Assessing the Energy Equity Benefits of Energy Storage Solutions

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***Abstract*—Safety, reliability, efficiency, and affordability are no longer the sole tenets of electric grid planning. The evolving social and policy climate have placed new explicit requirements to integrate energy equity and justice strategies in modern electric grid design to achieve a fair and just distribution of environmental, economic, and social benefits within the energy system. This study aims to characterize the energy equity and community benefits of energy storage systems (ESS) under the following three use case models: utility ESS that are operated within the distribution system, community-owned ESS, and behind-the-meter ESS that are customer-owned to serve the household. A resource adequacy analysis of a representative feeder subject to six outage scenarios is performed to assess energy access as a key equity metric in each use case. The energy access analysis can be used to inform further research on additional energy equity metrics such as energy burden, energy poverty, energy vulnerability, resilience, decarbonization, and job creation to create a prioritization framework matching community needs with system preferences for utility planning processes, market regulations, and the wider network of energy system stakeholders.**

Keywords—energy justice, energy storage, equity, reliability, resilience

I. INTRODUCTION

Energy storage systems (ESS) are recognized as the fundamental grid infrastructure required to facilitate a global clean energy transition. Renewable generation technologies like wind and solar depend on variable resources that experience mismatch between peak generation and demand. As levels of renewable penetration increase, storage assets can help balance the grid and match generation to electric load. In addition to facilitating renewable energy integration, storage assets can perform a myriad of grid services such as managing load volatility, frequency response, outage mitigation, demand charge reduction, and deferral of infrastructure upgrades. Storage can be deployed at all functional levels of the electric grid, which can support an advanced grid to withstand extreme weather events due to climate change, cyberattacks, and the increasing deployment of distributed energy resources [1].

As ESS become more widespread throughout the grid it is imperative that energy system planning processes be informed not only by their potential grid benefits but also by the equity benefits of such assets. Depending on ownership model, use case, and market and regulatory framework, ESS can support emissions reduction by providing energy to the grid during peak demand, preventing the highest fossil fuel burning "peaker" plants from being ramped up or brought online. Peaker plants are often located in disadvantaged communities that struggle with poor air quality and have less resources to prevent the siting of such plants in their neighborhoods, putting them at increased risk for respiratory illness, pre-term births, and respiratory-related hospital visits [2], [3]. Reducing the need for peaker plants can also lessen the intensity of peak pricing, reducing energy poverty and energy burden, or the percentage of median income spent on energy utility bills. ESS can also provide increased system and local resiliency during extreme weather events and outages to maintain operation of community shelters and critical healthcare and emergency services [2]. If community-owned, energy storage assets have the potential to provide a community revenue stream for grid services provided [4] as well as additional economic benefits through local job creation [2].

The numerous energy equity benefits of energy storage solutions cannot yet be captured simultaneously by one model. This analysis measures energy access according to supply-demand balance for six outage scenarios to inform a discussion of access as well as affordability, decarbonization, resilience, and environmental and social impact. This analysis is centered on Louisiana, as the South-Central region of the United States has the highest number of households facing high energy burden [5], with low-income residents of New Orleans experiencing some of the highest energy burden in the country, spending between 6 and 18.9% of their income on energy utilities [6]. Additionally, the severity and frequency of destructive hurricanes in Louisiana are exacerbated by climate change every year. Power outages after hurricane Katrina in 2005, prolonged up to two weeks due to flooding, forced dozens of hospitals to evacuate patients [7]. Such power outages and severe infrastructure damage along the Gulf Coast result in numerous equity related impacts, as low-income and medically vulnerable residents are often not able to preemptively evacuate.

Much of the nation's petroleum refinery capacity and natural gas processing plants are also located in this region, and without power, the emissions from these plants go unchecked and unmonitored, mitigated only by flares that are susceptible to strong hurricane winds [8]. As air quality monitoring stations also rely on grid power, it is difficult to measure the full health impacts of these events, especially for residents that must work outside to repair damages to their homes in these conditions [8]. The goal of this analysis and discussion is to capture the benefits that ESS can provide to address the above equity and grid concerns of Louisiana and in turn the rest of the United States.

This paper is structured as follows: Section II provides a background discussion on energy equity and current energy storage solutions; Section III offers a storage adequacy analysis based on supply-demand balance to compare the equity impacts of three distribution-level energy storage use cases for six different outage scenarios; Section IV offers a discussion on the analysis results and concludes the paper; and section V briefly comments on future work.

II. BACKGROUND

A. Connecting Energy Equity and Energy Storage

Energy equity impacts must be adequately considered as energy resources shift away from fossil fuels to lower-carbon variable energy resources, such as renewable energy and energy storage deployments. Without an active consideration for the principles of equity and justice alongside grid needs, the clean energy transition could perpetuate existing energy

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system inequities and create new disparities in the distribution of benefits and burdens [9]–[11].

In a broad sense, energy equity and justice seek to ensure that all individuals “have access to energy that is affordable, safe, sustainable and capable of supporting a decent lifestyle, as well as the opportunity to participate in and lead energy decision-making processes with the authority to make change” [9]. Energy equity incorporates concepts such as energy affordability, energy insecurity, and energy vulnerability to ensure people have access to low-carbon energy sources, detailed in Table 1[10].

Jenkins et al. [12] offer three energy justice tenets to identify where inequities occur, who they affect, and how it affects them. The first tenet, distributive justice, relates to understanding the unequal allocation of energy burdens and benefits and their associated responsibilities and consequences. The second tenet, recognition justice, relates to uncovering the practice of cultural domination, disregard of people and their concerns, and misrecognition to allow for a more inclusive energy system. The third tenet, procedural justice, deals with the fairness of the decision-making process and assesses whether public participation, information disclosure, decision-making transparency, and due diligence processes exist and are accessible to everyone. In McCauley and Heffron [10], restorative justice is added as a fourth tenet to account for a retrospective and proactive assessment of the energy system and to respond to those historically affected by the energy system.

Energy equity is useful to analyze the past, present, and future of the energy system performance and its relationship to people. Disadvantaged and frontline communities face a number of disproportionate energy effects, including: higher likelihood of living near fossil fuel burning generation assets and resource extraction facilities, increased risk of climate-related vulnerabilities, longer and more frequent outages, increased energy burden and energy insecurity (Fig. 1) [13], less access to sustainability and resilience measures, and limited access to the benefits of electrification [14]. Low-income households (income < 200% of the federal poverty level) are reported to spend three times more of their income on energy costs than more affluent households [6], putting them at greater risk of energy insecurity and energy poverty. Recent state and local level equity-centered policy efforts have paved the way for the design and implementation of energy storage projects that enhance equity for disadvantaged or underserved communities facing energy challenges [4]. For example, the California Public Utility Commission’s Self-Generation Incentive Program offers energy storage rebates prioritizing the low-income and medically vulnerable [15]; Massachusetts’s Solar Massachusetts Renewable Target program offers incentives for behind-the-meter (BTM) solar projects and an adder for energy storage to increase participation from low-income communities [16]; Connecticut’s Equitable Modern Grid Initiative Electric Storage Program offers upfront and annual performance-based incentives with an additional incentive for low-income customers who have historically experienced frequent and longer storm-related outages [17]; and Oregon’s Solar + Storage Rebate Program expands access to renewable energy by reserving at least 25% of rebates for low and moderate-income households and service providers [18].

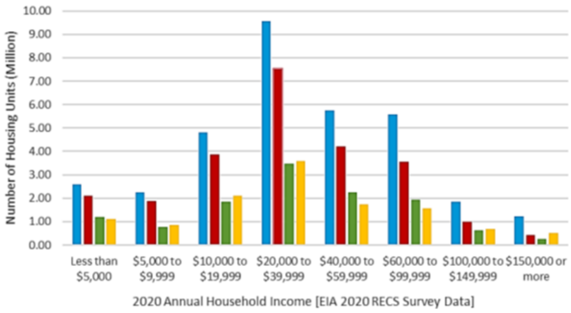

Fig 1. Household energy insecurity (blue), reducing or forgoing food or medicine to pay energy costs (red), receiving disconnect or delivery stop notice (green), and leaving home at unhealthy temperature (yellow), by 2020 income data [13]

B. Current Storage Solutions and Use Cases

Energy storage can be categorized based on its location within the grid, ownership model, or duration/capacity. Three use cases that offer significant contrasts in these categories and are instructive for equity effects were selected for this analysis: (1) utility ESS that are operated within the distribution system, (2) community-owned ESS, and (3) BTM ESS that are customer-owned to serve the household. This section briefly describes each use case and provides a selection of example projects within the United States.

1) Utility-Owned: Utility-owned energy storage assets sited within the distribution system are able to perform non-market services such as Volt-VAR control, improved system resiliency, energy conservation through feeder voltage reduction, and infrastructure upgrade deferral through congestion management [19], [20]. FERC Order 841 was

TABLE I: USE CASES OF ENERGY STORAGE TO SUPPORT COMMUNITY OBJECTIVES

Energy Equity Benefit	Storage-Equity Linkage	Example Applications
Access	Energy storage can provide energy access when integrated with a fuel source (fossil or renewable)	Unelectrified areas, limited resource availability, disconnection rates, system capacity for small-scale renewables, electrified vehicles, eligibility for demand response programs, and future load growth
Affordability	Energy storage can reduce energy costs for consumers and enhance energy affordability by providing consumers more control of their energy use	Energy cost burden, demand charges, energy market revenue, shut-off notices for non-payment
Decarbonization	Energy storage integrated with renewable energy generation mitigates greenhouse gas effects	Climate/renewable energy targets (solar, wind, etc.), fossil fuel power plant decommissioning, peaker power plant replacement
Environmental Impact	Energy storage can replace fossil fuel-based peaker plants or backup generators mitigating local pollution	Health improvement, air quality improvement, emissions reduction
Resilience	Energy storage integrated into critical grid locations provides energy that is accessible to vulnerable communities during extreme weather events	Avoided energy outages, avoided disruption costs (financial and otherwise), enhanced reliability, sustained critical loads during extreme events (especially for community/cooling centers, libraries, schools, etc.)
Social Impact	Energy storage can serve as a community asset, providing flexibility community empowerment	Energy independence, wealth creation, community ownership, community building

recently issued to remove the barriers preventing ESS participation in capacity, energy, and ancillary service markets, allowing utility-owned storage assets to now serve a wider set of grid functions across the United States.

Despite the still-evolving regulatory and policy landscape, the falling cost of batteries and updated utility business models capturing multiple benefits of ESS have allowed utility-scale energy storage to become increasingly prevalent across the United States [21]. In 2019 alone, Southern California Edison announced multiple storage projects totaling 195 MW in lieu of constructing another natural gas peaker plant; Pacific Gas and Electric Company (PG&E) was approved for four ESS installations for a total of 567.5 MW to facilitate the decommissioning of a natural gas plant; Arizona Public Service announced its goal of installing 850 MW of ESS by 2025; and Portland General Electric announced a combined wind, solar, and 30 MW battery storage project [21].

2) Community-Owned: Community Energy Storage (CES) is considered an intermediary operating between utility and BTM storage solutions [4], characterized by the community ownership and governance structure resulting in community-wide benefits such as higher penetration and self-consumption of renewables, decoupling of energy demand and supply, reduced dependence on fossil fuel sources and improved air quality, reduced energy bills, and the potential for communities to generate revenue from the various services provided [22]. CES can take on various forms, from a network of shared residential BTM assets to larger storage assets installed at the neighborhood level, both managed over the local grid [22]. There is no standard business model for CES, and many CES assets are community scale, but actually owned and controlled by utilities [23]. The CES model is difficult to adequately capture and compensate, and as such, there are relatively few true community energy storage projects that have been realized in the United States.

CES is technically capable of providing the same grid services as utility-owned ESS, but non-utility owned assets can only be used for contracted and market-based services. Additionally, the utilization potential depends on capacity allocation and controls—if most of the storage capacity is reserved for an extended outage scenario, the CES will have limited economic feasibility due to underutilization. If appropriately utilized, communities can enjoy considerable cost savings, emissions reductions, and improved system reliability. When multiple consumers with different energy use profiles co-own a network of ESS, individual investment risk is lowered, and the staggered energy profiles lead to increased storage utilization [24].

The Sacramento Municipal Utility District (SMUD) and partners piloted a PV and Storage Demonstration project in 2010 with both fifteen 7.7 kWh residential BTM and three 34kWh CES units to study the difference in impact and utilization between the two types of deployments [25]. The CES assets were sited at utility facilities. SMUD found that the CES assets were easier to install over the individual consumer-level assets, were sized with greater capacity to serve multiple consumers, and resulted in lower homeowner liability and risks [25].

Michigan-based Detroit Edison Energy (DTE) also piloted a 1 MW CES project, installing eighteen 50 kWh lithium-ion batteries, a 500 kW PV system with battery storage, and two repurposed electric vehicle batteries to be shared across 2,000 community members in Monroe, Michigan managed by a Distributed Energy Resource Management System [DERMS] [26], [27]. The system provided backup power to residents as well as voltage correction and increased integration of consumer-level renewables. At the system-level, the community asset performed load levelling services at the substation, power factor correction, and various ancillary services [27]. The economic analysis DTE later performed on its CES system highlighted what has since become widely accepted in the storage community: storage solutions can rarely be economically justified if relegated to perform just one service—only by stacking services and benefits, in this case frequency regulation, capacity, distribution investment deferral, and electricity sales, do these system benefits outweigh the investment costs [26].

3) Customer-Owned: Customer-owned BTM storage assets are smaller in size than both community and utility-owned storage and are typically adopted due to a consumer's desire for increased grid independence, backup power supply, and increased self-consumption of residential solar PV installations [20]. The business model for BTM storage operation is also not standardized. Assets can be consumer-owned and operated or consumer-owned but third-party operated. BTM storage is not limited to a stationary battery, as some utilities are working to allow consumers to receive compensation for electing their electric vehicles to provide grid balancing services while charging at home [28].

Sacramento's previously mentioned SMUD pilot demonstration reported that the customer-owned assets had the benefit of being sheltered from the elements due to the installations typically being located within customer garages, and depending on the consumer's utility rate structure, BTM units were able to reduce utility bills. If configured to serve as an uninterruptable power supply, the storage units were also able to provide backup power in the case of outages [25]. From a behavior perspective, SMUD also found that despite various outreach efforts and monetary incentives, most consumers were not interested in being connected to a shared community energy storage asset over having their own residential unit [25], highlighting a need to better understand consumer willingness to adopt various storage solutions.

Vehicle-to-grid (V2G) is another customer-owned ESS model that has received increasing attention as the adoption of electric vehicles (EV) continues to grow with the help of many state and federal incentives and the maturation of EV technologies. The growing EV trend has substantial implications for the national electric grid, as the increase in demand due to EV charging is likely beyond the current capabilities of the grid [29]. However, charging EVs have the potential to provide many grid services that may help offset the burden of their charging, such as peak shaving, improved load factor and grid reliability, frequency and voltage regulation, and spinning and non-spinning reserves [29].

III. STORAGE ADEQUACY ANALYSIS

To study the equity impacts of different energy storage use cases within the Louisiana area, a storage adequacy analysis was performed on a representative non-urban core, radial distribution feeder corresponding to the hot/humid climate region of the United States. The representative feeders developed through the Department of Energy's Modern Grid Initiative by the Pacific Northwest National Laboratory and based on data from 17 different utilities are classified by voltage and climate region, as those characteristics have the most influence on the design of a feeder system [30], [31]. The 13.8 kV, 265-node feeder chosen for this analysis is representative of a heavily populated suburban area with a moderate urban center, with 145 residential transformers and 26 commercial transformers. Fig. 2 shows how the feeder is augmented with battery energy storage units: BTM, CES (in this case part of a community or resilience hub), and utility-scale storage units.

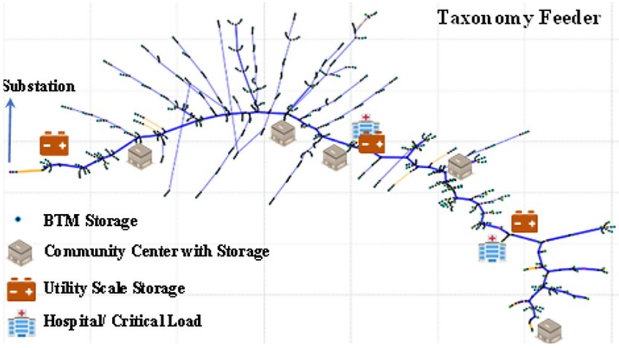

Fig. 2. Taxonomy Feeder Model and ESS Locations

A. Feeder Structure Modification and Management

The feeder is divided into five communities. The main trunk of the feeder has 44 nodes that branch into lateral sections of the feeder. Every eight consecutive laterals form one community, resulting in communities dominated by residential transformers. The last 12 laterals form one community that is dominated by commercial loads. Two commercial loads along the feeder have been identified as critical loads, such as a hospital. The total load in the feeder is 10.5 MW. For the purposes of this analysis, the total storage in each use case is rated to meet 30% of load, or 3.15 MW, with a 12.6 MWh battery capacity to meet four hours of demand.

Six different outage scenarios are analyzed for each use case for supply-demand balance based on the integral number of trunk nodes that can be powered by the storage units. One outage scenario is loss of the substation, and the other five scenarios are within the communities along the line connecting to the trunk node supplying largest load. The amount of unserved load reported is the result of only parts of the feeder being supplied, with the other regions remaining in blackout or brownout. The metric chosen to measure energy access is percent access, computed based on how many nodes on the feeder (sectionalized to ensure stability) have supply-demand balance. Energy access and amount of unserved load in each outage scenario is compared for the three use cases, described in the next section and summarized in Table II.

B. Energy Storage Use Cases

1) Customer-Owned: In the customer-owned use case, each unit has access to storage, sized to meet 30% of the individual load for four hours in an outage event. If the energy is used judiciously, the storage units can power a smaller fraction of the normal load for a longer duration of time, increasing community resilience in extreme weather events that often result in delays to repair work.

2) Community-Owned: For this analysis, community storage is linked to resilience or community hubs, such as a library, serving the community in case of emergency. The CES is rated at 30% of the load of the entire community operating for four hours. In this use case, individual homes will not have direct access to electricity, and residents will need to travel to the community hubs for energy and resources during outage events.

3) Utility-Owned: Utility-owned storage is again rated at 30% of the total community load, though it cannot provide for each load on the feeder in an outage scenario. Since there is no active control to limit individual customer usage, as these are absent in traditional distribution system operations, the nodes farther from the storage location will not have energy access and only a part of the feeder will behave like a microgrid. Three locations along the feeder are analyzed for this use case: the start of the feeder closest to the substation, the middle of the feeder, and end of the feeder.

IV. DISCUSSION AND CONCLUSIONS

Based on this storage resource analysis, summarized in Table II, customer-owned BTM storage provides the greatest access and flexibility, as the individual customer has control over their energy usage. Community-owned storage maintains the same access and flexibility, though residents must travel to the community center to share the load and resources as a group. In the case of utility-owned storage, access depends on both where the storage unit is located and the outage location. Though the amount of unserved load is similar in all three use cases, utility storage provides the least amount of energy access. For all use cases, storage units can be coupled with solar panels to replenish capacity and increase resilience during prolonged outages typical after extreme weather events in Louisiana. Integration with renewable generation sources in all use cases can further decarbonization efforts and should be considered during grid and resource planning activities.

The affordability of each use case depends on regulatory and market structures as well as economics of scale. Louisiana has one of the lowest energy rates in the United States [6] and the utility Entergy New Orleans even offers reduced rates after a certain usage amount [7]. Louisiana also

TABLE II: COMPARISON OF ACCESS AND UNSERVED LOAD FOR EACH USE CASE

Outage Location	Customer-Owned		Community-Owned		Utility-Owned					
					Start of Feeder		*Middle of Feeder*		*End of Feeder*	
	Access	*Unserved [MW]*	*Access*	*Unserved [MW]*	*Access*	*Unserved [MW]*	*Access*	*Unserved [MW]*	*Access*	*Unserved [MW]*
Substation	100 % Direct	7.35	100 % Indirect	7.35	31%	7.86	36.4%	7.35	36.4%	7.44
Line 173-105					9%	10.26	36.4%	7.35	36.4%	7.44
Line 147-160					29.5%	8.28	36.4%	7.35	36.4%	7.44
Line 133-156					31%	7.86	38.6%	7.39	36.4%	7.44
Line 41-46					31%	7.86	25%	7.85	36.4%	7.44
Line 90-91					31%	7.86	36.4%	7.35	22.7%	8.07

does not legally allow third parties to sell electricity to consumers, prohibiting most power purchase agreement financing models. These factors make the economic feasibility of small-scale renewables and storage solutions a greater challenge for non-utility entities such as customers and communities than in other regions [7]. However, there are novel business models with enhanced economic feasibility such as virtual community energy storage, where customers purchase virtual shares of an energy storage asset sized according to the combined need of all shareholders and sited to most benefit grid operations [32]. In such models, shareholders benefit from demand charge reductions without any of the installation, operation, and maintenance costs. Virtual community energy storage increases the affordability of the ESS via economics of scale, and it improves system reliability for all utility customers despite not providing direct backup to shareholders in an outage. It is likely that novel business strategies will continue to be required until the regulatory and market structures have adapted to capture and compensate the full functionality of ESS. This is especially true for community-owned storage as the social impact potential from the energy independence and wealth creation of true CES is presently stifled by the regulatory and market structure in the United States.

V. FUTURE WORK

Leveraging the full equity benefits of storage—improved access, affordability, decarbonization, resilience, and environmental and social impact—in tandem with the grid benefits of storage during utility planning, market, and regulatory processes is necessary to ensure an equitable energy transition. This task is no small feat, as evaluating equity metrics requires improvements to data quality and availability across all sectors, as well as the development and coordination of models able to capture metrics beyond just access and reliability. For example, a more informed evaluation of the environmental impacts of storage requires detailed air quality data, which is difficult to capture during extreme weather events when monitors often go offline during power outages [8]. This analysis is but one piece of the equity puzzle, and the authors hope to build upon this work to deliver a more comprehensive equity analysis in the future.

REFERENCES

[1] R. O'Neil, A. Becker-Dippmann, and J. D. Taft, "The Use of Embedded Electric Grid Storage for Resilience, Operational Flexibility, and Cyber-Security," 2019.

[2] Union of Concerned Scientists, "How to Ensure Energy Storage Policies are Equitable," 2019.

[3] E. M. Krieger, J. A. Casey, and S. B. C. Shonkoff, "A framework for siting and dispatch of emerging energy resources to realize environmental and health benefits: Case study on peaker power plant displacement," *Energy Policy*, vol. 96, pp. 302–313, Sep. 2016, doi: 10.1016/j.enpol.2016.05.049.

[4] B. Tarekegne, R. O'Neil, and J. Twitchell, "Energy Storage as an Equity Asset," *Current Sustainable Renewable Energy Report*, vol. 8, pp. 149–155, 2001, doi: 10.1007/s40518-021-00184-6/Published.

[5] A. Drehobl, L. Ross, R. Ayala, A. Zaman, and J. Amann, "How High Are Household Energy Burdens? An Assessment of National and Metropolitan Energy Burden across the United States," 2020.

[6] American Council for an Energy-Efficient Economy (ACEE), "How energy efficiency can help low-income households in Louisiana," 2020.

[7] Clean Energy Group, "Exploring Opportunities for Solar+Storage in New Orleans, LA."

[8] S. Sneath, "Louisiana Shell refinery left spewing chemicals after Hurricane Ida," *The Guardian*, Norco, Sep. 04, 2021.

[9] S. Carley and Konisky D, "The justice and equity implications of the clean energy transition," *Nature Energy*, vol. 5, pp. 569–577, 2020.

[10] D. McCauley and R. Heffron, "Just transition: Integrating climate, energy and environmental justice," *Energy Policy*, vol. 119, p. 17, 2018.

[11] J. Hoffman *et al.*, "Working to align energy transitions and social equity: An integrative framework linking institutional work, imaginaries and energy justice," *Energy Research & Social Science*, vol. 82, 2021.

[12] K. Jenkins, D. McCauley, R. Heffron, H. Stephan, and R. Rehner, "Energy justice: A conceptual review," *Energy Research & Social Science*, vol. 11, pp. 174–182, 2016.

[13] "2020 Residential Energy Consumption Survey (RECS)," *U.S. Energy Information Administration*. 2022.

[14] "The hidden cost of fossil fuels," *Union of Concerned Scientists*, Aug. 30, 2016.

[15] "Self-Generation Incentive Program (SGIP)," *State of California Public Utilities Commission*, 2021.

[16] "Solar Massachusetts Renewable Target (SMART)," *Commonwealth of Massachusetts*, 2022.

[17] M. Gillett, J. Betkosk III, and M. Caron, "PURA Investigation into Distribution System Planning of the Electric Distribution Companies - Electric Storage," 2021.

[18] "Oregon Solar + Storage Rebate Program," *Oregon Department of Energy*, Sep. 02, 2022.

[19] P. J. Balducci, M. J. E. Alam, T. D. Hardy, and D. Wu, "Assigning value to energy storage systems at multiple points in an electrical grid," *Energy and Environmental Science*, vol. 11, no. 8, pp. 1926–1944, Aug. 2018, doi: 10.1039/c8ee00569a.

[20] "Transactive Energy System for Multi-Scale, Multi-Owner Storage Systems," 2022.

[21] S. Golden, "Utilities' energy storage growing like gangbusters," *GreenBiz*, Jun. 14, 2019.

[22] B. P. Koirala, E. van Oost, and H. van der Windt, "Community energy storage: A responsible innovation towards a sustainable energy system?," *Applied Energy*, vol. 231, pp. 570–585, Dec. 2018, doi: 10.1016/j.apenergy.2018.09.163.

[23] D. Boff and J. Twitchell, "Community Energy Storage and Energy Equity," 2021.

[24] A. Walker and S. Kwon, "Analysis on impact of shared energy storage in residential community: Individual versus shared energy storage," *Applied Energy*, vol. 282, Jan. 2021, doi: 10.1016/j.apenergy.2020.116172.

[25] "DE-EE0002066 Sacramento Municipal Utility District PV and Smart Grid Pilot at Anatolia Final Project Report."

[26] H. Asgeirsson, "DTE Energy Advanced Implementation of Energy Storage Technologies," 2015.

[27] H. Asgeirsson, "DTE Energy: Energy Storage Demonstration Projects," 2011.

[28] Pacific Gas and Electric Company, "PG&E and BMW Group Taking Next Step in Powering Electric Vehicles with Renewable Energy and Supporting Grid Reliability," *Business Wire*, Mar. 22, 2021.

[29] A. Alobaidi, H. Desroches, and M. Mehrtash, "Impact of vehicle to grid technology on distribution grid with two power line filter approaches," in *IEEE Green Technologies Conference*, Apr. 2021, vol. 2021-April, pp. 163–168. doi: 10.1109/GreenTech48523.2021.00035.

[30] K. P. Schneider, D. W. Engel, Y. Chen, S. E. Thompson, D. P. Chassin, and R. G. Pratt, "Modern Grid Initiative Distribution Taxonomy Final Report," 2008.

[31] K. P. Schneider, Y. Chen, D. Engle, and D. Chassin, "A Taxonomy of North American radial distribution feeders," in *2009 IEEE Power & Energy Society General Meeting*, Jul. 2009, pp. 1–6. doi: 10.1109/PES.2009.5275900.

[32] M. Costello, "SMUD's Energy StorageShares program: The first virtual energy storage program in the US," *Renewable Energy World*, Sep. 24, 2020.