table 3: State Restructuring Designations

State	AEE Designation	AEE Status of Retail Competition	2017 share of retail sales competitive	5 year average share of electricity production by IPP	This analysis 3-category designation	This analysis binary designation	State	AEE Designation	AEE Status of Retail Competition	2017 share of retail sales competitive	5 year average share of electricity production by IPP	This analysis 3-category designation	This analysis binary designation
AL	VI	0	25%	0%	VI	VI	MT	VI	0	64%	19%	AMB	VI
AK	VI	0	4%	0%	VI	VI	NE	VI	0	8%	0%	VI	VI
AZ	VI	1	16%	0%	AMB	VI	NV	VI	1	25%	11%	AMB	VI
AR	VI	0	21%	0%	VI	VI	NH	R	3	91%	53%	R	R
CA	VI	2	52%	14%	AMB	R	NJ	R	3	98%	49%	R	R
CO	VI	0	21%	0%	VI	VI	NM	VI	0	20%	0%	VI	VI
CT	R	3	97%	56%	R	R	NY	R	3	73%	52%	R	R
DE	R	3	86%	38%	R	R	NC	VI	0	6%	0%	VI	VI
DC	R	3	76%	73%	R	R	ND	VI	0	12%	0%	VI	VI
FL	VI	0	6%	0%	VI	VI	OH	R	3	63%	69%	R	R
GA	VI	1	10%	0%	AMB	VI	OK	VI	0	35%	0%	AMB	VI
HI	VI	0	38%	0%	VI	VI	OR	VI	1	24%	5%	AMB	VI
ID	VI	0	31%	0%	AMB	VI	PA	R	3	98%	68%	R	R
IL	R	2	94%	64%	R	R	RI	R	3	99%	47%	R	R
IN	VI	0	12%	0%	VI	VI	SC	VI	0	3%	0%	VI	VI
IA	VI	0	21%	0%	AMB	VI	SD	VI	0	18%	0%	VI	VI
KS	VI	0	22%	0%	AMB	VI	TN	VI	0	0%	0%	VI	VI
KY	VI	0	0%	0%	VI	VI	TX	R	3	70%	51%	R	R
LA	VI	0	14%	0%	VI	VI	UT	VI	0	6%	0%	VI	VI
ME	R	3	75%	46%	R	R	VT	VI	0	72%	0%	AMB	R
MD	R	3	98%	52%	R	R	VA	VI	2	16%	1%	AMB	VI
MA	R	3	96%	58%	R	R	WA	VI	0	11%	3%	VI	VI
MI	VI	2	23%	9%	AMB	VI	WV	VI	0	26%	0%	AMB	VI
MN	VI	0	17%	0%	AMB	VI	WI	VI	0	22%	0%	VI	VI
MS	VI	0	12%	0%	VI	VI	WY	VI	0	6%	0%	VI	VI
MO	VI	0	3%	0%	VI	VI							

Key: VI= Vertically Integrated, R= Restructured, AMB= Ambiguous
0= no competition, 1= limited C&I, 2= limited C&I&R, 3= full competition

RTO/ISO Markets Status

The primary source for information on wholesale market status for each RTO/ISO is the **National Energy Technology Laboratory (NETL) Power Market Primers**, which provides a detailed history of each type of wholesale market, as well as current status information for each regional organization (Booz Allen Hamilton & DOE, 2013). From this source binary designations for the existence of each of the following markets and/or mechanisms are created:

- Energy Market
- Capacity Market
- Financial Transmission Rights / Congestion Revenue Rights / Locational Marginal Pricing
- Ancillary Services Markets:
    - Regulation and Frequency Response
    - BES-friendly Regulation and Frequency Response
    - Operating Reserve
    - Black Start Service
    - Demand Response
    - Reactive Supply and Voltage Control

Treating the existence of any of these markets as a binary variable does not hope to capture the complexity of issues associated with the design and functioning of these markets or how that may affect the likelihood of a developer or customer to pursue BES adoption. The binary variable is a heuristic for an RTO/ISO's intention to facilitate monetization of each category of service. Market status changes after the issue date of the Power Market Primers are obtained from the web sites for each RTO/ISO and the North American Electric Reliability Corporation (NERC).

Additional Variables

There are a number of additional variables which are gathered due to the possibility they may be predictive of a propensity to adopt BES. The first is each state's **Grid Modernization Index (GMI)** score. This score is generated annually by the GridWise Alliance, and "benchmarks each state on a wide range of factors that influence grid modernization policies, investments, and accomplishments" *(Grid Modernization Index 2018: Key Indicators for a Changing Electric Grid, 2018).*

Figure 17: GMI Score Factors

Source: Gridwise Alliance, 2017.

Since generation intermittency is a challenge for which BES provides a solution, VRE penetration by state is an important variable. The EPA's Emissions & Generation Resource Integrated Database (eGRID) collates a wide range of information about electricity generation and its environmental attributes at a state and regional level. This analysis uses eGRID's state-level 2016 information for electricity generation sources, focusing on variable renewable energy sources only (solar and wind), because it is the variability that increases the value of storage to the grid.

Grid reliability is another important indicator of a potential demand for BES. Frequency and duration of electricity outages are reported to **EIA in survey form 861**. This analysis uses state-level values from 2017; specifically, the inverse of the product of the frequency of outages (SAIFI) and duration of outages (SAIDI). Using the inverse permits the interpretation that a larger value indicates higher reliability, whereas a lower value indicates more outages and lower reliability of electricity supply.

Appendix B: Detailed Findings

Descriptive Statistics and Analysis

Power & Energy Adoption by Vertically integrated and Restructured

Below are plots of the aggregated rated power capacity (*Figure 18*) and energy availability (*Figure 19*) operational in IOU territory in each state, along with the normalized values. These figures show the importance of normalizing power and energy availability. On the basis of volume alone, California's BES adoption far outweighs all other states, but when the size of each state is used in the denominator to normalize the power and energy availability, the relative importance of that state's BES adoption can be more easily understood.

Figure 18: Top 15 States by Normalized BES Power Capacity

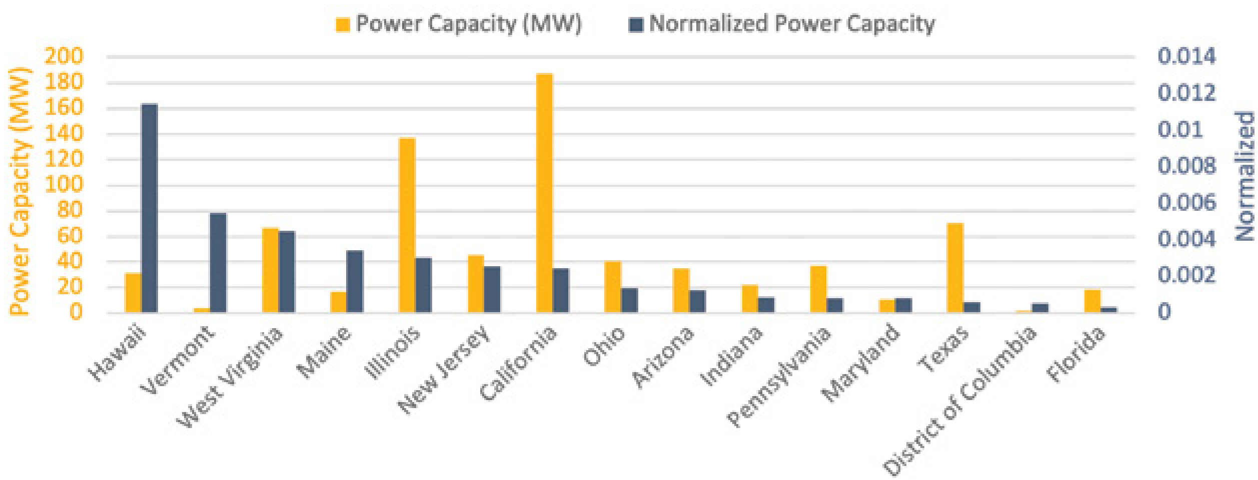
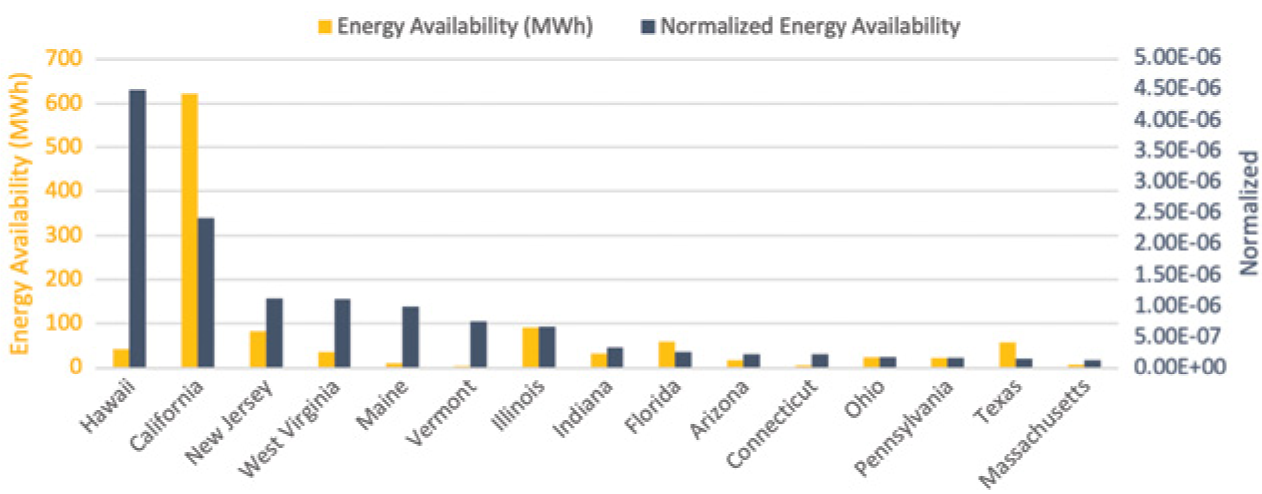


Figure 19: Top 15 States by Normalized BES Energy Availability



The IOU structure is layered and results are aggregated. *Figure 20* shows aggregated results of BES in states categorized as either having a regulatory structure that yields clearly vertically integrated IOUs, clearly restructured IOUs, or ambiguous status IOUs.

Figure 20: Summed Power and Energy Availability and Normalized Capacity by Structure (3)					
Vertically Integrated	Ambiguous	Restructured	Vertically Integrated	Ambiguous	Restructured
Power Capacity (MW)			Energy Availability (MWh)		
91	259	367	132	714	324
Normalized Power Capacity			Normalized Energy Availability		
0.0133	0.0140	0.0136	5.26×10^{-6}	4.87×10^{-6}	3.85×10^{-6}

There is a great deal of power capacity and energy availability developed to date in IOUs, which have ambiguous restructuring status. When ambiguous states are forced into a binary designation based on how much actual generation or retail competition appears in EIA data in 2017, results change are as shown in *Figure 21*.

Figure 21: Summed Power and Energy Availability and Normalized Capacity by Structure (2)			
Vertically Integrated	Restructured	Vertically Integrated	Restructured
Power Capacity (MW)		Energy Availability (MWh)	
195	558	220	951
Normalized Power Capacity		Normalized Energy Availability	
0.0194	0.0215	6.96×10^{-6}	7.03×10^{-6}

Normalizing power capacity leads to a higher effective adoption of BES power capacity and energy availability in restructured states, but with values that are far closer in magnitude to one another than the comparative non-normalized values. Regression analysis will show whether these findings are statistically significant.

Service Offering Range by Vertically Integrated and Restructured

Figure 22 and *Figure 23* show the range of values for unique service offerings that occur in BES projects in vertically integrated and restructured states, respectively. Higher values suggest more experimentation with and learning about the range of services BES potentially offers, either at the grid scale or BTM.

Figure 22: Unique BES Service Offerings in Vertically Integrated IOUs

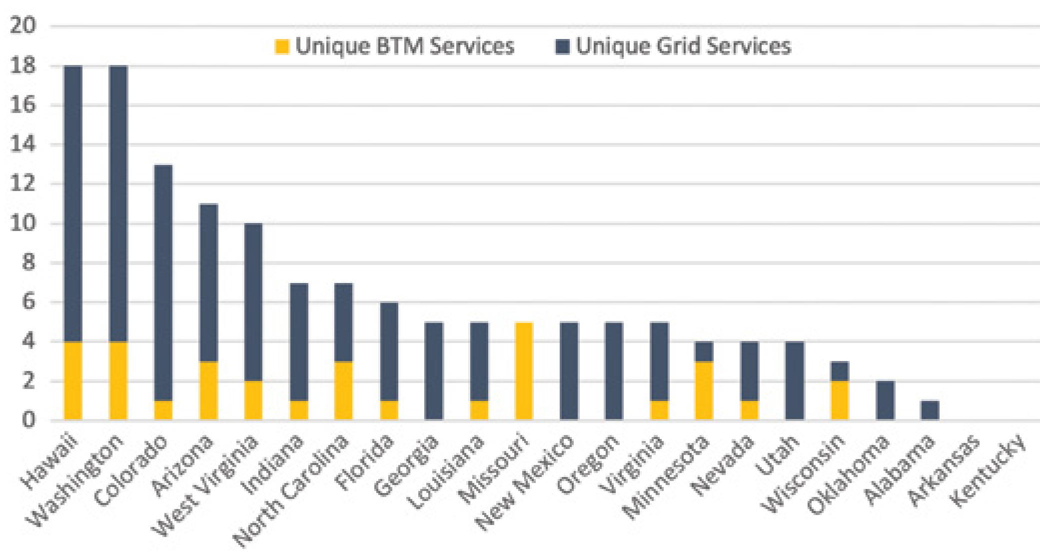
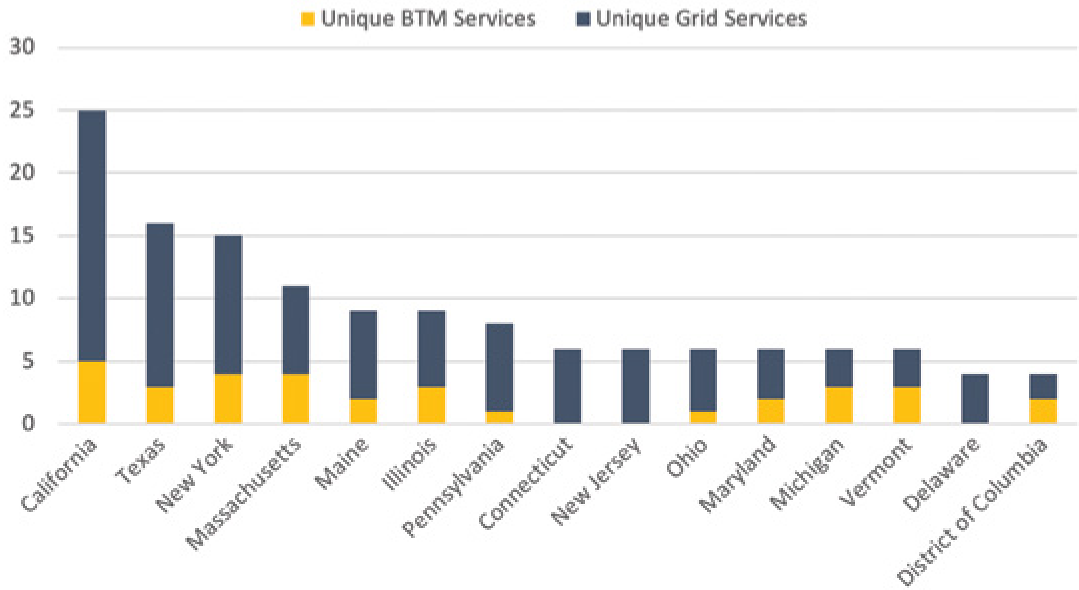


Figure 23: Unique BES Service Offerings in Restructured IOUs



Power & Energy Adoption by Driver for Vertically Integrated and Restructured

Figure 24 and *Figure 25* show the aggregated amount of normalized power capacity and energy availability, respectively, which exist in territories that are subject to the drivers indicated. These observations are description – power capacity and energy availability measures cannot be causally attributed to any of these specific drivers through this observation.

Figure 24: Normalized Power Capacity by Driver

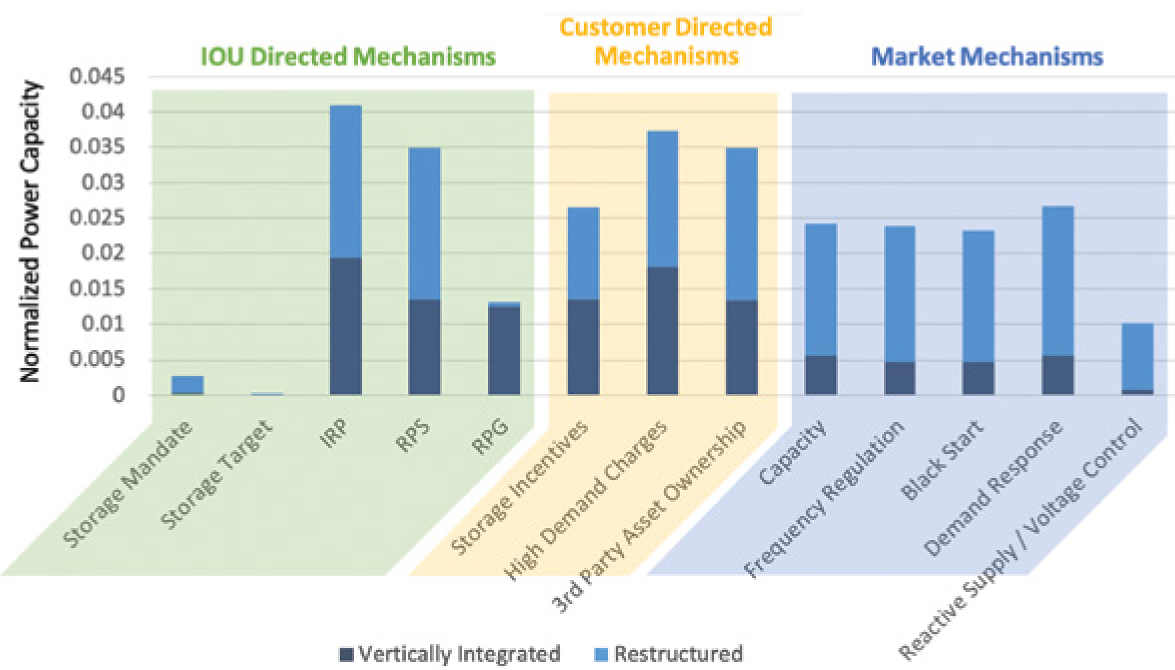
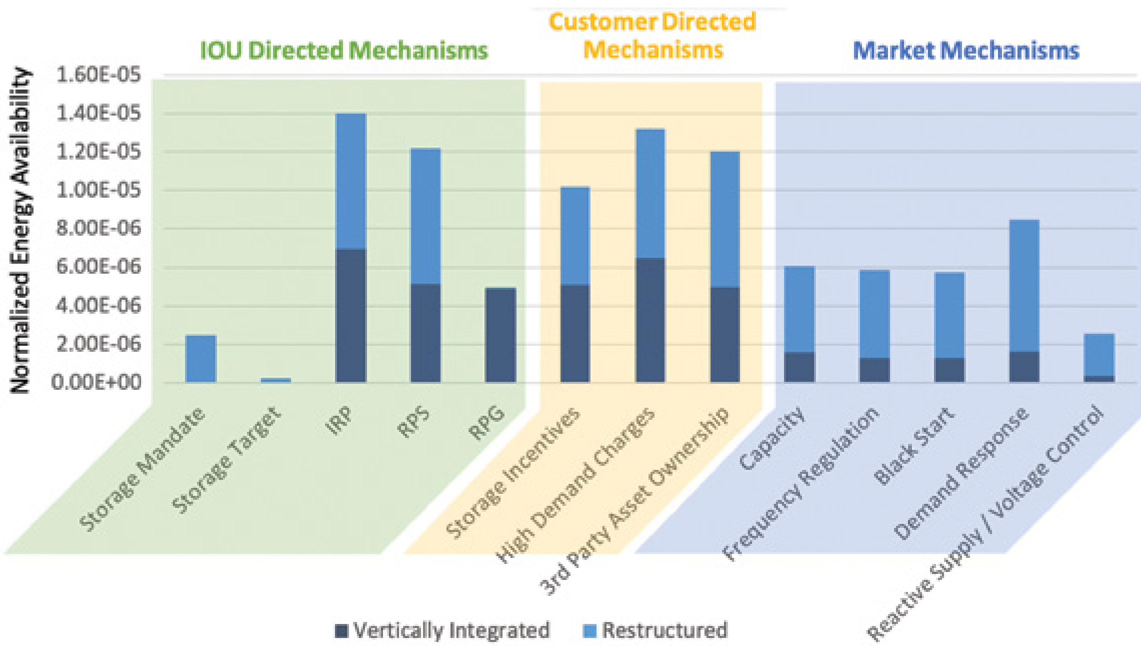


Figure 25: Normalized Energy Availability by Driver



Detailed Regression and Analysis

This research initially sought to answer three central questions. Below are each of these questions restated, and the findings associated with them:

Question 1: To date, has battery adoption been higher in territories served by vertically integrated or restructured IOUs?

The descriptive statistics in the prior section suggest that the total rated power capacity and energy availability observed is greater in restructured IOUs, but the normalized power capacity and energy availability is only marginally greater in restructured IOUs. The significance of this finding is outlined in *Figure 26*, *Figure 27*, and *Figure 28*.

Figure 26 shows overall battery adoption is higher in restructured IOUs, and that finding is statistically significant for power capacity only.

Figure 27 and *Figure 28* show, when evaluating on normalized power capacity and energy availability outcomes and including representative values from publicly owned utilities (which offer additional context, as they are subject to some of the same drivers), battery adoption is actually higher in vertically integrated IOUs, but that finding is not statistically significant. Control variables added are not significantly correlated to BES adoption outcomes, except that there is a strong positive correlation on an interaction

Figure 26: Power & Energy Outcomes by Structure

Regression Results of Power and Energy on Binary Utility Structure

	Power and Energy Outcomes	
	Power Capacity (MW)	Energy Availability (MWh)
	(1)	(2)
Vertically Integrated IOUs	11.592***	15.978**
	(3.610)	(6.775)
Restructured IOUs	16.334*	30.327
	(8.695)	(22.684)
Plus POUs	-10.606*	-18.077
	(6.252)	(16.449)
Clustered Standard Errors	State	
Observations	65	65
R^2	0.092	0.049
Adjusted R^2	0.063	0.019
Residual Std. Error (df = 62)	30.639	77.816
Note:		*p<0.1; **p<0.05; ***p<0.01

between restructured IOUs and renewable energy penetration. This suggests that, for normalized measures of power capacity and energy availability, battery adoption is positively correlated with high renewable energy penetration in restructured IOUs, but not in vertically integrated IOUs. There is a similar, though lower magnitude, interaction relationship between the presence of a demand response market in restructured IOUs.

Recall that coefficients in the figures are related to normalized measures of adoption, and some are scaled for legibility. Relative magnitude within the table, positivity or negativity of value, and statistical significance (or lack thereof) are the primary quantitative value to observe in these regression tables.

Figure 27: Normalized Power Capacity by Structure, With Controls

Regression Results of Normalized Energy on Binary Utility Structure, with control variables only

	Normalized Energy Availability							
	Installed BES Energy Rating (MWh) / State Annual Retail Sales (MWh)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Vertically Integrated IOUs	0.430*	0.431*	0.199	0.452	0.456	0.222	0.201	0.226
	(0.244)	(0.245)	(0.245)	(0.290)	(0.291)	(0.257)	(0.247)	(0.259)
Restructured IOUs	-0.213	-0.207	-0.353	-0.216	-0.209	-0.375	-0.346	-0.367
	(0.330)	(0.339)	(0.496)	(0.339)	(0.346)	(0.528)	(0.505)	(0.535)
Plus POUs	0.207	0.203	0.216	0.223	0.220	0.253	0.212	0.249
	(0.273)	(0.279)	(0.286)	(0.320)	(0.324)	(0.346)	(0.293)	(0.351)
Reliability Measures		-0.00001			-0.00001		-0.00000	-0.00001
		(0.00001)			(0.00001)		(0.00001)	(0.00000)
Grid Modernization Index			0.007			0.008	0.007	0.008
			(0.011)			(0.012)	(0.011)	(0.012)
Renewable Energy Penetration				-0.377	-0.412	-0.840		-0.882
				(1.552)	(1.556)	(1.722)		(1.728)
Clustered Standard Errors	State	State	State	State	State	State	State	State
Observations	65	65	65	65	65	65	65	65
R^2	0.015	0.016	0.026	0.016	0.016	0.028	0.026	0.029
Adjusted R^2	-0.016	-0.033	-0.022	-0.033	-0.049	-0.037	-0.039	-0.054
Residual Std. Error	0.00000 (df = 62)	0.00000 (df = 61)	0.00000 (df = 61)	0.00000 (df = 61)	0.00000 (df = 60)	0.00000 (df = 60)	0.00000 (df = 60)	0.00000 (df = 59)
Note:								*p<0.1; **p<0.05; ***p<0.01

These findings do not change when a different range of bes adoption measures are used,[34] and analysis of three-category utility regulatory structure designation[35] failed to yield any statistically significant findings.

34 Uncertainty values obtained from data cleaning effort discussed in Appendix A: Data Sources.

35 Clearly vertically integrated, clearly restructured, and ambiguous.

Figure 28: Normalized Energy Availability by Structure, with Controls

Regression Results of Normalized Energy on Binary Utility Structure, with control variables only

	Normalized Energy Availability							
	Installed BES Energy Rating (MWh) / State Annual Retail Sales (MWh)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Vertically Integrated IOUs	0.430*	0.431*	0.199	0.452	0.456	0.222	0.201	0.226
	(0.244)	(0.245)	(0.245)	(0.290)	(0.291)	(0.257)	(0.247)	(0.259)
Restructured IOUs	-0.213	-0.207	-0.353	-0.216	-0.209	-0.375	-0.346	-0.367
	(0.330)	(0.339)	(0.496)	(0.339)	(0.346)	(0.528)	(0.505)	(0.535)
Plus POUs	0.207	0.203	0.216	0.223	0.220	0.253	0.212	0.249
	(0.273)	(0.279)	(0.286)	(0.320)	(0.324)	(0.346)	(0.293)	(0.351)
Reliability Measures		-0.00001			-0.00001		-0.00000	-0.00001
		(0.00001)			(0.00001)		(0.00001)	(0.00000)
Grid Modernization Index			0.007			0.008	0.007	0.008
			(0.011)			(0.012)	(0.011)	(0.012)
Renewable Energy Penetration				-0.377	-0.412	-0.840		-0.882
				(1.552)	(1.556)	(1.722)		(1.728)
Clustered Standard Errors	State	State	State	State	State	State	State	State
Observations	65	65	65	65	65	65	65	65
R^2	0.015	0.016	0.026	0.016	0.016	0.028	0.026	0.029
Adjusted R^2	-0.016	-0.033	-0.022	-0.033	-0.049	-0.037	-0.039	-0.054
Residual Std. Error	0.00000 (df = 62)	0.00000 (df = 61)	0.00000 (df = 61)	0.00000 (df = 61)	0.00000 (df = 60)	0.00000 (df = 60)	0.00000 (df = 60)	0.00000 (df = 59)
Note:								*p<0.1; **p<0.05; ***p<0.01

Question 2: To date, have battery service offerings been broader in territories served by vertically integrated or restructured IOUs?

As a reminder, this question is answered in two different ways:

1. Is a project expected to have more service offerings if it is located within a vertically integrated IOU, or a restructured IOU?

Figure 29: Project Level BES Service Offerings by Structure

Regression Results of Count of BES Service Types on Binary Utility Structure

	Count of BES Service Types		
	Total Unique Services	BTM Services	Grid Services
	(1)	(2)	(3)
Vertically Integrated States	2.992***	0.562***	2.430***
	(0.108)	(0.086)	(0.060)
Plus Restructured States	-0.306***	0.196	-0.502***
	(0.085)	(0.134)	(0.052)
Clustered Standard Errors	State and IOU/POU	State and IOU/POU	State and IOU/POU
Observations	344	344	344
R^2	0.008	0.014	0.027
Adjusted R^2	0.006	0.011	0.024
Residual Std. Error (df = 342)	1.589	0.785	1.451
Note:			*p<0.1; **p<0.05; ***p<0.01

The high-level analysis is shown in *Figure 29*, and represents associations only – these findings are not in any way causal. This work estimates a project is likely to have more services embedded in it if installed in vertically integrated utility territory, though that appears to be largely driven by a higher number of grid-level services. These findings hold when control variables and variables related to policy and market mechanisms are considered. Some policies do mitigate the disparity in number of grid services at the project level between vertically integrated and restructured IOUs. High demand charges are correlated with fewer grid services overall, but more so in vertically integrated utility territory. Third-party asset ownership is strongly positively correlated with more grid services, and that correlation is greater for restructured utility territories. The presence of storage mandates exacerbates the disparity. Some wholesale markets also mitigate the disparity, namely capacity, storage-friendly frequency regulation, and reactive supply/voltage control markets.

BES projects located behind-the-meter in restructured utility territory are likely to have more services embedded. This finding does not hold, however, once control variables are included into regression, so the lack of significance is important. In fact, there is a strong positive correlation between renewable energy penetration and number of expected BTM services for all utility structure types, as well as a strong interaction between renewable energy penetration and restructured utility territory. Projects in restructured utility territories with high penetrations of renewable energy have far greater BTM services than those in vertically integrated utility territories of similar renewable energy penetration. Similar positive correlations and interactions with restructured utilities is observed for storage mandate policies, high demand charges, and where third-party asset ownership is allowed. When wholesale market status is considered, the finding of more services for BTM projects in restructured utility territory becomes stronger and statistically significant, in part due to strong interactions between the availability of markets in restructured states. Greater BTM services are positively correlated with the existence of demand response markets, and negatively correlated with the existence of capacity, storage-friendly frequency regulation, and black start markets.

2. Is a state expected to observe more unique service offerings from its aggregated BES projects if its IOUs are vertically integrated or restructured?

Restructured utilities are associated with deployment of a wider range of battery services. This finding is not causal, nor is it statistically significant. In fact, when the grid modernization index is included as a control variable, the finding is reversed, and vertically integrated utilities are associated with deployment of a wider range of battery services. A similar dynamic happens when third-party asset ownership is included, though there is a strong, positive correlation and interaction between third-party asset ownership and restructured utilities, such that, where third-party asset ownership is not allowed, vertically integrated utilities see a wider range of services than restructured, but where third-party asset ownership is allowed, restructured utilities see a wider range of battery services.

Figure 30: State-Level BES Service Offerings by Structure

Regression Results of Count of BES Service Types on Binary Utility Structure

	Count of BES Service Types
Vertically Integrated States	5.789***
	(0.422)
Plus Restructured States	1.729
	(1.298)
Clustered Standard Errors	State and IOU/POU
Observations	65
R^2	0.029
Adjusted R^2	0.013
Residual Std. Error	5.029 (df = 63)
Note:	*p<0.1; **p<0.05; ***p<0.01

There is a strong, positive correlation and interaction between renewable energy penetration and range of services in restructured utilities, and a similar strong, positive correlation and interaction between storage mandate policies and range of services in restructured utilities. There are strong, positive correlations between the range of services in restructured utilities and storage target policies, as well as demand response markets. The other wholesale markets all appear to be negatively correlated with range of service for both vertically integrated and restructured utility territories, with capacity markets being strongly and significantly negatively correlated.

Table 4 summarizes the direction and magnitude of the coefficients for each policy and market mechanism observed for both project- and state-level BES services. Many coefficients are not statistically significant, which means we cannot say with great confidence the *direction* of the correlation is as estimated. Interactions are noted where appropriate.

Table 4: Range of BES Services and Driver Mechanism Correlation

Driver Mechanism	Vertically Integrated IOUs			Restructured IOUs		
	# of Grid Services	# of BTM Services	Total # Services	# of Grid Services	# of BTM Services	Total # Services
Storage Mandate	(↑ ↑)	(↓ ↓)	(↓)	(↓)	(↑ ↑)	(↑ ↑)
Storage Target				(↓)	(↑)	(↑ ↑)
Integrated Resource Planning	↓ ↓	↑	↑	↓	↑ ↑	↑
Renewable Portfolio Standard						
Renewable Portfolio Goal						
Storage Incentives	(↓)	(↑ ↑)	↑	(↓)	(↑ ↑)	↑ ↑
High Demand Charges	(↓)	(↓ ↓)	↑	↓	(↑ ↑)	↑ ↑
3rd Party Asset Ownership	(↑)	↓	↑ ↑	(↑ ↑)	(↑ ↑)	(↑ ↑)
Capacity Market				(↓)	(↓ ↓)	(↓ ↓)
Frequency Regulation Market				(↑)	(↓ ↓)	↓
Black Start Market				↓	(↓ ↓)	↓
Demand Response Market				↓ ↓	(↑)	(↑ ↑)
Reactive Supply / Voltage Control Market				(↑)	↑ ↑	↓

↑ positive correlation

↓ negative correlation

↑ ↑ high magnitude positive correlation

↓ ↓ high magnitude negative correlation

(↑ ↑) greater than 95% confidence in direction of the correlation

Question 3: Which policy mechanisms have been utilized and effective at spurring battery adoption, and how is that different in states with vertically integrated or restructured IOUs?

In vertically integrated IOUs, BES adoption is positively correlated with better reliability performance in the state, as well as existence of renewable portfolio goals, and negatively correlated with the existence of IRP requirements. There is a strong, positive interaction and correlation between renewable portfolio standards and goals, as they relate to BES adoption, though the correlation of BES adoption to actual renewable energy penetration, and the interaction between renewable penetration and policies which encourage renewable penetration are insignificant. *Figure 31* and *Figure 32* show the coefficients for the subset of policy mechanisms and control variables that have the strongest correlation for these states, for normalized power and energy, respectively.

Figure 31: Normalized Power on Policy Mechanisms, for Vertically Integrated Only

Regression Results of Normalized Power on Subset of Policy Mechanisms with Reliability Control, Vertically Integrated States only

	Normalized Power Capacity	
	Installed BES Power Capacity (MW) / State Summer Peak Demand (MW)	
	(1)	(2)
Vertically Integrated IOUs	3,243.630*	-101.700
	(1,945.049)	(974.014)
Plus POUs	1,090.127	1,568.883
	(1,344.468)	(1,360.942)
Reliability Measures	13.421*	12.216
	(7.809)	(8.020)
Integrated Resource Planning	-3,310.061*	
	(1,923.197)	
Renewable Portfolio Goal		1,459.321
		(1,544.115)
Observations	38	38
R^2	0.165	0.116
Adjusted R^2	0.091	0.037
Residual Std. Error (df = 34)	0.004	0.004
Note:		*p<0.1; **p<0.05; ***p<0.01

Figure 32: Normalized Energy on Policy Mechanisms, for Vertically Integrated Only

Regression Results of Normalized Energy on Subset of Policy Mechanisms with Reliability Control, Vertically Integrated States only

	Normalized Energy Availability	
	Installed BES Energy Rating (MWh) / State Annual Retail Sales (MWh)	
	(1)	(2)
Vertically Integrated IOUs	0.379	-0.199
	(0.717)	(0.329)
Plus POUs	0.570	0.652
	(0.496)	(0.460)
Reliability Measures	0.005*	0.005*
	(0.003)	(0.003)
Integrated Resource Planning	-0.346	
	(0.709)	
Renewable Portfolio Goal		1.098**
		(0.522)
Observations	38	38
R^2	0.122	0.217
Adjusted R^2	0.044	0.148
Residual Std. Error (df = 34)	0.00000	0.00000
Note:		*p<0.1; **p<0.05; ***p<0.01

In restructured IOUs, BES adoption is positively correlated with higher shares of variable renewable energy generation, storage mandates, as well as markets for capacity and demand response. *Figure 33* and *Figure 34* show the coefficients for the subset of policy and market mechanisms and control variables that have the strongest correlation for these states, for normalized power and energy, respectively.

Figure 33: Normalized Power on Policy & Market Mechanisms, for Restructured Only

Regression Results of Normalized Power on Subset of Policy and Market Mechanisms with Reliability Control, Restructured States only

	Normalized Power Capacity				
	Installed BES Power Capacity (MW) / State Summer Peak Demand (MW)				
	(1)	(2)	(3)	(4)	(5)
Restructured IOUs	717.743**	666.571*	-472.600	-260.436	-483.082
	(340.082)	(350.830)	(549.338)	(542.761)	(581.688)
Plus POUs	-1,348.601***	-1,309.725***	-1,140.482***	-1,155.906***	-1,119.402**
	(462.922)	(470.751)	(423.094)	(438.049)	(449.247)
Variable Renewable Energy	9,484.949***	10,979.750***	13,518.530***	11,059.650***	13,481.610***
	(3,480.730)	(4,083.838)	(3,486.431)	(3,305.465)	(3,936.628)
Storage Mandates		-598.836			-236.825
		(832.071)			(1,203.309)
Capacity Market			1,251.732***		889.707
			(480.285)		(1,405.944)
Demand Response Market				1,077.269**	368.401
				(486.464)	(1,317.436)
Observations	27	27	27	27	27
R^2	0.350	0.365	0.499	0.465	0.500
Adjusted R^2	0.296	0.282	0.433	0.395	0.381
Residual Std. Error	0.001 (df = 24)	0.001 (df = 23)	0.001 (df = 23)	0.001 (df = 23)	0.001 (df = 21)
Note:					*p<0.1; **p<0.05; ***p<0.01

Figure 34: Normalized Energy on Policy & Market Mechanisms, for Restructured Only

Regression Results of Normalized Energy on Subset of Policy Mechanisms with Reliability Control, Restructured States only

	Normalized Energy Availability				
	Installed BES Energy Rating (MWh) / State Annual Retail Sales (MWh)				
	(1)	(2)	(3)	(4)	(5)
Restructured IOUs	0.217	0.266*	0.110	-0.145	0.009
	(0.142)	(0.139)	(0.260)	(0.232)	(0.235)
Plus POUs	-0.430**	-0.467**	-0.411**	-0.358*	-0.376**
	(0.193)	(0.187)	(0.200)	(0.187)	(0.181)
Variable Renewable Energy	3.394**	1.959	3.759**	3.977***	2.431
	(1.453)	(1.620)	(1.647)	(1.410)	(1.590)
Storage Mandates		0.575*			0.050
		(0.330)			(0.486)
Capacity Market			0.113		-0.698
			(0.227)		(0.568)
Demand Response Market				0.399*	0.966*
				(0.208)	(0.532)
Observations	27	27	27	27	27
R^2	0.261	0.347	0.269	0.363	0.467
Adjusted R^2	0.199	0.262	0.173	0.280	0.340
Residual Std. Error	0.00000 (df = 24)	0.00000 (df = 23)	0.00000 (df = 23)	0.00000 (df = 23)	0.00000 (df = 21)
Note:					*p<0.1; **p<0.05; ***p<0.01

Please note that all findings are based on relatively small sample sizes and the measures of fit suggest many factors that have a stronger correlation are still not being observed. For the factors we do observe, this represents the strongest set of correlations.

For a summary of the quantitative findings on a wider range of policy and market mechanisms, see *Table 5*. This summarizes the direction and magnitude of the coefficients for each policy and market mechanism which is observed for both vertically integrated and restructured states. Most coefficients are not statistically significant, which means we cannot say with great confidence the *direction* of the correlation is as estimated.

Table 5: Driver Mechanism Correlation to BES Adoption

	Vertically Integrated IOUs		Restructured IOUs	
Driver Mechanism	Correlation to Normalized Power (MW)	Correlation to Normalized Energy (MWh)	Correlation to Normalized Power (MW)	Correlation to Normalized Energy (MWh)
Storage Mandate	↓	↓	↑	(↑ ↑)
Storage Target			↓	↓
Integrated Resource Planning	↓ ↓	↓ ↓	↓	↑
Renewable Portfolio Standard	↓	↑ ↑		
Renewable Portfolio Goal	↑ ↑	(↑ ↑)	↓	↓ ↓
Storage Incentives	↓	↑	↑	↑
High Demand Charges	↓	↑ ↑	↑ ↑	↑ ↑
3rd Party Asset Ownership	↑ ↑	↑ ↑		
Capacity Market			↑	↓
Frequency Regulation Market			↑	↓
Black Start Market			↑ ↑	↓
Demand Response Market			↑ ↑	↑ ↑
Reactive Supply / Voltage Control Market			↑	↑

↑ positive correlation

↓ negative correlation

↑ ↑ high magnitude positive correlation

↓ ↓ high magnitude negative correlation

(↑ ↑) greater than 95% confidence in direction of the correlation

Bibliography

Aznar, A. (2015). Word of the Day: Fixed Charges and Volumetric Charges. Retrieved April 20, 2019, from https://www.nrel.gov/state-local-tribal/blog/posts/word-of-the-day-fixed-charges-and-volumetric-charges.html

Booz Allen Hamilton, ESPA, & DOE, NETL (2013). *Power Market Primers*. Washington, DC.

Borenstein, S. (2015, February 17). "The Job Creation Shuffle," *Energy Institute at Haas*, https://energyathaas.wordpress.com/2015/02/17/the-job-creation-shuffle/

Borenstein, S., & Bushnell, J. (2015). "The U.S. Electricity Industry after 20 Years of Restructuring." Annual Review of Economics 7: 437-63. https://doi.org/10.1146/annureveconomics-080614-115630

Borenstein, Severin, and James Bushnell J. (2018). *Do Two Electricity Pricing Wrongs Make a Right? Cost* Recovery, *Externalities, and Efficiency* no. 24756). Berkeley. Retrieved from https://www.nber.org/papers/w24756.

Canada, E. S. (2018). Ontario Electricity Market Barriers to Energy Storage Presentation to IESO Energy Storage Advisory Group. Canada Energy Storage. Retrieved from http://www.ieso.ca/-/media/Files/IESO/Document-Library/engage/esag/esag-20180508-esc-presentation.pdf?la=en

Cohn, L. (2017). California Doubles SGIP Benefits, Gives Big Boost to Energy Storage Funding. Retrieved December 9, 2018, from https://microgridknowledge.com/energy-storage-funding-sgip/

Davis, L. W., & Wolfram, C. (2012). Deregulation, Consolidation, and Efficiency: Evidence from US Nuclear Power. *American Economic Journal: Applied Economics*, 4(4), 194–225. https://doi.org/10.1257/app.4.4.194

Economy, A. E. (2019). *WHOLESALE MARKET BARRIERS TO ADVANCED ENERGY – AND HOW TO*. Retrieved from https://info.aee.net/hubfs/Wholesale Market Barriers_FINAL (1).pdf

EIA. (2018). *U.S. Battery Storage Market Trends*. Washington DC. Retrieved from https://www.eia.gov/analysis/studies/electricity/batterystorage/archive/2018/pdf/battery_storage.pdf.

EIA. (2019, August 19). Investor-Owned Utilities Served 72% of U.S. Electricity Customers In 2017. Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=40913#.

Energy Storage Working Group. (2019). Proof of Regulatory Concept Draft Proposal. In PC44 (pp. 1–16). Public Service Commission of Maryland. Retrieved from https://webapp.psc.state.md.us/newIntranet/Casenum/NewIndex3_VOpenFile.cfm?filepath=C:%5CAdminDocket%5CPublicConferences%5CPC44%5C172%5C%5CPC44-Letter2(Attachment1)-StorageWorkingGroupprogramproposal.pdf.

Esch, N., & Keller, M. (2018). *2018 Utility Energy Storage Market Snapshot*. Washington DC. Retrieved from https://sepapower.org/thank-you-2017-utility-energy-storage-market-snapshot-aug17/.

Fabrizio, K. R., Rose, N. L., & Wolfram, C. D. (2007). Do Markets Reduce Costs? Assessing the Impact of Regulatory Restructuring on US Electric Generation Efficiency. *American Economic Review*, 97(4), 1250–1277. https://doi.org/10.1257/aer.97.4.1250

Gahran, A. (2019). *State of the Electric Utility: Survey Results. UtilityDive.*

Gheorghiu, I. (2019a, May 14). Tech giants pressure Dominion for more storage, renewables, less gas in Virginia. *UtilityDive*. Retrieved from https://www.utilitydive.com/news/tech-giants-pressure-dominion-for-more-storage-renewables-less-gas-in-vir/554692/.

Gheorghiu, I. (2019b, May 17). FERC commissioners deny opportunity for state-by-state opt out of storage order. UtilityDive. Retrieved from https://www.utilitydive.com/news/ferc-commissioners-deny-opportunity-for-state-by-state-opt-out-of-storage-o/554984/

Gridwise Alliance. (2018). *Grid Modernization Index 2018: Key Indicators for a Changing Electric Grid*. https://gridwise.org/wp-content/uploads/2018/12/GWA_18_GMI-2018_FinalReport_12_17_18.pdf

Hirsh, R. (1999). *Power Loss: The Origins of Deregulation and Restructuring in the American Electric Utility System*. Cambridge: The MIT Press.

Hirsh, R. (2017). Fifteen Years Later: Whither Restructuring in the American Electric Utility System? Technology's Stories, 1–28. https://doi.org/10.15763/jou.ts.2013.12.1.01

Hirsh, R. F. (1989). *Technology and transformation in the American utility inustry* (First). Cambridge: Cambridge University Press.

Hittinger, E., & Lueken, R. (2015). Is inexpensive natural gas hindering the grid energy storage industry? *Energy Policy*. https://doi.org/10.1016/j.enpol.2015.08.036

Hledik, R., Lueken, R., Mcintyre, C., & Bishop, H. (2017). *Stacked Benefits: Comprehensively Valuing Battery Storage in California*. Retrieved from http://files.brattle.com/files/7208_stacked_benefits_-_final_report.pdf

Hughes, T. P. (1983). *Networks of Power - Electrification in Western Society*, 1880-1930 (2nd ed.). Baltimore, MD: The Johns Hopkins University Press.

Jamison, M. A. (2007). RATE OF RETURN: REGULATION. In Barney Capehart (Ed.), *Encyclopedia of Energy Engineering and Technology* (pp. 1252–1257). New York: CRC Press, Taylor and Francis. Retrieved from https://bear.warrington.ufl.edu/centers/purc/docs//papers/0528_jamison_rate_of_return.pdf

K Y Mou N, R. C., Fitzgerald, G., Mandel, J., Morris, J., & Touati, H. (2015). *The Economics of Battery Energy Storage: How multi-use, customer-sited batteries deliver the most services and value to customers and the grid*. Boulder, CO. Retrieved from http://www.rmi.org/electricity_battery_value

Kintner-Meyer, M. (2014). Regulatory policy and markets for energy storage in North America. *Proceedings of the IEEE*. https://doi.org/10.1109/JPROC.2014.2319243

Lazard. (2019). *Lazard's Levelized Cost of Storage Analysis - Version 5*.0. Retrieved from https://www.lazard.com/media/451087/lazards-levelized-cost-of-storage-version-50-vf.pdf

Lee, T. (2017a). *Energy Storage in PJM: Exploring Frequency Regulation Market Transformation*. Philadelphia. Retrieved from https://www.researchgate.net/publication/320963151

Lee, T. (2017b). PG&E Battery Demonstration - Implications for the Energy Storage Value Stack. Retrieved November 17, 2018, from https://kleinmanenergy.upenn.edu/policy-digests/pge-battery-demonstration

Maloney, P. (2017a, May 4). California PUC finalizes new 500 MW BTM battery storage mandate. *UtilityDive*. Retrieved from https://www.utilitydive.com/news/california-puc-finalizes-new-500-mw-btm-battery-storage-mandate/441901/

Maloney, P. (2017b, November 7). Energy storage gets a bigger seat at the utility planning table. *UtilityDive*. Retrieved from https://www.utilitydive.com/news/energy-storage-gets-a-bigger-seat-at-the-utility-planning-table/510216/

Maloney, P. (2018a, June 12). California looks to next steps as utilities near energy storage targets. *UtilityDive*. Retrieved from https://www.utilitydive.com/news/california-looks-to-next-steps-as-utilities-near-energy-storage-targets/525441/

Maloney, P. (2018b, August 7). As second wave of state storage targets builds, utilities propose new projects. UtilityDive. Retrieved from https://www.utilitydive.com/news/as-second-wave-of-state-storage-targets-builds-utilities-propose-new-proje/529495/

Maloney, P. (2018c, August 20). BTM storage is booming in Ontario. UtilityDive. Retrieved from https://www.utilitydive.com/news/btm-storage-is-booming-in-ontario/530518/

McLaren, J. (2016). Batteries 101 Series: How to Talk About Batteries and Power-To-Energy Ratios. Retrieved May 12, 2019, from https://www.nrel.gov/state-local-tribal/blog/posts/batteries-101-series-how-to-talk-about-batteries-and-power-to-energy-ratios.html

McLaren, J., Mullendore, S., Laws, N., & Anderson, K. (n.d.). *Identifying Potential Markets for Behind-the-Meter Battery Energy Storage: A Survey of U.S. Demand Charges*. Retrieved from https://www.nrel.gov/docs/fy17osti/68963.pdf

Merchant, E. F. (2018, December 10). Virginia Regulator Asks Dominion Energy for More Accurate Resource Plan. *Greentech Media*. Retrieved from https://www.greentechmedia.com/articles/read/virginia-utility-regulator-dominion-resource-plan-more-accurate#gs.g36skb

Morehouse, C. (2019a, March 15). How Arkansas eliminated third-party solar barriers in a red state. *UtilityDive*. Retrieved from https://www.utilitydive.com/news/how-arkansas-eliminated-third-party-solar-barriers-in-a-red-state/550588/

Morehouse, C. (2019b, June 5). US energy storage market sees 232% year-on-year growth. *UtilityDive*. Retrieved from https://www.utilitydive.com/news/us-energy-storage-market-sees-232-year-on-year-growth/556186/

NARUC Staff Subcommittee on Rate Design. (2016). *Distributed Energy Resources Rate Design and Compensation*. Washington, D.C. Retrieved from https://pubs.naruc.org/pub/19FDF48B-AA57-5160-DBA1-BE2E9C2F7EA0

Neukomm, M., Nubbe, V., & Fares, R. (2019). *Grid-interactive Efficient Buildings*. Washington, DC. Retrieved from https://www.energy.gov/sites/prod/files/2019/04/f61/bto-geb_overview-4.15.19.pdf

Prol, J. L., Steininger, K. W., & Zilberman, D. (2018). *The cannibalization effect of wind and solar in the California wholesale electricity market*. Retrieved from https://www.iaee.org/en/publications/proceedingsabstractpdf.aspx?id=15267

Rule, T. A. (2018). *Renewable Energy: Law, Policy and Practice* (1st ed.). West Academic Publishing.

Satchwell, A., Cappers, P., & Barbose, G. (2019). *Current Developments in Retail Rate Design: Implications for Solar and Other Distributed Energy Resources*.

Spector, J. (2018, May 15). Dominion's New Grid Plan Overlooks Energy Storage in Favor of Gas Peakers. *UtilityDive*. Retrieved from https://www.greentechmedia.com/articles/read/dominions-new-planning-doc-shows-the-uneven-pace-of-grid-modernization#gs.g345aj

Sprake, David & Vagapov, Yuriy & Lupin, Sergey & Anuchin, Alecksey. (2017). Housing Estate Energy Storage Feasibility for a 2050 Scenario. 10.1109/ITECHA.2017.8101925. Retrieved from: https://www.researchgate.net/figure/Applicable-power-ranges-and-discharge-power-duration-of-different-energy-storage_fig7_320273548

St. John, J. (2019a, May 23). San Diego Gas & Electric Hits Snag in California Microgrids Rollout. *Greentech Media*. Retrieved from https://www.greentechmedia.com/articles/read/san-diego-gas-electric-faces-challenge-to-microgrid-rollout?utm_campaign=GTMsocial&utm_medium=social&utm_source=twitter&utm_content=1558634038#gs.g2rs3k

St. John, J. (2019b, May 28). The Latest Skirmishes Around FERC Order 841. *Greentech Media*. Retrieved from https://www.greentechmedia.com/squared/dispatches-from-the-grid-edge/the-latest-action-on-ferc-order-841?checkout#checkout

Stromsta, K.-E. (2019, July 3). Orsted and Germany's EEW Plan Offshore Wind Factory in New Jersey. *Greentech Media*. Retrieved from https://www.greentechmedia.com/articles/read/orsted-and-germanys-eew-plan-offshore-wind-factory-in-new-jersey#gs.sbid8u

Trabish, H. K. (2019, January 28). An emerging push for time-of-use rates sparks new debates about customer and grid impacts. *UtilityDive*. Retrieved from https://www.utilitydive.com/news/an-emerging-push-for-time-of-use-rates-sparks-new-debates-about-customer-an/545009/

United States Environmental Protection Agency. (2015). *Regulatory Impact Analysis for the Clean Power Plan Final Rule*. Research Triangle Park. Retrieved from http://www.epa.gov/powersectorm

von Meier, A. (2006). *Electric Power Systems: A Conceptual Introduction*. Hoboken, NJ: John Wiley & Sons.

Walton, R. (2019, March 11). Duke defends IRP as greens push North Carolina regulators to reassess. *Greentech Media*. Retrieved from https://www.utilitydive.com/news/duke-defends-irp-as-greens-push-north-carolina-regulators-to-reassess/550112/

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