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Analysis of Energy Justice and Equity Impacts from Replacing Peaker Plants with Energy Storage

Bethel Tarekegne, Devyn Powell, Konstantinos Oikonomou, Eva Jacroux and Rebecca O'Neil
Pacific Northwest National Laboratory, Richland, WA, USA

Abstract—**Transitions to low-carbon energy systems are essential to mitigating and adapting to climate change. Energy storage systems are a key component in achieving a viable decarbonized electric grid. However, decarbonization alone does not guarantee a fairer, more inclusive, or socially just energy system. Energy equity and justice should be integrated in energy system transitions to ensure benefits and burdens are shared equitably. In this paper, we discuss the relationship between energy storage and social equity by assessing the use of energy storage to replace natural gas-fired (NG) peaker plants. Peaker plants are disproportionately located near disadvantaged communities and tend to be older and high emitters of health-affecting fine particulate matter and other pollutants. This paper investigates the equity implications of NG peaker plant replacements with battery energy storage in the context of Washington State's peaker plants to highlight the human-centered values of retiring the plants. The study performed production cost simulations using the latest Western Electric Coordinating Council Anchor Dataset 2030 case and found that total generation cost, locational marginal price, and total annual emissions were reduced with the replacements. These reductions will have equity benefits on local communities including access to clean air, enhanced health outcomes, and energy burden reductions.**

Keywords— Energy storage, energy justice, energy equity, peaker plants, decarbonization, energy transition

I. INTRODUCTION

Energy infrastructure development could lead to various negative social implications. Energy projects may cause forced displacement of communities, generate pollution and other environmental and human-health impacts, and have unreliable and expensive energy related services. For example, for low- and middle-income households, increasing electricity prices in places like California have constrained people's disposable income, leading to unsustainable livelihood choices [1]. Similarly, U.S. households in rural areas face high levels of energy burdens, spending a disproportionate share of their income on energy costs [2]. The uneven distribution and underinvestment in modern, efficient, and clean energy infrastructure across demographic groups highlights the deep inequities of the energy system that must be rectified to have a just energy future for all [3].

Climate change will exacerbate these inequities, albeit with varying degrees of impact across demographic groups. Climate-change-induced extreme weather events are expected to lead to more frequent and longer-lasting power outages, service disruptions, and fuel shortages [4]. For example, in 2019, Pacific Gas and Electric (PG&E), California's largest utility, cut power to two million people due to wildfires [5]. Marginalized communities disproportionately experience severe effects from climate change and extreme weather events, deepening their vulnerabilities due to underlying pollution overburden, underinvestment in clean energy infrastructure, and the lack of access to energy-efficient housing and transportation [2].

Climate change is also anticipated to have a dramatic impact on the future performance of the U.S. electricity system, including changes in the timing, availability, and efficiency of electric generation, alongside reductions in transmission capacity and increasing electricity demand [6, 7]. This will lead to changes in energy availability, energy pricing, and sustained outages. In 2003, a power grid blackout left 50 million people without power for two days across the United States and Canada, costing approximately $6 billion to the economy.

Decarbonization of the energy sector is a central pillar to achieving net-zero emissions and slowing the pace of climate change and mitigating its effects [8]. Therefore, there is a growing effort around a just transition to ensure that the energy transition from fossil fuels to the future low-carbon grid is fair and equitable, both in the distribution of benefits and in technology opportunities [9]. Energy storage systems (ESSs) are a key component of a viable decarbonized grid due to renewable energy challenges of intermittency, ESS supply flexibility, ESS power quality [10]. ESSs will play a critical role in expanding electrification, maintaining the electric grid's stability and reliability, and significantly supporting the replacement of polluting fossil fuel-fired peaker plants [11].

ESSs will also provide non-grid benefits that support energy equity, including reduced emissions, enhanced air quality and other environmental conditions, improved resilience to disasters and power outages, promotion of local economic development and job growth, reduced electricity bills from peak demand charges, and fostering of energy independence and wealth generation [12]. For example, during the August and September 2020 heat waves in California, Southern California Edison used its battery ESS to prevent disruptions to customers and address emergencies [13]. Similarly, Duke Energy's 2017 Western Carolinas Modernization Plan set aside $30 million investment dedicated to installing battery ESSs to provide backup power and improve North Carolina's grid reliability [14]. These attributes of ESSs offer an avenue to explore how improvements and investments in the grid can be targeted to respond to social and health challenges in transitioning the energy system to be more sustainable and equitable.

This paper explores the potential equity impacts and community benefits of replacing NG peaker plants with energy storage. Peaker plants are traditionally used to meet peak demand on the grid, and they are only turned on during times of peak electricity demand (~100–300 hours a year). These plants, which are mostly natural gas-fired (NG) plants, tend to be older and more polluting with high emissions of health-impacting fine particulate matter (PM) and other

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Corresponding author, Email: bethel.tarekegne@pnnl.gov

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pollutants. Historically, peaker plants have been disproportionately located near disadvantaged communities, including those that are low-income and racial minorities. As such, the paper will discuss the energy justice and equity impacts of replacing peaker plants with energy storage to minimize the health disparities experienced by these frontline communities. Taking Washington State's peaker plants as case studies, the study replaced ten natural gas-peaking (NG-P) units located in the Northwest (NW) region, and particularly in the Puget Sound Electric (PSE) balancing authority with hybrid wind and battery energy storage systems (BES). Production cost simulations were performed using the latest version of the Western Electric Coordinating Council (WECC) Anchor Dataset (ADS) 2030 case as it contains the best available projection of new generation, generation retirements, transmission assets, and load growth in the 10-year planning horizon within the WECC grid planning community.

The rest of the paper is structured as follows. Section II provides a background discussion on ESSs and energy equity; Section III offers a case study analysis of peaker plant replacement strategies for Washington State; Section IV discusses the equity implications of retiring and replacing Washington's peaker plants with storage; and Section V concludes the paper.

II. ENERGY STORAGE SYSTEMS AND ENERGY EQUITY

ESSs provide wide applications, including supporting communities facing disproportionate environmental stressor burdens and exposure to unhealthy criteria pollutants [15]. In the United States, nine states have adopted policies mandating energy storage targets. A third of these have already integrated equity-focused mechanisms into their policies. For example, Connecticut and Oregon currently have higher rebate levels for low- or moderate-income (LMI) groups, and California has higher rebate levels for equity and equity resilience groups. The Massachusetts storage policy includes adders for LMI groups or systems installed on brownfields or landfills. While there are advantages and disadvantages to each policy, they all highlight the growing interest in the intersection between energy storage and equity. For this paper, we define energy equity as the ability of the electric system to fairly distribute burdens and benefits to ensure that electricity benefits of renewable energy—affordability, reliability, job creation, health, and comfort—extend to all levels of society, regardless of ability, race, or socioeconomic status [9].

A. Energy Storage Technologies

ESSs refer to a broad range of technologies that store energy for future use. There are several categories of energy storage technologies—electrochemical, electromechanical, thermal, flexible generation, flexible buildings, and power electronics. Recent energy storage deployment has centered on short-duration (< 1–6 hours) technologies, with cost-competitive lithium-ion batteries. Research forecasts ESSs will advance to involve cost-competitive longer-duration storage (4–12 hours) and eventually reach durations of days to months. Although growth trends are dependent upon renewable energy implementation and market predictions, the U.S. Energy Information Administration (EIA) projects a significant number of battery ESSs will be added to the U.S. power grid with an additional 59–108 GW of energy storage expected to be deployed in 2050 depending on cost reductions [16]. Others project that the installed capacity of diurnal (< 12 hours) energy storage will grow between 125 and 680 GW [17].

ESSs can be deployed either with behind-the-meter (BTM)—referring to small-scale, customer-sited batteries installed at a home or business—or with front-of the-meter, which refers to generally larger, often utility-operated systems that are interconnected directly to the transmission or distribution systems. Most deployed energy storage is in the form of large-scale, pumped hydroelectric projects that were implemented in the 1990s. Due to land, water, and cost constraints, these hydroelectric capabilities have had limited applications. Other energy storage technologies have been growing rapidly, with battery energy storage being the most prevalent. Ninety percent of the current battery storage market is lithium-ion batteries, providing an average of 1.7-hour backup duration with a maximum of 4 hours. As storage technologies continue to develop and become more cost-effective, they will offer a wide variety of applications and grid/non-grid benefits.

B. Energy Storage for Peaker Plant Replacement

The application of storage for peaker plant replacements is one viable scenario to envision the equity enabling characteristics of storage systems. Peaker plants produce disproportionately large amounts of harmful emissions and local air pollution (e.g., sulfur oxides [SO_X], nitrous oxide [NO_X], carbon monoxide [CO], etc.) for their short run times. Health effects from pollution exposure have been linked to heart and lung disease, and very recently, it has been shown that those that had long-term exposure to air pollution experienced the worst effects of COVID-19 and an increased death rate once infected [18].

As peaker plants are often older and dirtier than other power plants, they are linked to high incidence of local air quality and public health effects. Across the United States, two thirds of these plants are located in communities where 29% or more of the population is low-income, predominantly people of color, and aging (65% and above). Emissions from peaking plants are 44% higher than average, and as such, the effects disproportionately affect disadvantaged and vulnerable communities [18]. For example, in New York, peaker plants account for 10% of NOx emissions while only running a few hours a year and costing ratepayers around $4.5 billion to keep them running [19].

In March 2021, the PEAK coalition, a group of mostly New York based environmental justice and clean energy advocacy groups released a report outlining a strategy to retire New York City's fleet of peaker plants by 2030 [19]. The report highlighted that 50% of the city's peakers ran for 8 hours each time they were on, and 28 units ran for four hours or less, meaning that these "peaking" needs could easily be replaced by storage systems. The study showed that the city would need 4.2 GW of 8-hour duration storage to replace the city's peaker plants by 2030. This would total about 33,500 MWh of energy storage capacity. Other reports have detailed equity-focused peaker plant replacement and climate strategies in more states with similar results, suggesting future long-duration energy storage technologies could replace combustion capacity altogether and that states should prioritize replacing peaker plants with storage capacity and other clean energy alternatives.

III. CASE STUDY: RETIRING AND REPLACING WASHINGTON STATE'S PEAKER PLANTS

Washington is a national leader in hydropower, which produces 66% of the state's net generation whereas NG produced 12% of the state's power in 2020. Renewables besides hydropower, predominantly wind, followed closely behind at 9%. Nuclear produced 8%, and coal produced less than 5% [20]. In 2019, Washington committed to a target of 100% renewable energy by 2045 in its Clean Energy Transformation Act. The Washington Clean Energy Strategy highlights the incompatibility of continuing current uses of NG with the state's long-term greenhouse gas emissions limits and proposes to replace the plants with clean electricity or synthetic gas [21].

There are four major peaker plants in Washington, three of which are owned and operated by PSE and one by Avista Utilities. PSE has not yet released targets to phase out its NG peaker plants. In 2019, Avista stated that it would produce 100% clean energy by 2045. However, departing from the ambitious clean energy replacement targets laid out in Avista's 2020 Integrated Resource Plan (IRP), the utility's 2021 IRP mentions that new NG peaker plants would return because of an absence of long-term storage technologies.

A. Background on Washington's Peaker Plants

Whitehorn Generating Station: the Whitehorn generating station is located in Whatcom County, Washington. It is owned and operated by PSE, Washington's largest utility. The facility is made up of two single-cycle combustion-turbine generating units and has a 169.2 MW nameplate capacity with a capacity factor of 0.5% (i.e., the plant runs approximately for 44 hours per year). The plant burns both gas (94%) and oil (6%) and emits 7,393 tons of CO2e, 17.23 tons NOx, and 0.19 tons SO2 per year. The Whatcom County area began as largely agricultural but slowly became a more industrial town. The town is home to 2,979 residents with 29% of the population identified as low-income and 12% as people of color [18].

Fredonia Generating Station: the Fredonia generating station is located in Skagit County, Washington. PSE owns and operates the plant, which consists of four single-cycle generating units. The gas-fueled peaker plant has a nameplate capacity of 376.0 MW with a capacity factor of 5.9%, which means it is running for roughly 517 hours a year. The emissions from the plant include 20,421 tons of CO2e, 2.53 tons of NOx, and 0.23 tons of SO2 annually. The Skagit County area is home to 4,002 residents with 17% of the population identified as low-income and 13% as people of color [18].

Northeast Power Plant: the Northeast power plant is located in Spokane County, Washington. Avista Corp, the local utility, operates the NG plant. The facility has a nameplate capacity of 62 MW with a capacity factor of 0.6%, meaning it runs for roughly 53 hours per year. The plant emits 2,499 tons of CO2e, 6.7 tons of NOx, and 0.07 tons of SO2 annually. Spokane county is home to 56,844 residents with 46% of the population identified as low-income and 18% as people of color [18].

Frederickson Generating Station: the Frederickson Generating Station is located in Pierce County, Washington. PSE owns and operates the single-cycle gas-fired plant, which has a nameplate capacity of 178 MW and a capacity factor of 5.2% or runs for approximately 456 hours per year. The plant emits 71,395 tons of CO2e, 176.81 tons of NOx, and 1.95 tons of SO2 per year. Pierce county is home to 66,155 residents with 23% of the population identified as low-income and 37% as people of color [18].

B. Analysis of Replacing Washington's NG Peakers

The study replaced 10 NG-P units located in the NW region, and particularly in the PSE balancing authority, with hybrid wind and BES. The 10 NG-P units together with their installed capacity are listed in Table I. In Table I, we also show the wind and storage capacity installed to replace the NG peaking units. To prevent resource adequacy problems, wind farm installed capacity was selected to be four times the capacity of the retired NG-P units, under the assumption that wind resource capacity factors in the greater NW region are four times lower than that of NG-P units. The installed capacity of the BES was selected to be 35% of the wind units' installed capacity, while the storage duration is selected to be 4 hours based on industry accepted storage to generation ratios [23].

TABLE I. NG PEAKING UNITS INSTALLED CAPACITY

Unit Name	Installed Capacity (MW)	Wind Capacity (MW)	Energy Storage Capacity (MW)
Frederickson1	67.0	268.0	134.0
Frederickson2	67.0	268.0	134.0
FredericksonCC-Total	269.2	1076.8	538.4
Fredonia_1	93.4	373.6	186.8
Fredonia_2	93.4	373.6	186.8
Fredonia_3	61.0	244.0	122.0
Fredonia_4	61.0	244.0	122.0
Northeast	60.0	240.0	120.0
Whitehorn_2	81.1	324.4	162.2
Whitehorn_3	84.6	338.4	169.2
Total	**937.7**	**3751**	**1875**

Simulation setup: In order to investigate the impact of replacing the NG-P units with hybrid wind and storage systems, production cost simulations were performed in GridView using the latest version of the WECC Anchor Dataset (ADS) 2030 case. The WECC ADS 2030 contains the best available projection of new generation, generation retirements, transmission assets, and load growth in the 10-year planning horizon within the WECC grid planning community.

Results and discussion: This section discusses the benefits of retiring and replacing peaker plants in Washington. Table

II shows PSE's total generation cost reductions with BES replacements compared to the base case with NG-P. As can be seen, PSE's total generation cost (i.e., fuel cost and start-up cost) was reduced by 16.5% in the NG-Replacement Case. Similarly, in Table III, the analysis results show that locational marginal price (LMP) averaged over all simulated hours (8760) was reduced by 6.3%. These reductions in generation cost and LMP will have an impact on the cost of electricity and prices consumers pay for retail electricity highlighting the energy burden reduction potential of the replacement strategies.

TABLE II. PUGET SOUND ELECTRIC TOTAL GENERATION COST

Cases	**Puget Sound Electric Total Generation Cost (M$)**
Base Case	295.7
NG-Replacement Case	246.8
Difference from Base Case	48.9
Percentage Difference	**16.5%**

TABLE III. PUGET SOUND ELECTRIC AVERAGE LMP

Cases	**Puget Sound Electric LMP ($/MWh)**
Base Case	24.79
NG-Replacement Case	23.23
Difference from Base Case	1.56
Percentage Difference	**6.3%**

As mentioned earlier, peaker plants are often older and dirtier than other power plants, with disproportionately large amounts of harmful emissions and local air pollution including SO_2, NOx, and CO_2. The health effects from local pollution exposure to these pollutants could increase heart and lung disease on those in close proximity to the plants, mainly low-income communities. NG-P retirement and replacement strategies that target local air pollution reduction will have the highest equity potential in improving health and comfort outcomes in disadvantaged communities. The BES replacement analysis in this study was able to show a reduction of 14% in PSE's total annual emissions (including total reductions in NO_x by 21% and SO_2 by 18%) (see Table IV).

TABLE IV. PUGET SOUND ELECTRIC TOTAL EMISSIONS

Cases	**Puget Sound Electric Total Annual Emissions (Short Ton)**			
	CO_2	***NOx***	***SO_2***	***Total***
Base Case	6775092	2854	24	6777970
NG-Replacement Case	5838657	2255	20	5840931
Difference from Base Case	936435	599	4	937039
Percentage Difference	**14%**	**21%**	**18%**	**14%**

IV. THE ENERGY EQUITY IMPLICATIONS OF REPLACING WASHINGTON'S PEAKER PLANTS WITH ENERGY STORAGE

Nationwide, power plants and other polluting facilities are disproportionately likely to be sited in communities that are predominantly low-income or non-white. In Washington, two of the state's four peaker plants are located in demonstrably disadvantaged communities, as shown in Fig. 1 below. Data was used from the Washington Environmental Health Disparities Map, developed by the Washington State Department of Health, to identify the vulnerability levels of the census tracts in which each plant is located.

The "Environmental Health Disparities" decile score incorporates exposure to pollution; socioeconomic factors including race, poverty, housing costs, language isolation, and unemployment; rates of cardiovascular disease and low birth weight; and additional environmental risks such as proximity to Superfund sites. The "Social Vulnerability to Hazards" decile score includes additional factors, including education, transportation access, overcrowded housing, and disability, among other factors.

The estimated NOx and SO_2 emissions reductions from retiring each of the four peaker plants were entered into the Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool, a modeling tool developed by the Environmental Protection Agency to estimate the health and economic benefits of pollution reduction. Using a 3% discount rate, the statewide health benefits that would arise from plant retirements and the economic value of those health benefits are summarized in Table V below. As an additional note, these benefits are likely to be even greater in reality due to the value of PM 2.5 reduction, which was not included in the production cost simulation results above.

Retirement of Washington's four peaker plants would reduce the health and economic harms of pollution in nearby communities, with the benefits likely to be most strongly felt in the communities near the Frederickson and Northeast plants, who face disproportionate levels of socioeconomic and health vulnerabilities exacerbated by the local air pollution.

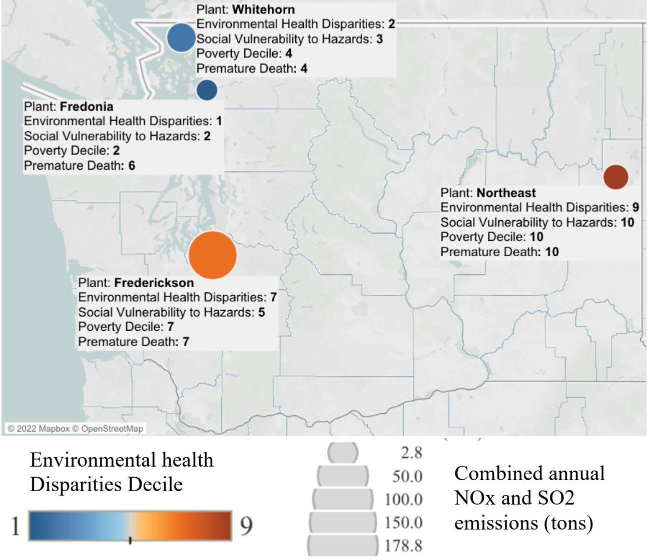

Fig 1. Map of Washington Peaker Plants and Environmental Health Disparities by Census Tract

TABLE V. WASHINGTON ESTIMATED STATEWIDE HEALTH BENEFITS OF PEAKER PLANT RETIREMENT

	Total Health Benefits	
	$4,341,345 *Low Value*	$9,799,845 *High Value*
	Change in Incidence	**Monetary Value**
Mortality	0.390 / 0.884	$4,269,600 / $9,678,936
Nonfatal Heart Attacks	0.038 / 0.351	$5,929 / $55,092
Infant Mortality	0.002	$21,496
Hospital Admits, All Respiratory	0.068	$3,674
Hospital Admits, Cardiovascular (except heart attacks)	0.072	$2,597
Acute Bronchitis	0.562	$347
Upper Respiratory Symptoms	10.154	$434
Lower Respiratory Symptoms	7.145	$193
Emergency Room Visits, Asthma	0.187	$105
Asthma Exacerbation	10.495	$779
Minor Restricted Activity Days	297.392	$26,071
Work Loss Days	50.562	$10,122

V. CONCLUSION

Power plant type (fuel source) and siting have long been the cause for the power sectors' impacts on environmental and energy justice. Fossil fuel-fired power plants are known to be high emitters of CO_2, SO_2, NO_X, PM, and other pollutants that can have significant health impacts, including respiratory and cardiovascular problems. Low-income populations, minorities, and indigenous populations often bear these adverse environmental and human-health effects as the plants are mostly sited near disadvantaged communities.

This study demonstrated the potential energy justice benefits of replacing NG peaker plants with wind and energy storage. The results showed a 14% total emissions reduction, highlighting the opportunity to plan and invest in storage resources to enhance equity effects in affected communities. In addition to health impacts, future work could explore the full extent of equity benefits storage assets could provide by examining the various ways power grid planning and operations interact with people.

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