Charles River Associates

The contribution of offshore wind to grid reliability & resource adequacy

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Executive summary

1.1 Summary of findings

The US is facing growth in electricity demand not seen in decades and faces real challenges in reliability and affordably accommodating this load growth. If new resources are not quickly interconnected to the grid, reliability will deteriorate and/or the desired level of load growth will be curtailed. Either outcome would harm American interests. A decline in grid reliability threatens national security, public health, economic competitiveness, and – at its worst – human life. At the same time, delaying or constraining load growth would impede the development of critical data center infrastructure needed to compete in the global race for artificial intelligence leadership[1] and slow or reverse recent gains in domestic manufacturing – particularly in semiconductors[2] and other strategic sectors.[3,4,5]

No single resource type will solve the imminent resource adequacy crisis. Each technology brings distinct and necessary contributions across different seasons and conditions, providing affordable power both for immediate consumption and for charging storage. But as reliability risks intensify, increasing scrutiny is being placed on each resource's ability to contribute to grid reliability. In this context, the national conversation has shifted from an **"all-of-the-above"** strategy to an **"everything-that-works"** approach. As a result, policymakers and market operators are examining more closely the real-world barriers and reliability limits of each resource.

These challenges are not theoretical; they have implications for the grid's ability to accommodate growing demand. Natural gas additions are further constrained by multi-year turbine backlogs,[6] permitting hurdles, and fully subscribed gas infrastructure.[7,8] Solar and

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1 Gregory C. Allen, *Is China Beating the U.S. to AI Supremacy?,* (Cambridge, MA: Belfer Center for Science and International Affairs, Harvard Kennedy School, 2019), https://www.belfercenter.org/publication/china-beating-us-ai-supremacy.

2 Semiconductor Industry Association, *2025 State of the U.S. Semiconductor Industry*, accessed July 10, 2025, https://www.semiconductors.org/wp-content/uploads/2025/07/SIA-State-of-the-Industry-Report-2025.pdf.

3 Atlas Public Policy, *Tracking the State of U.S. EV Manufacturing* (2025) accessed January 2025, https://atlaspolicy.com/wp-content/uploads/2025/01/Tracking-the-State-of-U.S.-EV-Manufacturing.pdf.

4 The White House, *Made in America Agenda Delivers Manufacturing Boom* (2025), accessed August 13, 2025, https://www.whitehouse.gov/articles/2025/08/made-in-america-agenda-delivers-manufacturing-boom/.

5 U.S. Congress Joint Economic Committee, *Fact Sheet: The Manufacturing Renaissance That Will Drive the Economy of the Future* (April 24, 2024), (Washington, DC: Joint Economic Committee, 2024), https://www.jec.senate.gov/public/index.cfm/democrats/2024/4/fact-sheet-the-manufacturing-renaissance-that-will-drive-the-economy-of-the-future.

6 Reuters Events | Renewables, *Rush for US Gas Plants Drives up Costs, Lead Times* (July 21, 2025), https://www.reutersevents.com/renewables/solar-pv/rush-us-gas-plants-drives-costs-lead-times.

7 Robert Walton, "Lack of Northeast Gas Pipeline Capacity Poses '*Severe Threats to Reliability*' in Cold Weather: NERC," *Utility Dive* (2025), accessed January 23, 2025, https://www.utilitydive.com/news/northeast-gas-pipeline-capacity-reliability-NERC-NPCC/738100.

8 *NERC Warns of Electricity Shortages in Winter Reliability Assessment*,(Cooperative.com, 2023), https://www.cooperative.com/news/Pages/NERC-Warns-of-Electricity-Shortages-in-Winter-Reliability-Assessment.aspx.

onshore wind require significant land and transmission expansion,[9] and storage depends on sufficient generating resources to charge. Due to these combined effects, load growth may not be met through additions of natural gas, solar, onshore wind, or storage resources alone.

In this white paper, the authors – consultants at Charles River Associates (CRA) – evaluate the potential role that offshore wind (OSW) can play in solving these emerging challenges. This analysis examines load growth patterns across the United States, identifies periods and regions of growing grid stress, and evaluates the role reliability benefits of OSW through the lens of the **Effective Load Carrying Capability (ELCC) framework**. It also incorporates operational insights from Europe, where OSW is a mature technology.

This analysis finds that, from a resource adequacy perspective OSW has real potential: it provides an additional and complementary pathway to add new generation with high capacity accreditation and strong reliability contributions to the grid. It also brings a key set of attributes that are increasingly valuable in today's context. Most importantly, OSW has strong performance during key periods of emerging grid stress and relatively steady output year-round. Also, it has the ability to be built at scale and brings locational advantages due to its siting near coastal load centers where new generation is otherwise difficult to build.

Further, while OSW faces its own supply chain and permitting challenges, several projects are in advanced stages of development or are shovel-ready,[10] positioning OSW as a meaningful near- to medium-term resource. The American OSW pipeline grew by 53% from 2023 to 2024, reaching **80.5 GW of total capacity**. Several projects are now in advanced stages of development or under construction – including Vineyard Wind 1 (806 MW), Revolution Wind (704 MW), and Coastal Virginia Offshore Wind Commercial (2,600 MW) – collectively representing over 4 GW of new capacity and positioning OSW as a meaningful near- to medium-term resource. Meanwhile, additional OSW lease areas in the Atlantic, Pacific, and Gulf of Mexico are expanding the longer-term pipeline, with 80.5 GW of resources in various stages of planning as of 2024.[11] As of August 2024, states along the East Coast have collectively set procurement targets exceeding **45 GW by 2040**, viewing OSW as a tool to meet rising energy

[9] Peter J. Davis and David A. Blackhurst, *Renewables, Land Use, and Local Opposition in the United States*, (*Brookings Institution,* April 2025, https://www.brookings.edu/articles/renewables-land-use-and-local-opposition-in-the-united-states/.

[10] Avangrid, "Avangrid Receives Full Federal Approval for Construction of New England Wind Offshore Projects," press release, July 2, 2024, https://www.avangrid.com/w/avangrid-receives-full-federal-approval-for-construction-of-new-england-wind-offshore-projects.

[11] Ibid.

and capacity needs, advance decarbonization goals, diversify fuel supply, strengthen local economies, and ease grid constraints.[12]

Early projects illustrate this potential growing role of OSW in maintaining grid reliability given load growth and infrastructure constraints. South Fork Wind (132 MW), interconnected at the constrained South Fork load pocket on Long Island, is helping to meet load growth and relieve fuel and transmission constraints on Long Island. Coastal Virginia Offshore Wind is supporting Dominion Energy's efforts to serve rapid data center-driven load growth and advance Virginia's decarbonization targets.

However, OSW's full near-term adequacy impact is tempered by project delays, rebids, or cancellations amid rising costs, supply-chain pressures, and uncertainty surrounding federal permitting and tax-credit guidance. Such projects include Ocean Wind 1 and 2, Empire Wind 2, and Commonwealth Wind. Some OSW projects have demonstrated cost-competitiveness on a levelized cost of energy (LCOE) basis, while others have faced affordability challenges.[13] Continued learning around construction practices, project design, and procurement and contracting can further enhance OSW's cost effectiveness over time. At the same time, OSW's initially high accreditation values are expected to decline with greater penetration, underscoring the need for planners to determine the optimal scale of investment and pursue complementary technologies that sustain OSW's reliability contribution as deployment grows.

1.2 Emerging resource adequacy challenges

The US electricity grid is entering a new and more challenging era for maintaining resource adequacy. Historically, electric system planners primarily focused on meeting summer afternoon peaks, when air-conditioning loads were highest and overall demand growth was relatively modest. Grid operators could depend on healthy reserve margins and a dispatchable, fuel-assured generating fleet to meet these needs.

That paradigm is changing rapidly. Load is growing at a pace not seen in decades, driven by the explosive expansion of hyperscale data centers, a resurgence of domestic manufacturing, and other energy-intensive industries. At the same time, many systems are shifting toward winter peaks as electrification of heating and transportation accelerates. Large amounts of firm thermal generation are retiring, while the entry of new capacity is constrained by supply chain challenges and interconnection backlogs. Moreover, much of the new capacity consists of non-dispatchable resources (solar and wind), energy-limited resources (storage), or just-in-time fuel resources (natural gas). Together, these shifts are yielding a grid with lower reserve margins

[12] NREL. 2024. "OFFSHORE WIND MARKET REPORT 2024 EDITION." Nrel.gov. 2024. https://www.nrel.gov/docs/fy24osti/90525.pdf

[13] Ibid.

and risks spread across a broader range of hours. The result is that many markets are already showing signs of strain: capacity prices have surged to record levels in PJM and MISO, and reliability studies are raising concerns from industry and government leaders.

Although resource adequacy concerns were once concentrated in the summer, many markets now face their greatest vulnerabilities in the winter. Electrification of space heating is driving rapid winter load growth, while cold weather places stress on natural gas systems, which continue to supply most of the dispatchable fleet. Winter Storms Uri (2021) and Elliott (2022) revealed how exposed the grid becomes when gas supplies are disrupted by pipeline freezes or competing heating demand. Even in markets where peak demand still occurs in the summer, operators are increasingly concerned about winter performance, with some now describing their systems as **summer-peaking but winter-constrained**. Across much of the country, winter mornings and evenings are emerging as the periods of greatest stress – times when solar output is minimal, heating demand is elevated, and storage resources may already be depleted.

This paper examines the role offshore wind (OSW) can play in solving these emerging resource adequacy challenges. Using the Effective Load Carrying Capability (ELCC) methodology and other approaches to measure the accredited capacity of variable resources, it benchmarks OSW's performance against other technologies in PJM, NYISO, ISO New England, CAISO, and ERCOT. This paper also draws lessons from international markets where OSW already operates at scale, such as the United Kingdom, Germany, and Denmark.

Based on the analysis, the authors find that OSW exhibits a combination of attributes that make it well-suited to today's evolving resource adequacy challenges due to its higher capacity factors than those of onshore wind and solar, steadier production profiles than those of onshore wind, and strong alignment with emerging high-risk periods. In markets such as PJM and ISO-NE, OSW's accredited capacity values are already competitive with, and in some cases exceed, those of thermal and storage resources. In other markets, like CAISO and NYISO, its accreditation is the highest for renewable resources and is likely to grow as current nascent capacity accreditation reforms advance to explicitly simulate OSW (CAISO) and better capture cold-weather risks (NYISO). Moreover, OSW offers locational advantages by being sited close to coastal load centers where other forms of new generation are difficult to build. However, we note these ELCCs will decline if OSW reaches levels of high penetration in the market.

As permitting and cost pressures are resolved, OSW can provide an auxiliary pathway to deliver both energy and accredited capacity needed to reliably accommodate substantial near-term load growth. Its generation profile demonstrates strong synergies with other technologies. OSW tends to produce more during evening and nighttime hours, directly filling periods when solar output declines and natural gas systems are stressed. It provides affordable surplus energy that can be used to charge storage resources, thereby enhancing storage accreditation under ELCC frameworks. OSW also serves as a hedge against relying against a single fuel source with natural gas generation, drawing on a completely different fuel source and producing its highest output during extreme cold events – when gas-fired generators are most likely to face fuel limitations and unplanned outages.

1.3 Key findings by market

Figure 1-1: Key Findings by Market

PJM	NYISO	ISO-NE
Challenges: Among the steepest load growth in the United States, driven by data centers. Risk now concentrated in winter months. Slow interconnection queues dominated by solar and storage. **Role of OSW:** Scalable near-term option in coastal zones. ELCC = 69% in latest auction – higher than many storage and thermal resources.	**Challenges:** Transitioning to winter-peaking by late 2030s. Constrained natural gas infrastructure. Downstate congestion and retirement of peakers driving localized risk. **Role of OSW:** Highest accreditation of renewables (CAF ~32%). Delivers directly into downstate load pockets (NYC, Long Island). South Fork currently online. Several projects have been cancelled or face uncertain futures due to cost pressures and permitting uncertainty.	**Challenges:** Winter peak growth 3x summer. Gas pipelines fully utilized in heating season. Storage vulnerable during prolonged cold snaps. **Role of OSW:** Accreditation projected at >90% in some studies, rivaling thermal resources. Block Island currently online. However, delays and uncertainty around key OSW projects, including Revolution Wind, due to stop-work order.
CAISO	**ERCOT**	**International**
Challenges: Summer peaks remain binding. Aggressive decarbonization targets accelerate solar/storage buildout. Managing the "duck curve" as solar drops off in evenings. **Role of OSW:** Coastal winds strongest in late afternoons/evenings. Complements solar, reduces need for storage, scalable in-state resource.	**Challenges:** Peak demand projected to nearly double by 2044. Ongoing exposure to extreme weather and natural gas disruptions. **Role of OSW:** Offshore faces cost barriers, but diurnal trends and strong winter performance gives indicator of OSW's potential role.	**Challenges:** Rising reliability and affordability crises due to age, economics, and policy driven retirements of coal and nuclear resources and geopolitical instability from the Russia-Ukraine war. **Role of OSW:** Commercially mature technology. Viewed as cornerstone of adequacy strategy by leaders in the U.K., Germany, and Denmark. Built at multi-GW scale with streamlined permitting and experienced developers. ELCCs have begun to decline.

PJM

PJM is facing some of the steepest load growth in the country, driven heavily by data centers in Northern Virginia, Ohio, and Pennsylvania. PJM's most recent load forecast projects an increase of 55 GW in summer peak demand and 62 GW in winter peak demand over the next decade.[14] Winter is now the dominant season of risk, with PJM studies showing that 87% of expected unserved energy (EUE) is concentrated in winter hours.[15]

OSW is aligned with this risk profile. In PJM's 2026/2027 capacity auction, OSW received a 69% ELCC, the highest of any renewable resource and higher than many storage and thermal technologies.[16] This means that for every 100 MW of installed OSW capacity, 69 MW can be reliably counted on during periods of grid stress – compared to 8 MW for solar, 41 MW for onshore wind, 50 MW for 4-hour storage, 74 MW for combined-cycle gas, and 78 MW for dual-fuel gas turbines.[17] The Coastal Virginia Offshore Wind (CVOW) project, currently under development by Dominion, will deliver capacity directly into one of PJM's most constrained zones. Given PJM's interconnection delays and rapid near-term load growth, OSW represents a scalable, near-coast options available to bolster resource adequacy. Without timely additions of new high-ELCC capacity resources, including OSW, PJM risks being forced to slow load and resulting economic growth, compromise reliability, or drive up electricity costs.

NYISO

NYISO is also experiencing a structural shift. While historically summer-peaking, New York is projected to become a winter-peaking system by the late 2030s, with winter peak demand approaching 50 GW.[18] Much of this growth will come from downstate regions – New York City and Long Island – where electrification of buildings and transportation is concentrated and where transmission import capacity is already limited. At the same time, 1,600 MW of peaking generating units have retired.[19] This reduction is creating tightening supply-demand conditions in the downstate regions of the grid, resulting in capacity prices in this region that are three times higher than the rest of the state.[20]

OSW is a valuable resource to mitigate these emerging reliability challenges. Its strongest generation periods, winter and nighttime, align closely with the hours of greatest system stress,

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14 PJM Interconnection, *2025 Long-Term Load Forecast Report,* (Valley Forge, PA: PJM, January 2025), Retrieved from PJM website.

15 PJM Interconnection, LLC, "ELCC Education: Data Transparency and ELCC Study Results*," Presentation to the ELCC Stakeholder Task Force* (December 5, 2024), accessed February 2024, https://www.pjm.com/-/media/DotCom/committees-groups/task-forces/elccstf/2024/20241205/20241205-item-07---informational-only-posting---data-transparency---elcc-education-from-special-planning-committee-sessions-on-february-16-and-21-2024.pdf.

16 PJM Interconnection, LLC, *2026/2027 BRA ELCC Class Ratings* (July 2024), https://www.pjm.com/-/media/DotCom/planning/res-adeq/elcc/2026-27-bra-elcc-class-ratings.pdf.

17 Ibid.

18 New York Independent System Operator, *2025 Load & Capacity Data Report* (Gold Book) (NYISO, 2025), https://www.nyiso.com/documents/20142/2226333/2025-Gold-Book-Public.pdf.

19 New York Independent System Operator (NYISO). *Q3 2025 Short-Term Assessment of Reliability (STAR).* Rensselaer, NY: NYISO, 2025. Available at: https://www.nyiso.com/documents/20142/39103148/2025-Q3-STAR-Report-Final.pdf

20 New York Independent System Operator, *2025 Load & Capacity Data Report (Gold Book),* (2025), https://www.nyiso.com/documents/20142/2226333/2025-Gold-Book-Public.pdf.

and its proximity to coastal load centers allows it to deliver power directly into transmission-limited zones where it is challenged to develop timely expansions onshore.

The region is targeting 9 GW of OSW by 2035[21] and has two projects under construction – Empire Wind 1 (810 MW) and Sunrise Wind (924 MW).[22] The region has faced challenges developing some OSW projects due to changing economic conditions, supply-chain challenges, and technical complexities. Some projects have been delayed or cancelled including Empire Wind 2 (1,260 MW), Attentive Energy One (1,404 MW), Community Offshore Wind (1,314 MW), and Excelsior Wind (1,314 MW).[23] Developers may return to some of projects – particularly Empire Wind 2[24] – in the future though the technical details and offtake agreements may evolve to capture current conditions and learnings as domestic OSW capabilities mature.

The South Fork Wind project is currently demonstrating the role OSW could play in NYISO. It came online in March 2024 and is now providing up to 132 MW of power, with a capacity factor of 46.4% in its first full year of operation.[25] It is directly tied into constrained areas of Long Island,[26] supporting reliability by easing pressure on the gas network and deferring the need for new transmission investments.[27]

This reliability value is reflected in the capacity accreditation NYISO assigns to OSW. NYISO currently assigns OSW a Capacity Accreditation Factor (CAF) of about 32%, higher than solar or onshore wind.[28] This accreditation is likely to increase over time as NYISO's evolving approach to capacity accreditation better captures winter risks, particularly due to correlated outages from fuel-limitations for its natural gas fleet.

21 New York State Energy Research and Development Authority. *2022 Offshore Wind Solicitation (Closed).* Albany, NY: NYSERDA, 2022. https://www.nyserda.ny.gov/All-Programs/Offshore-Wind/Focus-Areas/Offshore-Wind-Solicitations/2022-Solicitation

22 The New Bedford Light. "Our Offshore Wind Tracker: What's New with Wind Projects off Massachusetts and Beyond?" *The New Bedford Light*, accessed October 26, 2025. https://newbedfordlight.org/offshore-wind-tracker-whats-happening-to-massachusetts-projects/

23 New York State Energy Research and Development Authority. "2022 Offshore Wind Solicitation (Closed)." *Offshore Wind — Focus Areas*, January 26, 2023 (last updated). Accessed October 27, 2025. https://www.nyserda.ny.gov/All-Programs/Offshore-Wind/Focus-Areas/Offshore-Wind-Solicitations/2022-Solicitation

24 Equinor ASA. "Empire Wind 2 Offshore Wind Project Announces Reset, Seeks New Offtake Opportunities." *Empire Wind*, January 3, 2024. https://www.empirewind.com/2024/01/03/empire-wind-2-offshore-wind-project-announces-reset-seeks-new-offtake-opportunities/

25 Ørsted. *South Fork Wind Report*. Ørsted U.S. Offshore Wind, 2025. https://us.orsted.com/renewable-energy-solutions/offshore-wind/south-fork-wind-report

26 "Welcome to South Fork Wind" n.d. Southforkwind.com. https://southforkwind.com/.

27 PSEG Long Island. *2015 South Fork Resources Request for Proposals*. June 24, 2015. https://www.psegliny.com/aboutpseglongisland/proposalsandbids/2015southforkrfp

28 New York Independent System Operator, *Final Capability Adjustment Factors for the 2024–2025 Capability Year* (NYISO, [2023 or 2024], PDF file), https://www.nyiso.com/documents/20142/41593818/Final-CAFs-for-the-2024-2025-capability-year.pdf/3efc1e06-c1b0-72d6-f736-22721709c157?t=1708951801025.

ISO New England

ISO New England also has increasing winter risk. Winter peak demand is projected to grow at more than three times the rate of summer demand, and the region is heavily reliant on natural gas delivered through constrained pipelines.[29] ISO-NE studies have shown that during prolonged cold snaps, battery storage resources can become depleted and unable to recharge, leaving the system vulnerable. OSW, by contrast, produces strongly in winter and has been accredited at levels exceeding 90% in certain scenarios, rivaling dispatchable thermal units.[30] Vineyard Wind, the first large OSW project in the region, is partially operational,[31,32] and additional buildout could provide critical adequacy support near Boston and other coastal load pockets. As OSW penetration increases to roughly 3.3 GW, accreditation is projected to decline to around 52% as the higher penetration successfully shifts periods of risk to hours with lower OSW generation.[33] This modeling indicates that the first gigawatts of OSW deliver the largest resource adequacy benefit, while subsequent additions continue to enhance reliability but with diminishing incremental impact.

The regional OSW pipeline is advancing, with roughly 7 GW of projects under various stages of construction and permitting across Massachusetts, Rhode Island, and Connecticut. Vineyard Wind 1 (800 MW), the nation's first utility-scale OSW farm, began partial operations in 2024 and is expected to reach full commercial operation in 2025.[34,35] Revolution Wind (704 MW) is also under construction, serving Rhode Island and Connecticut, while South Coast Wind (2,400 MW) and New England Wind 1 and 2 (up to 2,600 MW) are moving through permitting and power purchase agreement finalization.[36] Collectively, these projects could provide substantive installed – and accredited – capacity and energy to high population coastal load pockets,

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29 ISO New England, *2025 CELT (Capacity, Energy, Loads and Transmission) Forecast,* https://www.iso-ne.com/static-assets/documents/100023/2025_celt.xlsx.

30 ISO New England, *Impact Analysis Sensitivity Results—May 2024*, presentation to the NEPOOL Markets Committee, Milford, MA, May 7–8, 2024, https://www.iso-ne.com/static-assets/documents/100011/a02c_mc_2024_05_07_08_impact_analysis_sensitivity_results_may2024.pdf.

31 Massachusetts Executive Office of Energy and Environmental Affairs, "*Vineyard Wind, America's First Large-Scale Offshore Wind Farm, Delivers Full Power from 5 Turbines to the New England Grid*," press release, February 22, 2024, https://www.mass.gov/news/vineyard-wind-americas-first-large-scale-offshore-wind-farm-delivers-full-power-from-5-turbines-to-the-new-england-grid.

32 Lennon, A. E. "*Vineyard Wind Nears 30% Power Production*." *The New Bedford Light*, July 23, 2025. https://newbedfordlight.org/vineyard-wind-nears-30-power-production/

33 Ibid.

34 Massachusetts Executive Office of Energy and Environmental Affairs, "*Vineyard Wind, America's First Large-Scale Offshore Wind Farm, Delivers Full Power from 5 Turbines to the New England Grid*," press release, February 22, 2024, https://www.mass.gov/news/vineyard-wind-americas-first-large-scale-offshore-wind-farm-delivers-full-power-from-5-turbines-to-the-new-england-grid.

35 Lennon, A. E. "*Vineyard Wind Nears 30% Power Production*." *The New Bedford Light*, July 23, 2025. https://newbedfordlight.org/vineyard-wind-nears-30-power-production/

36 The New Bedford Light. "Our Offshore Wind Tracker: What's New with Wind Projects off Massachusetts and Beyond?" *The New Bedford Light*, accessed October 26, 2025. https://newbedfordlight.org/offshore-wind-tracker-whats-happening-to-massachusetts-projects/

significantly strengthening winter adequacy and easing natural gas constraints near Boston and southeastern New England.

OSW development in ISO-NE has not been without challenges. Rising project-financing costs, supply-chain bottlenecks, and regulatory uncertainty have created headwinds for the industry nationwide, including a federal stop-work order temporarily halting work on Revolution Wind in 2025.[37]

One OSW project is already online in the region – Block Island Wind Farm. The site is relatively small, with only 30 MW of installed capacity, but it delivers power directly into a constrained island load pocket and has enabled the island to shut down expensive and environmentally burdensome diesel generators. Though Block Island has experienced unanticipated maintenance events,[38] it has served as a proof of concept for how OSW can deliver power to constrained coastal areas and harden the existing grid.[39,40]

CAISO

CAISO is projected to remain a summer-peaking, summer-constrained system. One of its challenges is the "duck curve," in which solar output drops rapidly in the evening while demand remains high. OSW is well-suited to mitigate this challenge, as coastal wind resources often peak in the late afternoon and evening, complementing solar and reducing reliance on storage. CAISO's new Slice-of-Day accreditation framework[41] is still evolving and has not captured the potential impact of OSW.[42] However, based on trends in other markets and alignment with key risk periods, OSW is likely to receive higher Net Qualifying Capacity (NQC) values than onshore wind and solar due to strong performance in emerging risky hours.

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37 U.S. Department of the Interior, Bureau of Ocean Energy Management. "Director's Order to Revolution Wind, LLC (Aug. 22, 2025)." Washington, DC: BOEM, 2025. https://www.boem.gov/sites/default/files/documents/renewable-energy/Director%26%23039%3BsOrder-20250822.pdf?VersionId=Y674sNo8zi7jLu3VWRvq2hFb_8KtMldc

38 The Providence Journal. "Block Island Offshore Wind Farm Offline Two Months Due to Maintenance and Safety Concerns." *The Providence Journal*, August 14, 2021. https://www.providencejournal.com/story/news/2021/08/14/block-island-offshore-wind-farm-offline-two-months-due-to-maintenance-and-safety-concerns/8122841002/

Ørsted. "Block Island Wind Farm – Renewable Energy Solutions / Offshore Wind." Ørsted U.S. Offshore Wind. Accessed October 26 2025. https://us.orsted.com/renewable-energy-solutions/offshore-wind/block-island-wind-farm

40 The New York Times. "Offshore Turbines Let Block Island Shut Down Soot-Spewing, Earsplitting Diesel Generators … There Were Other Benefits, Too." *New York Times*, September 22, 2025. https://www.nytimes.com/2025/09/22/climate/block-island-rhode-wind-turbines.html

41 California Public Utilities Commission. 2025 Resource Adequacy and Slice of Day Guide. Issued September 25, 2024. California Public Utilities Commission. Accessed September 15, 2025. https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/resource-adequacy-homepage/resource-adequacy-compliance-materials/guides-and-resources/2025-ra-slice-of-day-filing-guide.pdf

42 Ibid.

ERCOT

ERCOT is experiencing some of the fastest load growth nationwide, with peak demand expected to nearly double by 2044.[43] ERCOT's May 2025 Report on the Capacity, Demand and Reserves (CDR) in the ERCOT Region, 2026-2030 projects tightening reserve margins and potential generator shortfall by 2028.[44] While summer has historically been the period of greatest load and reliability stress, the report – along with widespread outages during Winter Storm Uri partially caused by common mode generator failures[45] – highlights growing vulnerability in the winter months.[46] OSW's generation profile is strongest in winter and exhibits diurnal patterns that extend into evening hours,[47] helping to cover periods when solar output declines. This characteristic could help meet capacity shortfalls, particularly in winter, and increase fuel diversity, providing a hedge against the kind of common mode observed during Uri. Although offshore development faces cost barriers in the Gulf of Mexico due to deep and silty seabeds, it could play a role in the future as technology evolves and technology challenges specific to the region are solved.

International lessons

International lessons provide learnings for American leaders to observe OSW in practice, in addition to relying on modeling insights. The UK already operates 13.6 GW of OSW, and its Equivalent Firm Capacity (EFC) values have consistently been higher than those of solar and onshore wind, especially in winter.[48] Germany, facing nuclear and coal retirements, OSW is increasingly viewed as a cornerstone of its future adequacy strategy. Denmark and the Netherlands are scaling OSW rapidly to maintain adequacy while reducing dependence on neighboring systems that are also tightening. These markets show that though OSW's marginal

43 ERCOT, *2025 ERCOT System Planning Long-Term Hourly Peak Demand and Energy Forecast* (2025), https://www.ercot.com/files/docs/2025/04/08/2025-LTLF-Report.pdf.

44 ERCOT, *Report on the Capacity Demand Reserves (CDR) in the ERCOT Region 2026-2030*, May 2025, (2026 and 2026/27 Winter Morning and Evening ELCC values), https://www.ercot.com/files/docs/2025/05/16/CapacityDemandandReservesReport_May2025_Revised.pdf.

45 Federal Energy Regulatory Commission (FERC), North American Electric Reliability Corporation (NERC), and Regional Entities, *February 2021 Cold Weather Outages in Texas and the South Central United States: Causes, Recommendations, and Corrective Actions,* Washington, D.C., Federal Energy Regulatory Commission, November 2021, https://www.ferc.gov/media/february-2021-cold-weather-outages-texas-and-south-central-united-states-ferc-nerc-and.

46 ERCOT, *Report on the Capacity Demand Reserves (CDR) in the ERCOT Region 2026-2030*, May 2025, (2026 and 2026/27 Winter Morning and Evening ELCC values), https://www.ercot.com/files/docs/2025/05/16/CapacityDemandandReservesReport_May2025_Revised.pdf.

47 Randall, Alyssa L., Jonathan A. Jossart, Tershara Matthews, Mariana Steen, Idrissa Boube, Shane Stradley, Ross Del Rio, Dana Inzinna, Christopher Oos, Leonard Coats, Gregory Shin, Craig Griffith, and James A. Morris Jr. *A Wind Energy Area Siting Analysis for the Gulf of Mexico Call Area.* Technical Report prepared for the U.S. Dept. of the Interior, Bureau of Ocean Energy Management, October 2022. https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/GOM-WEA-Modeling-Report-Combined.pdf

48 *Seizing Our Opportunities: Independent Report of the Offshore Wind Champion*, n.d., GOV.UK, https://www.gov.uk/government/publications/accelerating-deployment-of-offshore-wind-farms-uk-offshore-wind-champion-recommendations/seizing-our-opportunities-independent-report-of-the-offshore-wind-champion.

contribution declines at higher penetration, it remains a durable resource adequacy contributor even at high penetration levels.

Summary of findings

Across American markets, OSW offers a stress-aligned resource option that may help address emerging reliability challenges. It performs strongest during the very hours when emerging risks are most acute – winter mornings and evenings in most of the country – and delivers capacity directly into constrained coastal zones that are otherwise difficult to develop local resources due to transmission, land, and natural gas pipeline. OSW's high capacity factors, stress-aligned performance, and growing scalability make it a valuable near- to medium-term solution for maintaining reliability as load growth accelerates.

Across all markets, OSW provides a stronger reliability contribution than any other renewable resource, generally delivering about twice the capacity value of solar and roughly fifty percent more than onshore wind. However, there is significant variability by market. In PJM, its reliability contribution is greater than short-duration storage and approaches that of thermal peaking units without dual fuel, reflecting its strong performance during winter and evening hours when system stress is greatest. In New York, OSW ranks as the highest-accredited renewable resource – two to three times that of solar or onshore wind – while its proximity to downstate load pockets further amplifies its reliability benefit. In New England, OSW's contribution rivals that of dispatchable generation and far exceeds that of storage or other renewables during prolonged cold spells. However, it is outpaced by onshore wind, due to strong onshore wind in the region and assumed lower levels of onshore penetration. In California, it could play a complementary role in mitigating evening ramping risks.

Experience abroad supports these findings: in the United Kingdom, Germany, and Denmark, OSW are more highly rated than other variable renewables in capacity accreditation and are viewed as a critical to European resource adequacy. Though, Europe highlights that capacity accreditation will decline at high penetration. Collectively, these results indicate that OSW is a substantive potential reliability asset that complements the broader portfolio investments needed to meet the nation's growing and increasingly winter-based demand. While OSW faces non-trivial supply-chain and permitting challenges, its deployment pipeline is substantial – over 80 GW nationally. When integrated alongside wider generation and transmission investments and aligned with prudent procurement and contracting structures, it provides a potential scalable pathway to meet the nation's growing electricity demand reliably and affordably.

Preliminaries: Emerging resource adequacy challenges in the United States

2.1 Introduction

The electricity grid is foundational to American civic life, supporting public health, maintaining economic and industrial activities, and bolstering our national security. As such, ensuring its reliability (while balancing other system needs like affordability) is the central objective of electricity system planning and operation. One element of maintaining reliability is resource adequacy*,* defined as the ability of the bulk power system to meet all end-use electricity demand in all hours of the year, under all weather conditions, and accounting for both planned maintenance and unplanned equipment outages.[49]

This white paper examines the role offshore wind (OSW) can play in addressing emerging resource-adequacy challenges in American electricity markets. While the contribution of dispatchable generation to system reliability is well established, OSW's reliability value remains less fully recognized among industry stakeholders and policymakers, given its status as an emerging technology in the United States – though it is well established in Europe – and its weather-dependent nature.

This paper quantifies the Effective Load Carrying Capability (ELCC) of OSW across multiple markets and benchmarks it against other resource types. It discusses emerging resource adequacy challenges in these markets and discusses potential future trends in ELCC values. Special attention is placed on transmission-constrained regions and high load growth regions. For consistency, the terms "ELCC" or capacity accreditation are used across all markets. Though all markets draw from the same underlying ELCC principles, each market applies its own terminology and methodology when assessing portion of each resource type which can be counted toward meeting resource needs.

2.2 Maintaining resource adequacy

Resource adequacy focuses on ensuring that the bulk electricity generation system, subject to transmission constraints, can deliver sufficient power to meet all end-use demand. It represents a single, but critical element of overall grid reliability, which includes transmission and distribution reliability.

[49] National Renewable Energy Laboratory, *Explained: Fundamentals of Power Grid Reliability and Clean Electricity*, (Golden, CO: National Renewable Energy Laboratory, NREL/FS-6A40-85880, January 2024), accessed August 15, 2025, https://www.nrel.gov/docs/fy24osti/85880.pdf.

Resource adequacy analysis considers the ability of the generator fleet to:

- Serve all end-use hourly demand, with an acceptable level of reliability, typically defined by reliability standards (discussed further below).
- Accommodate uncertainty and variability in load, variable renewable output, and unplanned generator outages – including weather-correlated events.
- Provide sufficient operating reserves and flexibility, including ramping capability, start times, minimum run times, and multi-hour duration needs.
- Ensure deliverability to load, accounting for internal transmission constraints.
- Manage seasonal variability, recognizing differing summer/winter risk drivers and shifting net load[50] dynamics.
- Withstand fuel assurance and common-mode risks, such as gas supply disruptions or cold/heat-related deratings.
- Reflect energy-limited characteristics, including storage discharge duration limits.

If a system does not have sufficient generation to meet demand at a given period, operators will perform **load shedding** – an intentional disconnection of certain customers to preserve the stability of the overall system. In practical terms, maintaining resource adequacy means ensuring that such events are exceedingly rare, so that households, businesses, and critical infrastructure can depend on a continuous and reliable supply of electricity.

To meet the resource adequacy standards that the American public expects, system planners and regulators rely on quantitative risk metrics to define the likelihood, duration, and magnitude of load shedding events. The most widely used metric in North America is the **Loss of Load Expectation** (LOLE), which measures the expected number of days per year with at least one instance of load shedding. North American planning standards typically target a LOLE value of less than 0.1 days/year – meaning that system planners design their system so that load shedding occurs at most once every ten years (i.e., "**1-Day-in-10-Years**"). While LOLE calculates the frequency of load shedding events, it does not consider the magnitude of events. Grid planners and regulators are adopting auxiliary metrics to improve resource planning that quantify the magnitude of potential outages. Planners are increasingly utilizing **Expected**

[50] Gross demand less renewable generation. This represents the amount of demand that needs to be met by dispatchable generation.

Unserved Energy (EUE) – the anticipated amount of energy that will not be served due to load shedding.[51]

Regardless of the selected planning risk metric and target, electricity grid planners employ two primary tools to identify a generator mix that achieves the desired level of resource adequacy:

1. **Planning Reserve Margin (PRM)** – The quantity of accredited capacity required above forecasted peak demand to maintain reliability under uncertainty in load, generator outages, and variable renewable resource output, and

2. **Accredited capacity** – The proportion of a resource's nameplate capacity that can contribute to meeting resource adequacy needs and can be counted toward the PRM, most often computed via using the **Effective Load Carrying Capability** (ELCC) methodology.

In layman's terms, an ELCC represents the portion of a resource that can be counted on during key periods of grid supply-demand tightness. These periods of stress are when an outage is most likely. Without sufficient generating capability during these key hours, load shedding will occur.

ELCCs enable resource planners to obtain a like-for-like comparison of the resource adequacy benefits of different generator technologies. Because reliability depends on the entire generation portfolio rather than a single unit, a resource's ELCC is shaped by the overall mix of resources and system load patterns. For example, solar and storage resources often exhibit synergistic effects that increase the ELCC of both when deployed together.[52] Similarly, the ELCC of wind rises when the effects of growing winter load due to electrification are considered.[53]

To determine ELCC values for a given resource type, planners use sophisticated probabilistic models of the power system that simulate a wide range of potential conditions, including variations in electricity demand, renewable generation output, and generator outages. The process of computing an ELCC is shown in Figure 2-1. A more detailed explanation of this process is given in the Appendix.

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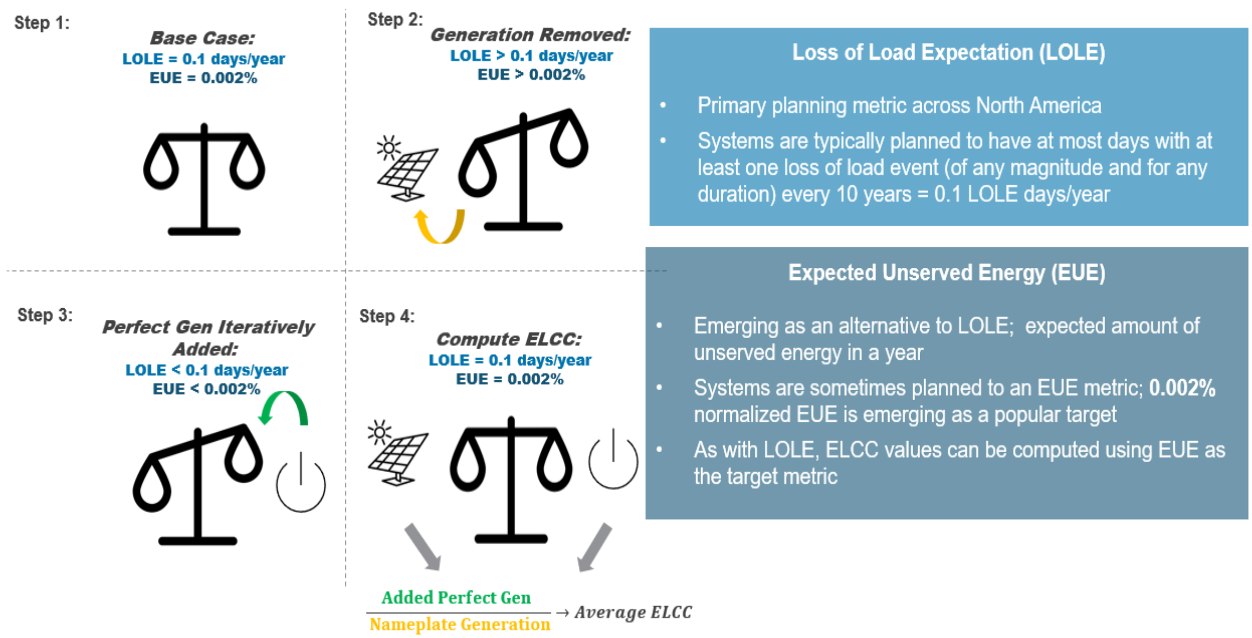
51 National Renewable Energy Laboratory, *Explained: Fundamentals of Power Grid Reliability and Clean Electricity*, Golden, CO: National Renewable Energy Laboratory, January 2024, NREL/FS-6A40-85880, https://www.nrel.gov/docs/fy24osti/85880.pdf.

52 Energy and Environmental Economics, Inc., *Reliability Planning in the Era of Decarbonization: Practical Application of Effective Load Carrying Capability in Resource Adequacy* (San Francisco: E3, August 2020), https://www.ethree.com/wp-content/uploads/2020/08/E3-Practical-Application-of-ELCC.pdf.

53 Charles River Associates (CRA), *Introducing CRA AdequacyX: CRA's Resource Adequacy Model* (white paper, October 2024), https://media.crai.com/wp-content/uploads/2024/10/17133654/Introducing-CRA-AdequacyX-whitepaper-October2024.pdf.

Figure 2-1: ELCC Computation Procedure



By comparing this **accredited capacity** (the total nameplate capacity of all the resources multiplied by their relevant ELCC values) to the planning reserve margin target, system planners can assess the system's resource adequacy. When the system's accredited supply reaches levels near or below the target reserve margin, the grid is deemed to no longer be resource adequate. ELCC values can be determined using two primary approaches.

Marginal versus average ELCCs: Two philosophies for capacity accreditation

- An **average** basis represents the reliability contribution of the entire installed capacity of a given resource type. An average ELCC captures the reliability contribution of an entire technology type, including both existing and planned incremental resources.
- A **marginal** basis, reflecting only the incremental benefit of the next MW of a given resource type. A marginal ELCC is best used to send a forward-looking market signal of the optimal resource types to solve *emerging* resource adequacy challenges and guard against overbuilding a resource type. However, this approach does not capture resource adequacy contribution of *existing* generating resources.

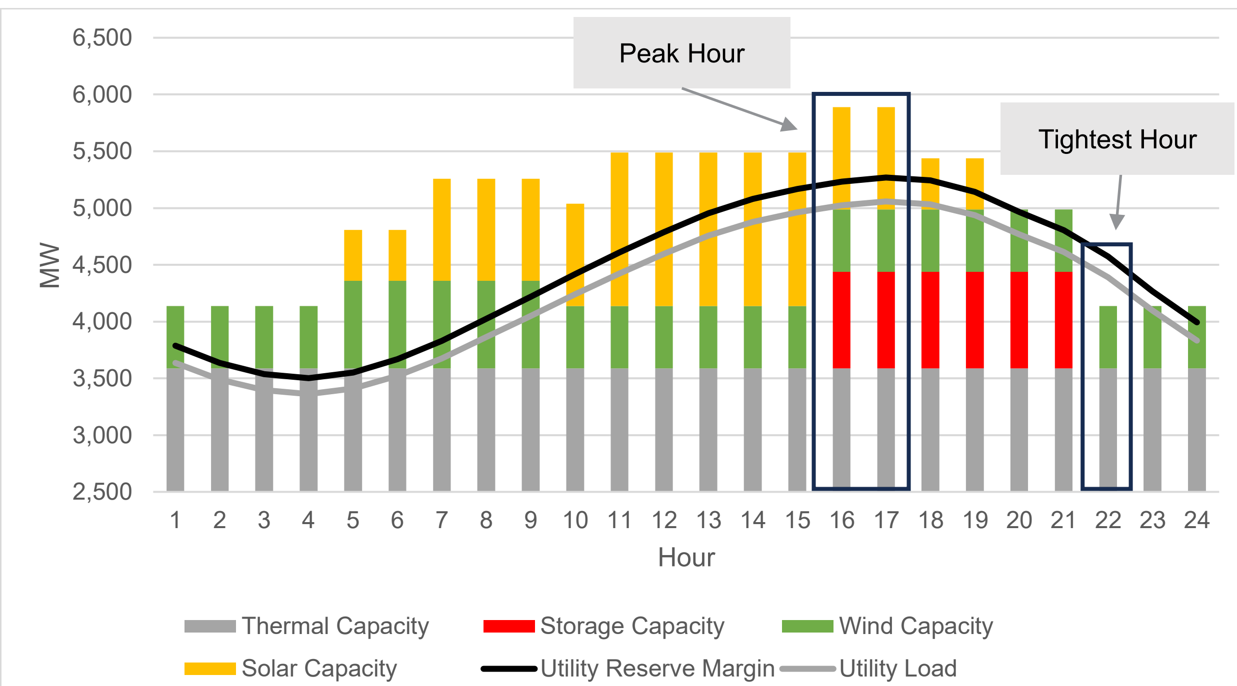
Takeaway: Choosing between average and marginal ELCCs changes how resources are accredited: average ELCCs inform system planning and valuation of the existing fleet, while marginal ELCCs capture the value of the next MW of a resource.

The selection of an average or marginal ELCC approach to capacity accreditation can significantly impact the relative values assigned to different technology types. In both cases, ELCCs decline as the penetration of a resource increases, reflecting diminishing incremental reliability benefits. This effect is more pronounced under the marginal ELCC approach, which by design only evaluates new entry. As a result, marginal ELCC values can substantially understate the reliability contribution of the existing fleet.

This decline reflects the inherent daily and seasonal variations of generator technologies, which are tied to underlying seasonal weather patterns. For example, solar generation is limited to daytime hours, wind generation follows seasonal average wind speed patterns, and thermal generators can experience higher outages in certain weather conditions. These seasonal resources can contribute strongly to reliability during periods of high output but provide little or no contribution during low-output hours.

If sufficient generation of a given technology is brought onto the grid, it will successfully mitigate risk during periods of stronger output and shift the periods of grid stress to months and hours when that technology has relatively weaker performance. As a result, these generator technologies make a declining contribution to resource adequacy – and therefore receive lower ELCC ratings -as the periods of greatest resource adequacy risk increasingly occur during periods of lower generation. However, an ELCC value could rise again if the overall dynamics of the grid mix again shift periods of risk to hours of stronger performance.

Figure 2-2: Shifting Riskiest Hour



This effect of declining ELCCs with greater penetration is most pronounced for renewable resources, particularly solar, which are heavily influenced by annual and daily weather trends. Solar resources can play a critical role in offsetting high-load summer afternoons, which align with periods of higher solar irradiance and daytime hours. However, as solar penetration rises, it will effectively shift the periods of greatest risk to nighttime hours. As a result, its ELCC value will decline, sometimes sharply. Capturing these dynamics is an important aspect of maintaining resource adequacy as the grid mix and load characteristics evolve. This phenomenon is shown in Figure 2-2, where the contribution solar and storage generation shift the period of highest stress from Hour 16 to Hour 22.

Why ELCCs decline with growing penetration?

As more of any single technology is added, its ELCC often falls. Each new unit reduces reliability risk during its strongest hours but shifts system stress to periods when it performs least well.

Marginal ELCC methods capture this dynamic most sharply – often understating the contribution of existing fleets. The effect is most evident for solar: early projects help meet summer peaks, but as penetration rises, reliability risk shifts into evening hours.

Key takeaway: ELCCs decline with greater penetration not because the resource becomes less reliable, but because the grid's needs evolve. In many cases, resources are victims of their own success. As such, a resource's ELCC acts as a fair market signal, but may not reflect the reliability risk its retirement would create.

Evolving approaches to capacity accreditation with capacity markets

Planning reserve margins and ELCCs are typically used within a wider capacity market construct to maintain resource adequacy. Many parts of the United States are organized into wholesale electricity markets. Formal capacity markets include PJM Interconnection (PJM), Midcontinent Independent System Operator (MISO), ISO New England (ISO-NE), and New York Independent System Operator (NYISO). Other regions impose capacity requirements without a centralized capacity market, notably the California Independent System Operator (CAISO) and Southwest Power Pool (SPP). In all of these frameworks, the planning reserve margin (PRM) specifies the amount of accredited capacity required to meet the reliability target, while capacity accreditation determines the portion of each resource's nameplate capacity – often via ELCC – that counts toward that obligation.

Initially, ELCCs in many of these markets were only applied to renewable generators and storage resources. However, in response to learnings from Winter Storms Elliott and Uri, where thermal generators experienced wide-area outages due to disruptions in fuel supply and cold weather induced outages, resource planners and ISOs have been increasingly applying ELCC-type evaluations to all resources, including thermal resources.[54]

Each market's construct and approach to computing ELCC values varies. As a result, direct comparison of exact capacity accreditation values across markets is not appropriate. Instead, the analysis focuses on relative ELCC ratings between resource types within each market to draw insights into the comparative resource adequacy contribution of OSW and other resources. Next, the paper highlights the emerging resource adequacy challenges faced by markets across the United States.

Emerging resource adequacy challenges

In recent years, the American grid has entered an era of resource adequacy concerns as the accredited reserve margins have declined.[55] These emerging challenges are driven by surging demand, the retirement of aging generation, lagging investment in new capacity additions, and a slow entry due to interconnection queue backlogs and supply chain constraints. These conditions have produced sharp increases in capacity prices[56] and during extreme weather events, load shedding has occurred. Notably, Winter Storm Uri in Texas[57] and Winter Storm Elliott across the Eastern United States[58] caused wide-area load shedding – leaving millions without power, inflicting billions in economic losses, and resulting in significant loss of human life.

Until recently, trends in electricity usage have been relatively flat in the United States. Population and economic growth – both historical drivers of load growth – have been offset by investments in energy efficiency and demand side management, with per capita residential

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54 Advanced Energy Economy, *Getting Capacity Right: How Current Methods Overvalue Conventional Power Sources,* (Washington, DC: Advanced Energy Economy, March 2022), https://info.aee.net/hubfs/Getting%20Capacity%20Right%20-%20How%20Current%20Methods%20Overvalue%20Conventional%20Power%20Sources.pdf.

55 North American Electric Reliability Corporation (NERC), *2024 Long-Term Reliability Assessment,* December 2024.

56 PJM Interconnection, *2025/2026 Base Residual Auction Report,* (Audubon, PA: PJM Interconnection, July 2025), https://www.pjm.com/-/media/DotCom/markets-ops/rpm/rpm-auction-info/2026-2027/2026-2027-bra-report.pdf; Midcontinent Independent System Operator (MISO), *MISO's Planning Resource Auction Indicates Sufficient Resources* (Carmel, IN: MISO, April 15, 2025), https://www.misoenergy.org/meet-miso/media-center/2025---news-releases/misos-planning-resource-auction-indicates-sufficient-resources/.

57 Federal Energy Regulatory Commission (FERC), North American Electric Reliability Corporation (NERC), and Regional Entities, *February 2021 Cold Weather Outages in Texas and the South Central United States: Causes, Recommendations, and Corrective Actions,* Washington, D.C., Federal Energy Regulatory Commission, November 2021, https://www.ferc.gov/media/february-2021-cold-weather-outages-texas-and-south-central-united-states-ferc-nerc-and.

58 Federal Energy Regulatory Commission (FERC) and North American Electric Reliability Corporation (NERC), *Final Report on Lessons from Winter Storm Elliott*, press release, Washington, D.C., Federal Energy Regulatory Commission, April 2024, https://www.ferc.gov/news-events/news/ferc-nerc-release-final-report-lessons-winter-storm-elliott.

electricity usage declining by 5% between 2010 and 2020.[59] Since 2020, electricity consumption has begun to grow again, primarily driven by commercial and industrial customers.[60]

This reversal is not a modest rebound within historical norms—it reflects a structural transformation in the American economy.

Data centers – amplified by significant advances in Artificial Intelligence (AI)[61] – are the principal driver in this structural shift in the nation's electric needs. Other factors are also driving up electricity demand such as domestic manufacturing.[62] These industries are not only central to American economic growth – they are also vital to national security and America's leadership in advanced technologies.

Federal policymakers have explicitly recognized AI data centers as critical defense facilities and has strongly promoted domestic investment in these industries to ensure the United States prevails in the global AI race with China.[63] Similarly, onshoring of manufacturing, particularly for products like semiconductors, is viewed as essential to national security and a driver of high-wage job creation.[64] These industries are uniquely energy intensive. As such, they will require abundant reliable and affordable power to meet customers' stringent uptime requirements[65] and prevent costly disruptions to manufacturing processes.[66]

At the same time, existing industrial facilities are increasingly converting their fuel source from legacy fossil-fueled equipment and processes to electrified alternatives. This fuel transition is motivated by cost savings, technology advantages, and internal decarbonization goals.

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59 U.S. Energy Information Administration, "Per Capita U.S. Residential Electricity Use Was Flat in 2020, but Varied by State," *Today in Energy*, August 6, 2021.

60 U.S. Energy Information Administration, "After More Than a Decade of Little Change, U.S. Electricity Consumption Is Rising Again," *Today in Energy*, May 13, 2025.

61 Arman Shehabi, Sarah Josephine Smith, Alex Hubbard, Alex Newkirk, Nuoa Lei, Md Abu Bakar Siddik, Billie Holecek, Jonathan G. Koomey, Eric R. Masanet, and Dale A. Sartor, *2024 United States Data Center Energy Usage Report*, (Berkeley, CA: Lawrence Berkeley National Laboratory, December 19, 2024), https://doi.org/10.71468/P1WC7Q.

62 Batra, Lalit, Deb Harris, George Katsigiannakis, Justin Mackovyak, Himali Parmar, and Maria Scheller. *Rising Current: America's Growing Electricity Demand*. ICF, 2025. https://www.icf.com/-/media/files/icf/reports/2025/energy-demand-report-icf-2025_report.pdf

63 "Trump Plans Executive Orders to Power AI Growth in Race with China," *Reuters*, June 27, 2025, https://www.reuters.com/legal/government/trump-plans-executive-orders-power-ai-growth-race-with-china-2025-06-27/.

64 National Institute of Standards and Technology, *The CHIPS Program Office Vision for Success: Two Years Later,* (Gaithersburg, MD: NIST, 2025), https://www.nist.gov/document/chips-america-vision-success-two-year-report.

65 Uptime Institute, *2024 Data Center Resiliency Survey—Executive Summary*, (Fort Collins, CO: Uptime Institute, 2024), https://datacenter.uptimeinstitute.com/rs/711-RIA-145/images/2024.Resiliency.Survey.ExecSum.pdf?version=0&mkt_tok=NzExLVJJQS0xNDUAAAGSPCeKfdv0kYTrLS-6.

66 The Brattle Group, *Value of Lost Load Study for the ERCOT Region*, prepared for the Electric Reliability Council of Texas, Inc., Project No. 55837, (Cambridge, MA: The Brattle Group, September 2024), https://www.brattle.com/wp-content/uploads/2024/09/Value-of-Lost-Load-Study-for-the-ERCOT-Region.pdf.

Corporate emissions targets and sustainability goals have become increasingly important to American manufacturers – both in terms of investor relations and in attracting customers.[67]

Taken together, investment in hyperscale data centers and industrial electrification are driving substantial upward pressure on load forecasts. The North American Electric Reliability Corporation (NERC), which is tasked with ensuring the reliability of the American grid, projects that American electric load will grow by approximately 122 GW, or 15.7%, over the next decade.[68] However, even though this forecast was performed only a year ago, it may already be outdated given rapid upward revisions in utility and ISO outlooks over the past year due to accelerating build-out of data center infrastructure across the country. For example, the PJM forecast for the year 2030 increased by 16 GW (9.5%) between the 2024 and 2025 forecast vintages.

While the overall trend of upward growth is widely accepted, there is disagreement on the amount of growth, particularly due to data center development. As documented in the recent DOE report on grid reliability, forecasts for data center growth range from a national addition as high as 109 GW (S&P) or as low as 33 GW (Lawrence Berkeley National Laboratory's Low case).[69] This forecast uncertainty complicates procurement and planning, creating real challenges in sizing near-term resource additions and the determining the required scale and timing of grid investments.

Critically, it is not just the quantity of load that is increasing – the shape of demand is also changing. In many parts of the country, electrification of heating and transportation is accelerating winter load growth, shifting peak electric loads and/or periods of greatest load shedding risks from summer to winter. NYISO, for example, projects its winter peak will exceed its summer peak by the late 2030s, with winter peak growth (2.45% CAGR) far outpacing summer (0.67% CAGR).[70] Similar patterns are emerging in PJM, MISO, and other regions. In addition, the rise of large industrial customers is flattening electric demands across the day and across seasons, as these facilities consume relatively constant amounts of power consistently across all hours.

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67 Energy Innovation, *"Overcoming All Barriers To Industrial Electrification," Data Explorer*, June 20, 2025, Energy Innovation, accessed September 1, 2025, https://energyinnovation.org/data-explorer/overcoming-all-barriers-to-industrial-electrification/.

68 North American Electric Reliability Corporation (NERC), *NERC Announces 2024 Long-Term Reliability Assessment and Highlights Emerging Resource Adequacy Risks*, Princeton, NJ: NERC, December 17, 2024, https://www.nerc.com/news/Headlines%20DL/12_17_2024%20LTRA%20Announcement%20final.pdf.

69 U.S. Department of Energy, *Resource Adequacy Report: Evaluating the Reliability and Security of the U.S. Electric Grid* (DOE final report, July 7, 2025), developed with assistance from National Renewable Energy Laboratory and Pacific Northwest National Laboratory, and NERC data (DOE/Publication Number, July 7 2025), https://www.energy.gov/sites/default/files/2025-07/DOE%20Final%20EO%20Report%20%28FINAL%20JULY%207%29.pdf.

70 New York Independent System Operator, Inc., *2025 Load & Capacity Data Report (Gold Book)* (Albany, NY: NYISO, 2025).

An evolving resource mix resulting in increasing winter risk

Historically, the US electric grid was anchored by fossil fueled generation (e.g., coal, nuclear, and natural gas), which provided reliable, fuel-assured, and dispatchable electricity across all hour and seasons. In recent years, however, the resource mix has transitioned toward a combination of natural gas, wind, solar, and battery storage, driven by declining natural gas prices, clean energy and air mandates, federal tax incentives, and consumer preference.[71]

This shift has created a generator resource fleet that is more weather-dependent and subject to more variability and uncertainty than the primarily fuel-assured fleet of the past. Renewable generators, like wind and solar, are often referred to as intermittent generation, given their weather-driven fuel sources. For example, solar output is limited to daylight hours, diminishes during winter months, and varies based on daily cloudiness. Wind generation also varies daily and by season, and its output tends to be more variable than solar. Battery storage does not generate electricity but instead shifts energy across time, withdrawing electricity from the grid or a co-located generation resource during periods of lower cost or lower grid stress, and discharging during periods of higher cost or higher grid stress. However, batteries are referred to as "energy limited" because their ability to inject electricity is constrained by their storage capability and they are net consumers of energy due to efficiency losses.

Even thermal generators have experienced disruptions during extreme weather events. Natural gas generators, which currently serve as the primary source of electricity in the United States,[72] also provide the dominant form of dispatchable capacity in many regions. However, natural gas generators can also face reliability challenges during periods of extreme cold weather. Unlike coal, natural gas fuel is typically delivered to electricity generating units on a "just-in-time" basis via pipelines and is not stored onsite. During cold snaps, particularly extended ones, natural gas supplies can become severely constrained in some locations with constrained infrastructure because demand for natural gas increases to serve space-heating needs and to fuel other gas-fired generators.

Coal generators also experienced elevated outage rates during recent cold weather events, though not to the same extent as natural gas units, which were more severely affected by fuel supply constraints and common-mode failures.[73]

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71 U.S. Environmental Protection Agency, "Power Sector Evolution: Renewable Electricity Growth," *U.S. Environmental Protection Agency*, accessed July 2025, https://www.epa.gov/power-sector/power-sector-evolution.

72 U.S. Energy Information Administration, "Electricity in the United States," *Energy Explained*, accessed August 16, 2025, https://www.eia.gov/energyexplained/electricity/electricity-in-the-us.php.

73 Federal Energy Regulatory Commission (FERC) and North American Electric Reliability Corporation (NERC), *Final Report on Lessons from Winter Storm Elliott*, press release, Washington, D.C., Federal Energy Regulatory Commission, April 2024, https://www.ferc.gov/news-events/news/ferc-nerc-release-final-report-lessons-winter-storm-elliott.

NERC has identified interdependencies between the natural gas and electric systems as a key driver of electric reliability risks in the United States.[74] Natural gas supply to gas generators can become further stressed because delivery can be interrupted by pipeline freezes, wellhead outages, or constrained/curtailed supply as gas is diverted for heating. Some generators, known as dual-fuel generators, can run on two fuel types, a primary fuel and backup fuel (typically gas and oil) and store this backup fuel onsite as a hedge against natural gas supply disruptions. Even without fuel shortfalls, natural gas plants have been shown to be more sensitive to extreme weather than coal, sometimes experiencing mechanical outages during extreme cold weather events, when electricity demand is very high.[75] Performance of natural gas generators has improved during recent winter weather events due to hardening efforts and learnings following Winter Storms Uri and Elliott. Natural gas operators have taken steps to harden the systems and proactively prepare to fuel switch during stress events. Market operators have worked to better understand and plan for fuel availability during cold-weather outages; however, concerns due to fuel shortages or common mode outages persist given ongoing natural gas constraints on the aging and constrained natural gas infrastructure – in key regions of the country, especially the Northeast.[76]

This evolving generator resource mix has resulted in evolutions in electric reliability and resource adequacy risks. Reserve margins have declined across the country,[77] and the periods of greatest stress are changing. Historically, the most stressed periods of grid operation (i.e., when the generation supply was closest to the generation demand and load shedding risk was at its highest) aligned with the periods of peak load and were the key drivers of utility planning processes. However, the periods of stress are evolving and shifting away from traditional summer peaks. Due to solar generation's successful contribution during summer risks and risks due to wide-area natural gas outages during extreme cold, many grids are becoming ***summer peaking, but winter constrained***.[78]

Warning signs of tightening supply

The warning signs of a tightening grid have begun to emerge. One measure of grid tightness is capacity prices. While the exact dynamics vary across markets, generally, capacity markets are an electricity market construct used to incentivize sufficient electricity generating capacity to

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74 Federal Energy Regulatory Commission, North American Electric Reliability Corporation, and Regional Entity Participants, *Final Report: The December 2022 Winter Storm Elliott Event*, Washington, D.C.: FERC and NERC, November 2023, https://www.ferc.gov/media/winter-storm-elliott-report-inquiry-bulk-power-system-operations-during-december-2022.

75 Saeed Kamalinia and A. M. Nezhad, "Resource Adequacy Implications of Temperature-Dependent Electric Generation Outage Rates," *Applied Energy* 239 (2019): 21–28, https://www.sciencedirect.com/science/article/pii/S0306261919321117.

76 North American Electric Reliability Corporation. 2024. *2024–2025 Winter Reliability Assessment*. November. https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_WRA_2024.pdf

77 North American Electric Reliability Corporation (NERC), *2024 Summer Reliability Assessment,* May 15, 2024, accessed August 16, 2025, https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_SRA_2024.pdf.

78 North American Electric Reliability Corporation (NERC), *2024 Winter Reliability Assessment*, Princeton, NJ: NERC, November 2023, https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_WRA_2024.pdf.

maintain resource adequacy with some markets also rewarding generators for performing (or penalizing non-performance) during key stressed hours. Capacity markets typically operate through an auction in which prices are determined by the balance between forecasted demand and available accredited supply. As the supply of generation becomes tighter relative to demand, capacity prices tend to increase.

Capacity prices are jumping in PJM

Capacity prices have increased sharply in recent years. PJM's capacity auction held in July 2025 cleared at a historically high price of $39.17/MW-day, about nine times the value of the previous year for most zones.[79] In MISO's last capacity auction, held in April 2025, capacity prices for the summer season soared to $666.50/MW-day, representing a 22-fold increase across all zones.[80]

In addition to becoming more expensive, the grid is becoming less reliable.[81] Since 2011, five major winter storms have threatened the power grid. Heat waves have also caused summer rolling blackouts in Louisiana and California. See Table 2-1 for a summary of some of the recent reliability events across the US electric system and their impact on the American public.

In response to these emerging reliability and price challenges, system operators and regulators are taking action. MISO,[82] PJM,[83] and SPP[84] have all created short-term interconnection reforms to quickly bring reliability critical generator resources onto the system. ERCOT[85] and PJM[86] are

79 This auction was held for the June 1, 2026 through May 30, 2027 delivery period, PJM Interconnection, *2025–2026 Base Residual Auction Report*, 2025, https://www.pjm.com/-/media/DotCom/markets-ops/rpm/rpm-auction-info/2025-2026/2025-2026-base-residual-auction-report.pdf.

80 Midcontinent Independent System Operator (MISO), "MISO's Planning Resource Auction Indicates Sufficient Resources," *MISO News Center*, April 28, 2025, https://www.misoenergy.org/meet-miso/media-center/2025---news-releases/misos-planning-resource-auction-indicates-sufficient-resources/.

81 North American Electric Reliability Corporation (NERC), *2025 Summer Reliability Assessment*, Arlington, VA: NERC, May 2025, https://www.electric.coop/wp-content/uploads/2025/05/NERC_SRA_2025.pdf.

82 Midcontinent Independent System Operator (MISO), "FERC Approves MISO's Expedited Resource Addition Study," News release, Carmel, IN, July 22, 2025, https://www.misoenergy.org/meet-miso/media-center/2025---news-releases/ferc-approves-misos-expedited-resource-addition-study/.

83 PJM Interconnection, "PJM Chooses 51 Generation Resource Projects to Address Near-Term Electricity Demand Growth," *Inside Lines*, May 2, 2025, Valley Forge, PA, https://insidelines.pjm.com/pjm-chooses-51-generation-resource-projects-to-address-near-term-electricity-demand-growth/.

84 Southwest Power Pool (SPP), "SPP Board Approves Expedited Generation Interconnection Process to Help Meet Regional Resource Adequacy," press release, Little Rock, AR, May 8, 2025, https://www.spp.org/news-list/spp-board-approves-expedited-generation-interconnection-process-to-help-meet-regional-resource-adequacy/.

85 Electric Reliability Council of Texas (ERCOT), *Large Load Interconnection Status Update, August 5, 2024,* Presentation by Large Load Integration Team, Austin, TX: ERCOT, https://www.ercot.com/files/docs/2024/08/07/04-lli-queue-status-update-2024-8-5.pdf.

86 PJM Interconnection, "Large Load Additions: PJM Conceptual Proposal and Request for Member Feedback," (Valley Forge, PA, Presentation by Stu Bresler and Tim Horger, PJM Interconnection, August 18, 2025), https://www.pjm.com/-/media/DotCom/committees-groups/cifp-lla/2025/20250818/20250818-item-03---pjm-conceptual-proposal-and-request-for-member-feedback---presentation.pdf.

exploring large load interconnection processes and fast-tracking stake holder input. Many markets—including NYISO[87] and PJM[88]—have delayed retirements of often expensive peaking units. The DOE has taken similar action to delay the retirement of a coal plant in MISO[89] and a natural gas plant in PJM.[90] FERC recently held a technical conference on resource adequacy[91] and the DOE performed a national study of the resource adequacy of electricity grids across the country.[92]

87 New York Independent System Operator (NYISO), *Short-Term Reliability Process Report: 2025 Near-Term Reliability Need*, (Rensselaer, NY: NYISO November 20, 2023), https://www.nyiso.com/documents/20142/39103148/2023-Q2-Short-Term-Reliability-Process-Report.pdf/.

88 Sean Wolfe, "Two Fossil-Fired Plants Get a Life Extension as Part of PJM Agreement," *POWER Engineering*, January 30, 2025, https://www.power-eng.com/coal/two-fossil-fired-plants-get-a-life-extension-as-part-of-pjm-agreement/.

89 U.S. Department of Energy, *Order No. 202-25-7*, Issued by Secretary Chris Wright, August 20, 2025, Washington, D.C.: Department of Energy, https://www.energy.gov/sites/default/files/2025-08/MISO%20Order%20No.%20202-25-7.pdf.

90 U.S. Department of Energy, *Order No. 202-25-4*, May 30, 2025, Issued by Secretary Chris Wright, Washington, D.C.: Department of Energy, https://www.energy.gov/sites/default/files/2025-05/Federal%20Power%20Act%20Section%20202%28c%29%20PJM%20Interconnection.pdf.

91 Federal Energy Regulatory Commission, "FERC to Host Commissioner-Led Technical Conference on Resource Adequacy," *News Release*, February 20, 2025, Washington, D.C. https://www.ferc.gov/news-events/news/ferc-host-commissioner-led-technical-conference-resource-adequacy.

92 U.S. Department of Energy, 2025, *Report on Evaluating U.S. Grid Reliability and Security*, DOE final report, July 7, 2025, Washington, DC: U.S. Department of Energy.

Table 2-1: Recent Load Shedding Events

Event	Date	Region	Size / Impact
Winter Storm Uri	Feb 2021	Texas (ERCOT)	~20 GW load shed; ~4.5 million customers without power; >200 deaths; ~$100 billion in damages[93]
Winter Storm Elliott	Dec 2022	PJM & Eastern US	~90 GWs of coincident unplanned generating unit outages; ~1.7 million customers affected; large forced outages avoided by emergency measures[94]
California Heat Wave	Aug 2020	California (CAISO)	~1,000 MW load shed; ~500,000 customers impacted; first rolling blackouts since 2001[95]
Louisiana Load Shed (Higher than expected	May 2025	Southeast US	~600 MW load shed; ~100,000 customers impacted; regional economic losses[96]
Pacific Northwest Winter Event	Jan 2024	Oregon (WECC)	Multiple emergency alerts declared; ~550,000 customers without power; >$165 million in economic loss[97]
Tennessee Valley Rolling Blackouts	Dec 2022	Tennessee Valley Authority (TVA)	~6.5 GW generation outages; $170 million in financial impact[98]

The potential role of OSW in meeting the moment

Collectively, the trends discussed above make clear that the risk profile of the American power system has changed. The grid is now navigating a more volatile, weather-driven operating environment, where resource adequacy requires not just meeting a single seasonal peak but sustaining performance across diverse and shifting periods of stress. Leaders across the energy

93 Joshua D. Rhodes, *The Impact of an Additional 10 GW of Utility-Scale Solar in ERCOT During Winter Storm Uri* (GridLab, November 2023), https://gridlab.org/wp-content/uploads/2023/11/GridLab_More-solar-in-Uri.pdf.

94 Federal Energy Regulatory Commission (FERC), North American Electric Reliability Corporation (NERC), and Regional Entity Staff, *Inquiry into Bulk-Power System Operations During December 2022 Winter Storm Elliott,* (Washington, DC: FERC, October 2023), https://www.ferc.gov/sites/default/files/2024-02/24_Winter-Storm_Elliot_0207_UPDATE.pdf

95 California ISO, California Public Utilities Commission, and California Energy Commission, *Final Root Cause Analysis: Mid-August 2020 Extreme Heat Wave* (January 13, 2021), https://www.caiso.com/Documents/Final-Root-Cause-Analysis-Mid-August-2020-Extreme-Heat-Wave.pdf.

96 Paul Gerke, "Why MISO Asked Southeast Utilities to Load Shed, Prompting a Brownout for 100,000+ Customers," *Renewable Energy World*, May 27, 2025, https://www.renewableenergyworld.com/power-grid/outage-management/why-miso-asked-a-southeast-utility-to-load-shed-prompting-a-brownout-for-100000-customers.

97 North American Electric Reliability Corporation (NERC), *After-Action Report: January 2024 Winter Weather Event* (May 2024), https://www.nerc.com/pa/rrm/ea/Documents/2024_January_Winter_Weather_AAR.pdf.

98 Tennessee Valley Authority, *Winter Storm Elliott After-Action Report* (Knoxville, TN: Tennessee Valley Authority, 2023), https://www.tva.com/energy/system-operations/winter-storm-elliott-report.

space are increasingly calling for urgent action[99,100,101] and an "all-of-the-above" and "everything-that-works"[102] solution to emerging resource adequacy challenges and threats. While dispatchable resources remain essential, renewable resources play a vital role to providing an additional pathway to bringing new generation capacity to meet the nation's growing energy needs.

While there is no one path to resource adequacy, OSW stands out amount non-dispatchable resources. Compared to other renewables, OSW has several characteristics that make it particularly well-suited to contributing toward meeting resource adequacy including the following.

3.1 High capacity factor

OSW has higher capacity factors, the ratio of actual energy produced to the theoretical maximum if operating at full output in all hours,[103]compared to onshore wind facilities. By accessing steady costal winds at higher hub heights (i.e., height at which the turbine operates), OSW is projected to have a capacity factor around 46%[104] as compared to 37%[105] for the most recent onshore wind projects.[106] Both OSW and onshore wind have significantly higher capacity factors than solar generation (median capacity factor of 24% with a range from 7% to 35%).[107]

Though smaller than projects which are projected to come online in 2025, existing domestic OSW projects, South Fork and Block Island, demonstrate this potential. South Fork has shown strong performance, particularly in the winter months. Block Island has also delivered high capacity factors, but its performance has been disrupted by non-routine maintenance in 2021.[108]

99 PJM Interconnection, *Energy Transition in PJM: Resource Retirements, Replacements, and Risks*, Audubon, PA: PJM Interconnection, August 2023, https://www.pjm.com/-/media/DotCom/library/reports-notices/special-reports/2023/energy-transition-in-pjm-resource-retirements-replacements-and-risks.ashx.

100 Ethan Howland, "FERC Chair Christie Warns U.S. Needs More Dispatchable Resources Amid Heat and Grid Stress." *Utility Dive*, July 2, 2025, https://www.utilitydive.com/news/ferc-christie-dispatchable-resources-heat-wave-pjm-miso-iso-ne/751821/.

101 Federal Energy Regulatory Commission (FERC), "Commissioner-Led Technical Conference Regarding the Challenge of Resource Adequacy in RTO and ISO Regions," *FERC News Release*, February 20, 2025, https://www.ferc.gov/news-events/news/ferc-host-commissioner-led-technical-conference-resource-adequacy.

102 U.S. Department of Energy, "Secretary Wright's Interview with Fox News' Bret Baier at the Department of Energy – July 22, 2025," *YouTube video*, July 22, 2025, https://www.youtube.com/watch?v=tCt5fWXDTQg.

103 U.S. Energy Information Administration. "Capacity Factor." *EIA Glossary*. Accessed October 2025. https://www.eia.gov/tools/glossary/index.php?id=Capacity_factor

104 Offshore Wind – Eastern United States, https://www.belfercenter.org/publication/offshore-wind-eastern-united-states.

105 US Department of Energy, *Land Based Wind Market Report*, 2023, https://www.energy.gov/sites/default/files/2023-08/land-based-wind-market-report-2023-edition.pdf.

106 Ibid.

107 Energy Markets & Policy, Berkeley Labs, *Utility Scale Solar*, 2024, (Energy Technology Area, Berkeley Labs, Energy Markets and Policy, 2024), https://emp.lbl.gov/utility-scale-solar.

108 The Providence Journal. "Block Island Offshore Wind Farm Offline Two Months Due to Maintenance and Safety Concerns." *The Providence Journal*, August 14, 2021. https://www.providencejournal.com/story/news/2021/08/14/block-island-offshore-wind-farm-offline-two-months-due-to-maintenance-and-safety-concerns/8122841002/

Respectively, they have shown 46.4% and 41.4% annually. They have shown even stronger winter contribution with capacity factors of 47% and 50.9% in December.[109,110,111]

3.2 Consistent output

Beyond higher averages, OSW tends to deliver steadier hour-to-hour performance than many onshore sites. Historical production data indicate fewer extended periods of very low generation ("renewable droughts") offshore. Unlike solar, both onshore wind and OSW can produce throughout the day – with output often peaking overnight in much of the United States. While wind exhibits seasonal variation and typically dips in summer (except California), this slowdown is less pronounced offshore due to marine boundary-layer dynamics and sea-breeze effects.

To demonstrate, we compare two New England sites: the proposed Revolution Wind offshore location and a nearby onshore wind facility in Rhode Island. This is shown in Figure 3-17.

We recognize that Rhode Island has limited potential to add new onshore wind. However, we include this as a reference example to the benefits of going offshore: accessing higher hub heights and steadier hour to hour generation. While the exact performance of an onshore site would vary by location, this example shows similarities to generation in many locations across the country.[112]

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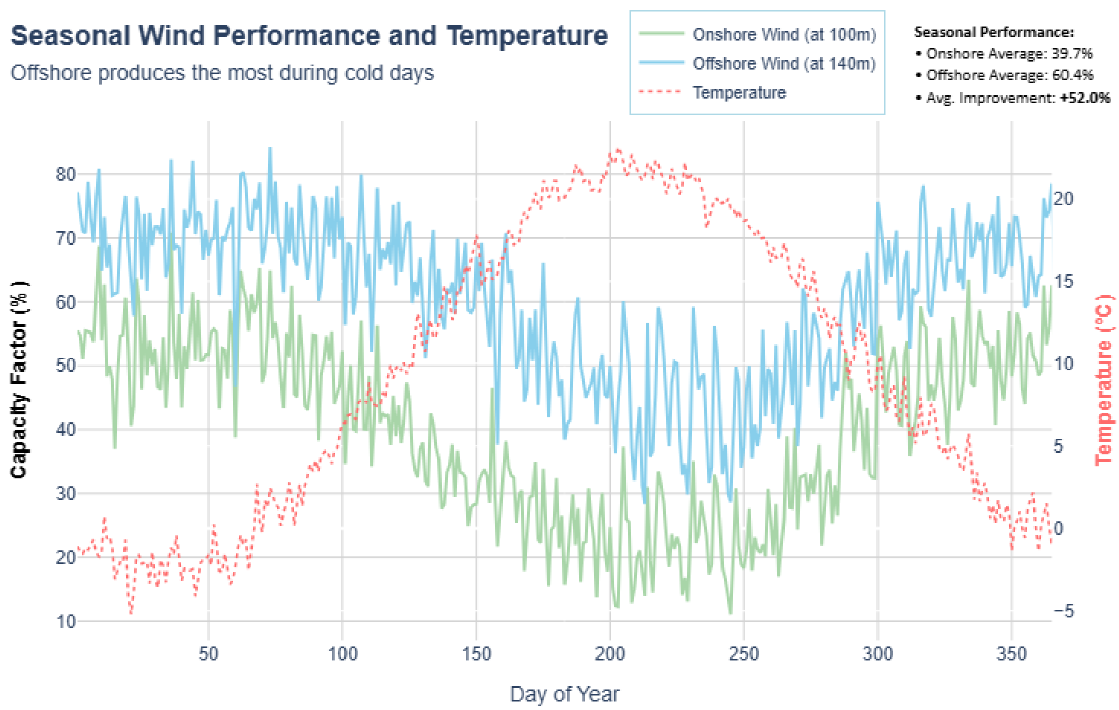
109 Note, South Fork's performance has only been based on a single full year of performance, and Block Island's performance has been influenced by two months of around 6% capacity factor due to non-routine maintenance event.

110 Ørsted. *One Year of South Fork Wind: Energy That Works.* Ørsted U.S. Offshore Wind, 2025. https://us.orsted.com/renewable-energy-solutions/offshore-wind/south-fork-wind-report

111 New York State Department of Public Service. *Block Island Wind Farm Methods Report.* Albany, NY: New York State Department of Public Service, 2021. https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={E7F04416-B795-4F0B-86D9-0FCFF83CF22C}

112 U.S. Energy Information Administration. "U.S. Electricity Markets and Natural Gas Pipeline Constraints (2024)." *Today in Energy*, August 30 2024. https://www.eia.gov/todayinenergy/detail.php?id=54819

Figure 3-1: Comparison of onshore and offshore wind performance in New England



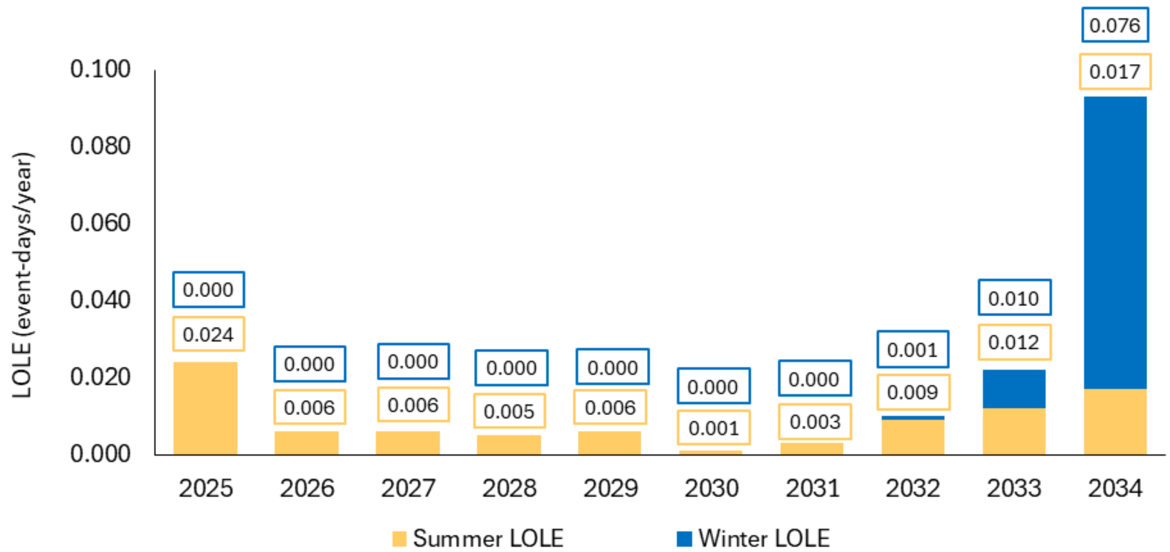
3.3 Alignment with emerging periods of reliability risks

Many regions – including parts of PJM, NYISO, and ISO-NE – are experiencing growing resource adequacy and reliability challenges during winter mornings and evenings. This can be seen with the reliability risk modeling produced by NYISO (shown in Figure 3-2) where the LOLE risk – representing the likelihood of a load shedding event – is growing exponentially and shifting overwhelmingly to winter. These are periods when heating demand is high, solar output is minimal, and storage resources may be depleted. OSW production patterns often align with these risk periods, particularly during extreme cold weather events when natural gas availability is constrained by fuel supply limitations and competition from heating load and other gas-fired generators. OSW can complement other resources by supplying generation during high-risk, low-supply hours. OSW can help regions that face constraints on the natural gas fuel systems, such as in the Northeastern United States.

Even as many systems shift toward winter-peaking risk profiles, summer adequacy challenges remain significant across much of the United States. Risk periods in summer have shifted later into the evening due to contributions from solar during daylight hours and batteries discharging in early evening. OSW can play a meaningful role in meeting residual demand in these later hours. However, its contribution in summer is typically smaller than in winter, as OSW output moderates in summer months – though the decline is much less pronounced than for onshore wind.

An important exception toward this dual winter and summer seasonal risk profile is California, where reliability risk remains concentrated in summer evening hours as solar output declines. However, California coastal OSW is well-timed to these stress periods, as it produces most during summer evenings. Critically, coastal wind speeds in California increase as the sun is setting, positioning OSW is a useful resource to dampen the significant impact net load ramping created by the sharp ramping after the sun has set.[113]

Figure 3-2: Risk Profile for NYISO[114]



As shown in Figure 3-3, both Eastern offshore and onshore wind exhibit meaningful synergies with natural gas generation. These wind resources produce their strongest output when gas units face the greatest risk of outages due to fuel constraints or maintenance events. Conversely, natural gas resources help fill low-wind hours, particularly during the summer, providing dispatchable capacity that smooths renewable variability.

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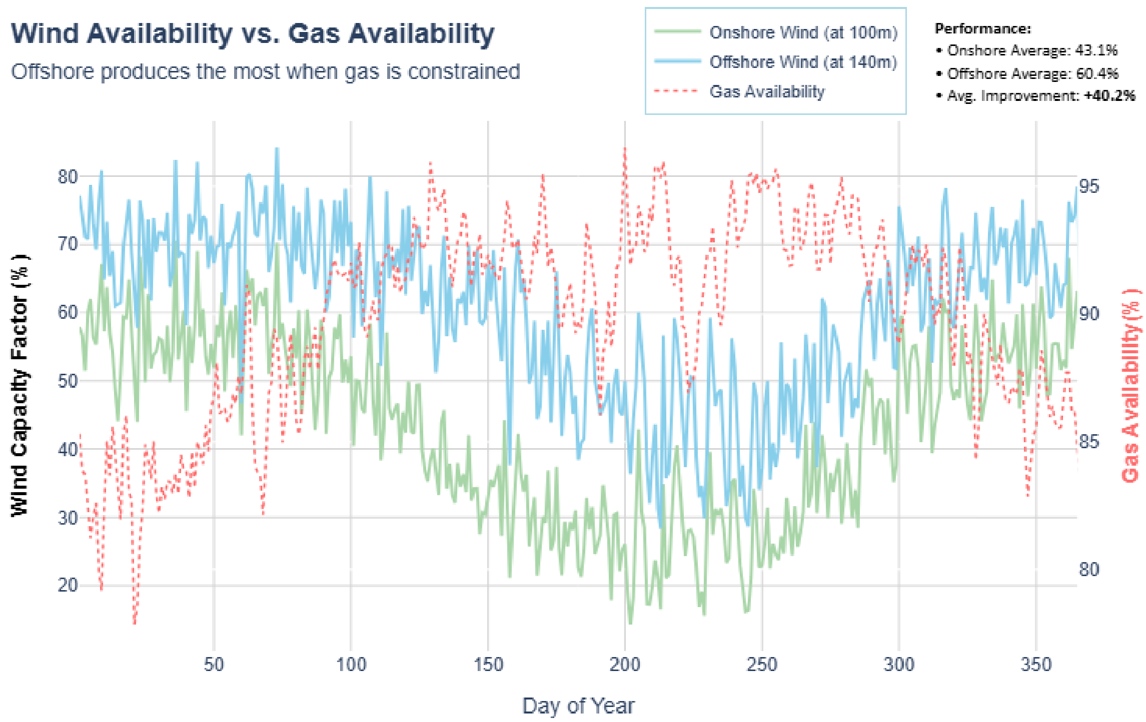
[113] M. Severy, C. Ortega, C. Chamberlin, and A. Jacobson, Wind Speed Resource and Power Generation Profile Report, In California North Coast Offshore Wind Studies, edited by M. Severy et al. Arcata, CA: Schatz Energy Research Center, September 2020, accessed August 13, 2025.

[114] New York Independent System Operator. *2024 Reliability Needs Assessment (RNA): A Report from the New York Independent System Operator.* November 19 2024. https://www.nyiso.com/documents/20142/2248793/2024-RNA-Report.pdf

Figure 3-3: Comparison of wind and natural gas performance in New England



3.4 Potential for large-scale deployment near load centers

OSW projects can be built at larger individual capacities than most onshore wind installations. OSW development can be sited in coastal regions near population centers. There is often limited opportunity to develop other resource types in these regions due to land availability, zoning, and access to natural gas pipelines. By siting turbines offshore rather than onshore, developers can access higher-quality wind resources without competing for limited onshore space. This greater space allows for larger turbine sizes, greater hub heights, and more generation capacity.

3.5 Auxiliary pathway for energy and capacity

OSW provides an auxiliary and complementary opportunity to add both energy and capacity to enable the grid to reliably accommodate substantial near-term load growth. It offers operational and temporal characteristics that differ from primary resources dominating interconnection queues – natural gas, energy storage, and solar. OSW draws on distinct supply chains for some key components and relies on a renewable and free fuel source, avoiding exposure to natural gas fuel constraints and turbine manufacturing bottlenecks that are affecting natural gas resources. Unlike storage, OSW is a net energy producer rather than a net consumer, thereby avoiding the round-trip efficiency losses inherent to charging and discharging batteries. Compared to solar, OSW delivers a materially higher accredited capacity contribution, particularly during non-daylight hours.

In this context, OSW is potentially valuable when integrated with complementary generation investments, enabling the grid as a whole to address emerging reliability gaps. It can supply incremental generation in regions where other resource types cannot be deployed quickly enough to meet load growth. Its production profile can fill critical operational gaps – nighttime hours when solar is unavailable and cold-weather periods when natural gas units may be constrained. Additionally, OSW can generate low-cost surplus energy suitable for charging storage resources, extending their availability into high-risk periods.

3.6 Increasingly cost competitive with some recent headwinds

OSW's cost competitiveness has improved over the past decade, though recent macroeconomic and policy headwinds have slowed progress. Inflation, supply chain disruptions, and policy changes have driven up costs for many projects. A key benchmark for comparing technologies is the **Levelized Cost of Energy (LCOE)**, which measures the average cost to build, operate, and retire a plant over its lifetime, normalized by the energy it produces.

LCOE has been fairly criticized for (sometimes) excluding transmission costs and system benefits, for not fully capturing least-cost system decisions when generation and transmission are planned together and not fully capturing energy and capacity contributions of a resource. To address the limitations of resource-by-resource cost assessments using metrics like LCOE, **Integrated Resource Planning** (IRP) provides a more complete framework – allowing planners to include location-specific transmission costs and jointly optimize both generation and sometimes transmission investments and holistically evaluating generating investments decisions in a portfolio-wide manner.[115] Despite its limitations, LCOE remains a useful benchmark because it allows for a simplified and intuitive comparison between technologies and over time.

Based on the LCOE metric, major American installations demonstrate that OSW has improved in competitiveness with other forms of generation, though it lags other renewables. South Fork Wind, which entered into service in 2024, reported an LCOE of $141/MWh.[116] Vineyard Wind, the first utility-scale OSW farm in the United States, reflects similar cost progress. Its two 400 MW phases signed Power Purchase Agreements (PPAs) at $74/MWh and $65/MWh (first-year prices). After accounting for federal tax credits and capacity revenues, this is translated to an estimated levelized cost of about $98/MWh.[117]

115 U.S. Department of Energy. *Best Practices for Utility Integrated Resource Planning (IRP).* Washington, DC: U.S. Department of Energy, November 2024. PDF. https://www.energy.gov/sites/default/files/2024-12/best_practices_irp_nov_2024_final_optimized.pdf

116 "Welcome to South Fork Wind" n.d. Southforkwind.com. https://southforkwind.com/.

117 Philipp Beiter, Paul Spitsen, Walter Musial, and Eric Lantz, *The Vineyard Wind Power Purchase Agreement: Insights for Estimating Costs of U.S. Offshore Wind Projects*, NREL/TP-5000-72981 (Golden, CO: National Renewable Energy Laboratory, February 2019), 5–12, https://www.nrel.gov/docs/fy19osti/72981.pdf

Another example is the Coastal Virginia Offshore Wind (CVOW). CVOW is a 2.6 GW project expected to be placed in service at the end of 2026 and is expected to fully deliver power at $62/MWh (including renewable energy credit sales).[118] This figure is well below many recent projects and competitive with new combined-cycle gas turbines, which have seen sharp increases in prices recently.

Broader market assessments of LCOE enable OSW to be compared to other resource. Lazard's 2025 LCOE analysis[119] (illustrated in Figure 3-4) shows that the lowest LCOEs are consistently achieved across renewables, specifically utility solar ($38-$78/MWh) and onshore wind ($37-$86/MWh). While OSW's range is higher ($70-$157/MWh), CVOW's competitive price indicates OSW's potential under differing pricing structures and as developer's gain experience in the American footprint. Comparing these figures to those of thermal technologies highlights that peaking gas units ($138-$262/MWh) and United States nuclear plants ($138-$222/MWh) fall at the top of the cost range, while coal also remains above most renewables. Together, this data shows how OSW has narrowed the gap with thermal generation while maintaining zero-fuel and winter-peaking advantages relative to solar generation.

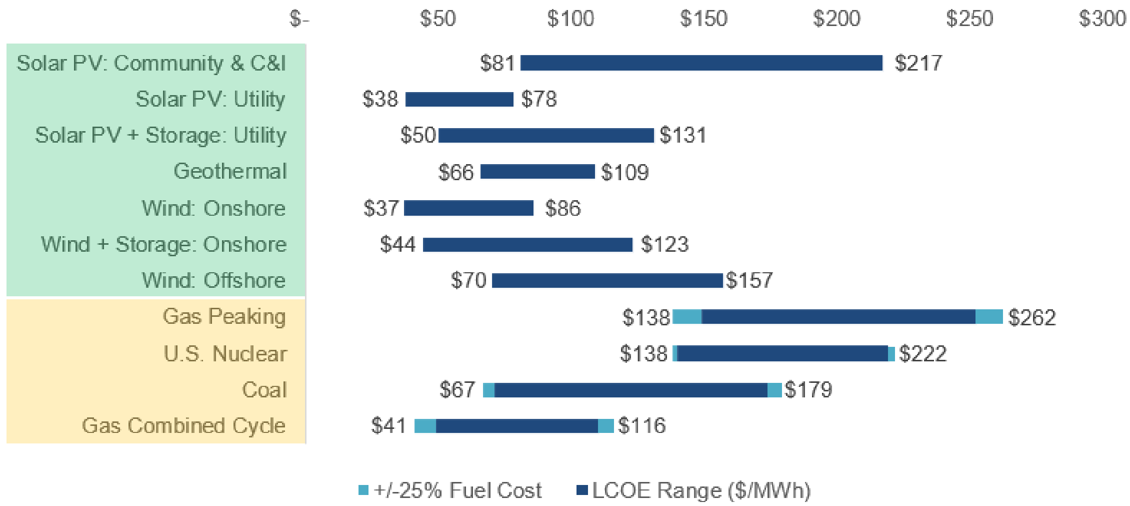
LCOE versus Integrated Resource Planning

- **LCOE** provides an intuitive, standardized way to compare the cost of energy ($/kWh) across technologies over time. It is simple to communicate and track, but it does **not** account for transmission costs (though it can be added), system balancing needs, or interactions with the broader resource mix.
- **Integrated Resource Planning** allows system planners to holistically identify the least-cost mix of generation and transmission investments to **meet both energy and capacity needs on a portfolio-wide basis**. However, IRP studies are resource-intensive and can take months to complete.
- **Takeaway:** LCOE has its shortcomings, but it remains the most widely used and intuitive tool for comparing the relative costs of different generation technologies over time.

118 "Coastal Virginia Offshore Wind (CVOW) Project, Part of Comprehensive 'All of the Above' Energy Strategy to Affordably Meet Growing Energy Needs, Continues on Schedule, Cost Updated." 2024. Dominionenergy.com. 2024. https://news.dominionenergy.com/press-releases/press-releases/2025/Coastal-Virginia-Offshore-Wind-CVOW-Project-Part-of-Comprehensive-All-of-the-Above-Energy-Strategy-to-Affordably-Meet-Growing-Energy-Needs-Continues-on-Schedule-Cost-Updated/default.aspx.

119 "Levelized Cost of Energy+ (LCOE+)." 2025. Https://Www.lazard.com. 2025. https://www.lazard.com/research-insights/levelized-cost-of-energyplus-lcoeplus/.

Figure 3-4: Levelized Cost of Energy (LCOE) comparison of various generation technologies



While these examples show steady progress, the sector has not been immune to broader cost pressures. Rising interest rates, global supply-chain challenges, and permitting delays have contributed to higher capital and equipment costs across the power sector. For example, onshore wind is facing upward pressures on costs due to supply chain disruptions and policy uncertainty. This has led to LCOEs rising as much as 23% in recent years, according to Lazard.[120] Importantly, cost pressures are not unique to OSW. As discussed above, natural gas turbines are facing steep increases in capital costs and multi-year wait times due to surging demand from data centers and industrial load growth. For example, NextEra Energy's CEO noted that a combined-cycle facility built in 2022 cost approximately $785 per kilowatt, while building the same facility in 2024 would exceed $2,400 per kilowatt – a threefold increase in just two years.[121] Solar, while still among the lowest-cost resources, is also contending with supply chain constraints and policy uncertainty.

While LCOE is a useful benchmark for typical energy costs, it does not capture the ability of a resource to deliver power during high-stress hours. Industry experts have highlighted the importance of considering both energy and reliability contributions when comparing resource costs. To address this, we introduce an additional metric: LCOE-normalized ELCC (N-ELCC).

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120 "Despite Low Gas Prices, Solar, Wind Remain Cheapest Sources of Power in U.S." 2025. Pv Magazine USA. June 17, 2025. https://pv-magazine-usa.com/2025/06/17/despite-low-gas-prices-solar-wind-remain-cheapest-sources-of-power-in-u-s/.

121 Sophie. 2025. "Costs to Build Gas Plants Triple, Says CEO of NextEra Energy." Gas Outlook. March 25, 2025. https://gasoutlook.com/analysis/costs-to-build-gas-plants-triple-says-ceo-of-nextera-energy/.

Beyond LCOE: Measuring Value Day-to-Day and Under Periods of Greatest Stress

While the Levelized Cost of Energy (LCOE) is a useful benchmark for typical energy costs, it does not reflect a resource's ability to deliver power during high-stress hours. To address this, we introduce a complementary metric—**LCOE-normalized ELCC** (N-ELCC)—defined as the ratio of a resource's Effective Load Carrying Capability (ELCC) to its LCOE.

This approach, similar to Lazard's *cost of firming intermittency* concept, highlights a resource's **capacity value per dollar spend on energy**:[122]

Higher N-ELCC = greater accredited capacity for each dollar spent on energy (MW UCAP-MWh/$).

Though simplified, N-ELCC offers an intuitive way to compare how technologies contribute to both energy and capacity value.

This is taken as the ratio of a resource's ELCC percentage divided by its LCOE. This is similar to the cost of firming intermittency concept used by Lazard.[123] In this metric, a higher value indicates a greater contribution to accredited capacity per dollar. While N-ELCC is a simplified measure, it provides an intuitive comparison of the cost-effectiveness of different technologies in delivering both energy and accredited capacity.[124]

Applying this metric using PJM's ELCC values, which cover all technology classes, not just intermittent resources, enables like-for-like comparisons which capture both capacity and energy contributions. Results (shown in Figure 3-5) show that gas combined-cycle units exhibit the highest N-ELCC, reflecting strong capacity contributions per dollar of energy cost. Their wide range reflects fuel price volatility, equipment costs, and permitting risks. Coal resources display comparable variability. While it has enjoyed recent support from federal policy makers, the development of new coal capacity in much of the United States is effectively constrained by unfavorable cost competitiveness, emissions profiles, and evolving regulatory standards.[125,126]

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122 "Levelized Cost of Energy+ (LCOE+)." 2025. Https://Www.lazard.com. 2025. https://www.lazard.com/research-insights/levelized-cost-of-energyplus-lcoeplus/.

123 Ibid.

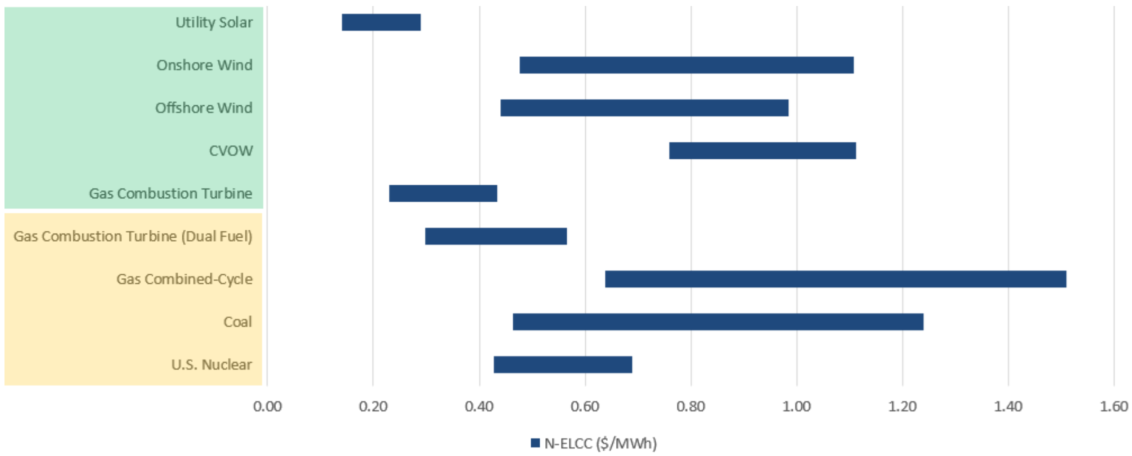
124 U.S. Department of Energy. *Best Practices for Utility Integrated Resource Planning (IRP).* Washington, DC: U.S. Department of Energy, November 2024. PDF. https://www.energy.gov/sites/default/files/2024-12/best_practices_irp_nov_2024_final_optimized.pdf

125 Kennard, H. (2023, June 29). *The Future of Coal in the US Electricity System*. Center on Global Energy Policy, Columbia University. https://www.energypolicy.columbia.edu/the-future-of-coal-in-the-us-electricity-system/

126 U.S. Congress. Congressional Research Service. *U.S. Coal Industry Trends*. CRS Report R48587. December 14, 2020. https://www.congress.gov/crs-product/R48587

Wind resources score among the highest N-ELCC for renewable technologies, though the value varies based on the exact pricing of the individual project. OSW performs better than peaking gas plants because they combine similar ELCC values with lower LCOEs. Solar, by contrast, has the weakest N-ELCC, despite some of the lowest LCOE values, because declining contributions during peak-stress hours have eroded its ELCC value. Nuclear shows N-ELCC due to its relatively high LCOE, despite very high ELCC values.

Figure 3-5: Normalized ELCCs across various generation technologies in PJM



This analysis illustrates OSW's ability to contribute to both capacity and energy needs. On an energy-only basis, it is competitive from an energy perspective for some projects, though the LCOE is variable. When considering OSW's contribution to both energy and capacity needs, OSW becomes increasingly competitive. Differences in affordability rankings between ELCC- and N-ELCC-based metrics indicate that reliance on LCOE alone could understate the reliability value of high-ELCC resources. In the next sections, these concepts are further explored. Further analysis is needed to consider the cost implications of OSW which captures synergies with the wider generator mix, availability and build limits of alternatives, and transmission costs to fully examine the cost competitiveness of OSW relative to alternatives. Next, we discuss the risks of solving emerging resource adequacy challenges without adopting new technologies, like OSW.

Limits of maintaining resource adequacy with legacy technologies alone

Nationally, substantial investment is ongoing to reliably and affordably maintain grid reliability as demand grows and demand patterns shift. Vertically integrated utilities, independent power producers, transmission operators, and natural gas utilities are investing in new generation, transmission, and natural gas storage resources to meet growing demand.

New generation includes natural gas, solar, onshore wind, and storage resources. However, these legacy resources may not be able to reliably meet demand alone, without the adoption of new technologies, like OSW. This section provides a brief summary of the role and potential limitations of natural gas, solar, storage, and onshore wind. These are wide-spread domestic technologies and are the primary resources being evaluated to support near-term load growth. The bulk of this section is spent exploring the role and limitations of natural gas, since it is presently the largest source of electricity generation in the United States. In the authors' view, new coal additions are unlikely. While new nuclear additions are likely, these will not materialize quickly enough to support near-term load growth.

3.1 Natural Gas

Natural Gas is energy-dense and dispatchable, but existing natural gas infrastructure and supply chains are strained

As the largest source of electricity generation[127] in the United States, natural gas is the current backbone of American grid reliability and is projected to continue to play a meaningful reliability role in the future.[128] Natural gas is energy-dense and dispatchable and achieves relatively high ELCC values in markets across the nation.

However, due to the pace, location, and seasonality of current load growth, natural gas investments alone may be insufficient to reliably meet ongoing load growth. Several key aspects of natural gas development have raised concerns from system operators and regulators including:

- **Supply chain limits:** Industry analysts estimate that global manufacturing capacity will be operating close to 90% utilization in 2025, leaving little flexibility to accommodate new orders.[129] This has led to significant backlogs in gas turbine orders, with deliveries now extending into 2029 and beyond. Gas turbine manufacturers, including GE Vernova and Siemens, have acknowledged that even expanded production capacity cannot keep pace with demand.[130]
- **Fully subscribed natural gas pipelines, particularly in New England:** Despite abundant domestic gas reserves in places like the Appalachian shale fields, there is limited ability to

127 U.S. Energy Information Administration (EIA). "What Is U.S. Electricity Generation by Energy Source?" Frequently Asked Questions. Accessed September 24, 2025. https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

128 U.S. Energy Information Administration (EIA). "What Is U.S. Electricity Generation by Energy Source?" Frequently Asked Questions. Accessed September 24, 2025. https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

129 Mackenzie, Wood. 2025. "Wood Mackenzie." Woodmac.com. May 14, 2025. https://www.woodmac.com/press-releases/despite-surging-power-demand-gas-fired-power-faces-manufacturing-constraints-that-could-limit-near-term-growth/.

130 Sophie. 2025. "Costs to Build Gas Plants Triple, Says CEO of NextEra Energy." Gas Outlook. March 25, 2025. https://gasoutlook.com/analysis/costs-to-build-gas-plants-triple-says-ceo-of-nextera-energy/.

transport the fuel to the some parts of the country due to pipeline capacity constraints, particularly New York and New England.[131] Several Massachusetts utilities have imposed moratoria on new gas hookups.[132] Additionally, NERC's Director has warned that there is insufficient gas pipelines to serve all existing electric generation in some regions of the Northeast.[133]

- **Cold-weather outages:** Gas fuel supplies remain susceptible to freezing during extreme cold. Winter Storms Uri (2021) and Elliott (2022) caused wellhead and pipeline freeze-offs that curtailed generation and led to widespread outages. While hardening efforts have improved recent performance,[134] these events underscore the risk of correlated outages when relying on a single fuel source for electricity generation.
- **Permitting delays and policy uncertainty:** Efforts to expand natural gas pipelines to relieve constraints have been delayed or cancelled due to permitting reversals and policy uncertainty. Natural gas pipeline projects must navigate a web of overlapping federal, state, and local requirements. These layers of oversight, combined with risks of litigation and stakeholder opposition, have made permitting both costly and unpredictable.[135] Even when projects receive federal approval, state denials or litigation can stall project development. Several proposed projects such as the Constitution Pipeline, Northeast Supply Enhancement (NESE) project, and Mountain Valley (MVP), aimed at expanding existing capacity were either delayed or canceled due to legal, regulatory, and community opposition.[136]

3.2 CRA analysis of natural constraints

To evaluate potential limitations of relying on natural gas alone to maintain grid reliability, the authors conducted additional analysis of the natural gas system. This analysis included quantification of the remaining available headroom on the existing natural gas system in the

131 AEA. 2024. "Northeastern Energy Corridor: Development, Regulation, and Threats to Expansion." American Energy Alliance. November 22, 2024. https://www.americanenergyalliance.org/2024/11/northeastern-energy-corridor-development-regulation-and-threats-to-expansion/.

132 Young, Colin A. 2019. "Natural Gas Hookups off Limits in More Mass. Towns." WWLP. February 19, 2019. https://www.wwlp.com/news/natural-gas-hookups-off-limits-in-more-mass-towns.

133 "NERC Warns of Electricity Shortages in Winter Reliability Assessment." 2023. Cooperative.com. 2023. https://www.cooperative.com/news/Pages/NERC-Warns-of-Electricity-Shortages-in-Winter-Reliability-Assessment.aspx.

134 North American Electric Reliability Corporation. 2024. *2024–2025 Winter Reliability Assessment*. November. https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_WRA_2024.pdf

135 Reuters. 2021. "Factbox: U.S. Oil and Natgas Pipelines Delayed by Legal and Regulatory Battles." Reuters. February 2021. https://www.reuters.com/article/us-usa-canada-pipelines-factbox/factbox-u-s-oil-and-natgas-pipelines-delayed-by-legal-and-regulatory-battles-idUSKBN2A11EI.

136 "Williams to Revive Constitution, NESE Pipelines in Joint Effort with Regulators." 2025. Pgjonline.com. 2025. https://pgjonline.com/news/2025/may/williams-to-revive-constitution-nese-pipelines-in-joint-effort-with-regulators.

Northeast and interviews with natural gas engineering, procurement, and construction (EPC) stakeholders.

3.2.1 Maximum available headroom on natural gas pipelines

The authors also assessed **maximum available winter headroom** in key gas-constrained regions in the United States using RBAC's Gas Competition Pipeline Model (GPCM)[137] and EIA data. We analyzed historical pipeline inflow and outflow data from the EIA and pipeline capacity between states.[138] This data was then paired with regional customer demand provided by RBAC to determine the maximum pipeline capacity available to electric utilities.[139]

Using GPCM, we quantified how much unused natural gas capacity is available for electric utilities to generate power while meeting peak demand by taking the minimum difference in pipeline capacity and historical natural gas flows during these winter months. From this the difference between pipeline capacity and historical natural gas flows (2021 to 2025), we computed available energy generation capacity by taking daily values for natural gas volumes reaching electric utilities and multiplying their energy content by the heat rate of a natural gas peaking plant (assumed to be 10,000 Btu/kWh).[140]

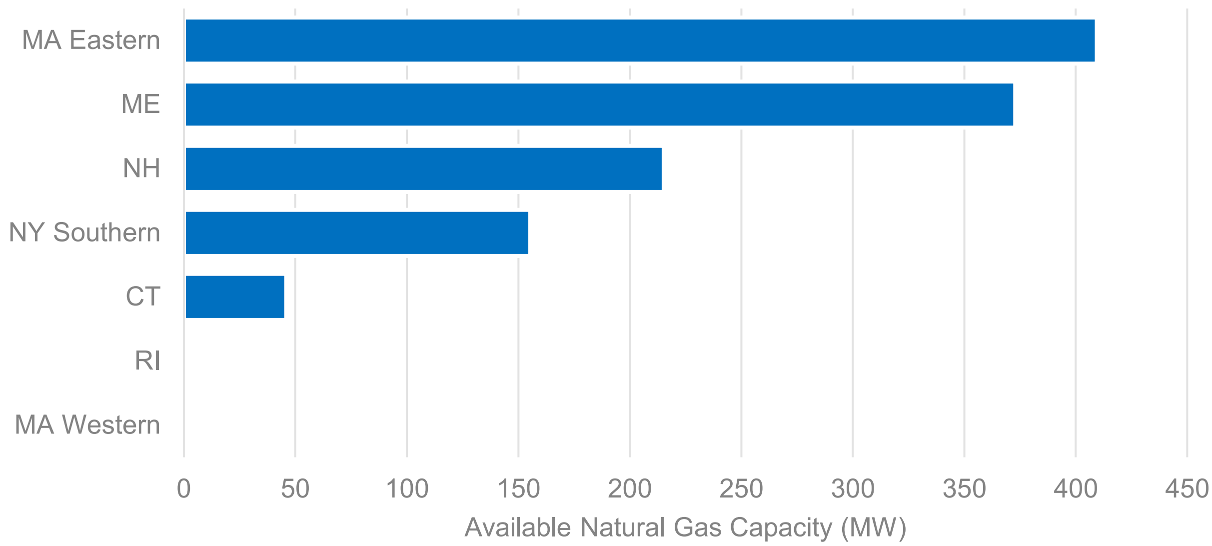
[137] RBAC's Gas Competition Pipeline Model (GPCM) is a nodal natural gas pipeline model which captures historical gas supply, demand, and pipeline flows as well as predicting future flows based upon user inputs.

[138] EIA Natural Gas: Pipelines: U.S. state-to-state capacity, Jan 2025. https://www.eia.gov/naturalgas/data.php

[139] RBAC: GPCM Database 2025 Q2; https://rbac.com/gpcm-base-case-natural-gas-forecast-briefing/

[140] EIA. "Use of natural gas-fired generation differs in the United States by technology and region." February 22, 2024. Use of natural gas-fired generation differs in the United States by technology and region - U.S. Energy Information Administration (EIA)

Figure 3-6: Electricity Generation from Available Natural Gas



The results—shown in Figure 3-6—indicate limited ability to add new natural gas generation under firm fuel contracts in the Northeast due to constraints on the existing system. This constraint has serious implications for grid reliability in the Northeast. These same regions are expected to experience faster winter than summer load growth as building heating electrifies, driven by state decarbonization goals and consumer preferences.[141] This trend in winter load growth will intensify pressure on existing pipelines and local gas delivery systems. While system upgrades are likely given ongoing investment in natural gas in the region, they are unlikely to materialize quickly enough to meet near-term winter demand.

3.2.2 Stakeholder engagement

We also conducted targeted outreach to key stakeholders in the natural gas and energy infrastructure sectors to ground our analysis in real-world experience. We spoke with or received written responses from five major organizations. These firms represent a cross-section of developers, equipment manufacturers, and EPCs actively involved in natural gas power plant development across the United States, particularly in the Northeast and Mid-Atlantic regions.

Our outreach focused on understanding the evolving role of natural gas in supporting grid reliability and industrial growth, as well as the industry's infrastructure constraints, permitting challenges, supply chain dynamics, and perspectives on complementary resource strategies. We asked a consistent set of questions across all interviews, covering topics such as data

141 "NERC Warns of Electricity Shortages in Winter Reliability Assessment." 2023. Cooperative.com. 2023.

center-driven demand, turbine availability, labor shortages, permitting timelines, and approaches to portfolio diversification.

Several key themes emerged:

- **Surging demand for gas turbines:** Developers reported a sharp increase in requests for flexible, high-availability natural gas projects driven by hyperscaler and industrial load growth. Many are designing modular plants to meet rapid deployment needs and accommodate load swings.
- **Severe supply chain constraints:** Turbines, transformers, and breakers were consistently cited as the most constrained components, with lead times extending into 2029. Developers are securing equipment years in advance through reservation agreements to avoid delays.
- **Labor shortages and workforce strain:** All stakeholders noted difficulty sourcing skilled labor, especially electricians and field service technicians. Large-scale data center and energy projects are competing for the same limited labor pool, particularly in regions with shallow workforce availability.
- **Lengthy and complex permitting processes:** Permitting timelines – especially for interconnection – were cited as a major barrier, with delays of three to five years or more in ISO-NE, PJM, and MISO queues. Developers emphasized the importance of early engagement with permitting agencies and local communities to mitigate delays.

3.3 Solar generation

Solar generation is limited to contribution during daytime hours

Solar generation has experienced a rapid decline in costs and expansion in capacity in recent years. Since 2010, the global average cost of utility-scale solar projects has fallen by roughly 87%.[142] Solar now has one of the lowest LCOE values among generation sources and produces emissions-free power. While its share of total generation remains modest,[143] solar is increasingly attractive because it requires no fuel and is cost-competitive with fossil options. More than 1 terawatt of solar capacity is currently in interconnection queues nationally -the largest of any single technology.[144]

Although solar contributes to decarbonization and affordability and supports daytime charging of storage resources, its direct role in maintaining resource adequacy is limited and expected to

142 International Renewable Energy Agency (IRENA). *Renewable Power Generation Costs in 2024.* Abu Dhabi: IRENA, July 2025. https://www.rinnovabili.it/wp-content/uploads/2025/07/IRENA-RENEWABLE-POWER-GENERATION-COSTS-IN-2024.pdf

143 U.S. Energy Information Administration (EIA). *"Table 1.01 — Net Generation from All Sources: Total (All Sectors), 1990 through Year to Date." Electric Power Monthly.* Washington, DC: EIA, accessed October 2025. https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=table_1_01

144 Lawrence Berkeley National Laboratory. *Queued Up: 2024 Edition.* Berkeley, CA: LBNL, April 2024. https://emp.lbl.gov/sites/default/files/2024-04/Queued%20Up%202024%20Edition_R2.pdf

decline over time. As shown in Figure 2-2, solar output aligns with daytime demand, but higher penetration shifts peak reliability risk to evening hours after sunset. Consequently, ELCC values for solar are currently relatively low and will decrease over time as solar capacity grows. Creative strategies, such as shifting electric-vehicle charging to daytime, [145]can slow, but not eliminate, this decline. Complementary nighttime and winter resources remain essential for a balanced and reliable grid.

3.4 Storage resources

Storage resources are energy limited and net energy consumers

Like solar generation, storage generation has experienced rapid cost declines and global growth. Since 2010, the global average cost of utility-scale storage projects has fallen by roughly 93%.[146] Storage resources are also being brought onto the system at scale with over 1 terawatt of storage capacity in queues nationally.[147]

Storage can play a role in maintaining resource adequacy. Its ELCC value varies by market but is typically between half and three quarters the values assigned to other dispatchable resources, like natural gas, coal, or nuclear. However, its contribution tends to decline as penetration increases and opportunities for intra-day arbitrage decrease. Storage is also less effective during multi-day or prolonged weather events.[148] Further, without sufficient excess generation for recharging, batteries may fully discharge before the event has ended. These challenges may be mitigated as long-duration storage resources become increasingly commercially viable and sufficient excess energy is brought onto the grid to recharge the resources.

Because of round-trip efficiency losses, storage is a net energy consumer, modestly increasing total system energy use. As with solar generation, balanced portfolio investments are needed to enable storage to successfully contribute to resource adequacy.

3.5 Onshore wind generation

Strong Midwestern resources, but far from coastal population hubs

Wind generation is strong in the winter in much of the country but often located far from population centers. Onshore wind has achieved significant cost declines and capacity growth in

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145 ZareAfifi, Fatemeh, Ricardo de Castro, and Sarah Kurtz. “Aligning Electric Vehicle Charging with the Sun: An Opportunity for Daytime Charging?” *The Electricity Journal* (2025). https://doi.org/10.1016/S1040-6190(25)00002-8

146 International Renewable Energy Agency (IRENA). *Renewable Power Generation Costs in 2024.* Abu Dhabi: IRENA, July 2025. https://www.rinnovabili.it/wp-content/uploads/2025/07/IRENA-RENEWABLE-POWER-GENERATION-COSTS-IN-2024.pdf

147 Lawrence Berkeley National Laboratory. *Queued Up: 2024 Edition.* Berkeley, CA: LBNL, April 2024. https://emp.lbl.gov/sites/default/files/2024-04/Queued%20Up%202024%20Edition_R2.pdf

148 ISO New England, *2021 Economic Study: Future Grid Reliability Study, Phase 1 (Report*, PDF file), July 29, 2022, https://www.iso-ne.com/static-assets/documents/2022/07/2021_economic_study_future_grid_reliability_study_phase_1_report.pdf.

recent years, though less dramatic than those seen in solar or storage. Since 2010, the global average cost of utility-scale wind projects has fallen by roughly 55%, driven by improvements in turbine technology—particularly taller hub heights and larger rotor diameters that capture higher wind speeds and improve capacity factors.[149]

Like solar, wind generation is weather-dependent and varies from hour to hour, resulting in ELCC values that are typically one-half to one-third of those for thermal generators. Wind output tends to be strongest at night and during winter months, creating natural complementarities with solar resources that peak during the day and in summer.

However, the best onshore wind resources are concentrated in the Great Plains and Upper Midwest,[150] far from major load centers such as New York, Boston, Washington D.C., and coastal California.[151] Meeting growing demand in these regions with onshore wind would require either relying on locally sited projects with lower capacity factors or making substantial new transmission investments to deliver power from high-resource areas to population centers.

3.6 CRA analysis of 2024 Dominion Integrated Resource Plan

The implications of relying on these legacy domestic technologies alone to meet load growth can be illustrated by examining the resource planning in a region with particularly high load growth – Dominion Virginia.

Dominion Virginia powers the largest data center market globally, more than five times larger than the next largest domestic market.[152] As a result of substantial investments in this sector, it is experiencing some of the fastest load growth in the country, with PJM projecting up to a 6.3% compound annual growth rate (CAGR) in peak demand in the Dominion zone over the next decade.[153] This is placing pressure on the system's ability to reliably and affordably meet growing demand – as reflected in warnings from the Department of Energy's recent reliability study,[154]

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149 International Renewable Energy Agency (IRENA). *Renewable Power Generation Costs in 2024.* Abu Dhabi: IRENA, July 2025. https://www.rinnovabili.it/wp-content/uploads/2025/07/IRENA-RENEWABLE-POWER-GENERATION-COSTS-IN-2024.pdf

150 Wiser, R., Millstein, D., Hoen, B., Bolinger, M., Gorman, W., Rand, J., Barbose, G. L., Cheyette, A., Darghouth, N. R., Jeong, S., Mulvaney Kemp, J., O'Shaughnessy, E., Paulos, B., & Seel, J. (2024, August). *Land-Based Wind Market Report: 2024 Edition*. Lawrence Berkeley National Laboratory. https://eta-publications.lbl.gov/sites/default/files/2024-09/land-based_wind_market_report_2024_edition.pdf

151 U.S. Department of Energy. (2023, October). *National Transmission Needs Study*. Washington, DC. https://www.energy.gov/sites/default/files/2023-12/National%20Transmission%20Needs%20Study%20-%20Final_2023.12.1.pdf

152 Joint Legislative Audit and Review Commission. *Data Centers in* Virginia. 2024. https://jlarc.virginia.gov/pdfs/reports/Rpt598.pdf.

153 PJM Resource Adequacy Planning Department. *PJM Long-Term Load Forecast Report*. 2025. https://www.pjm.com/-/media/DotCom/library/reports-notices/load-forecast/2025-load-report.pdf

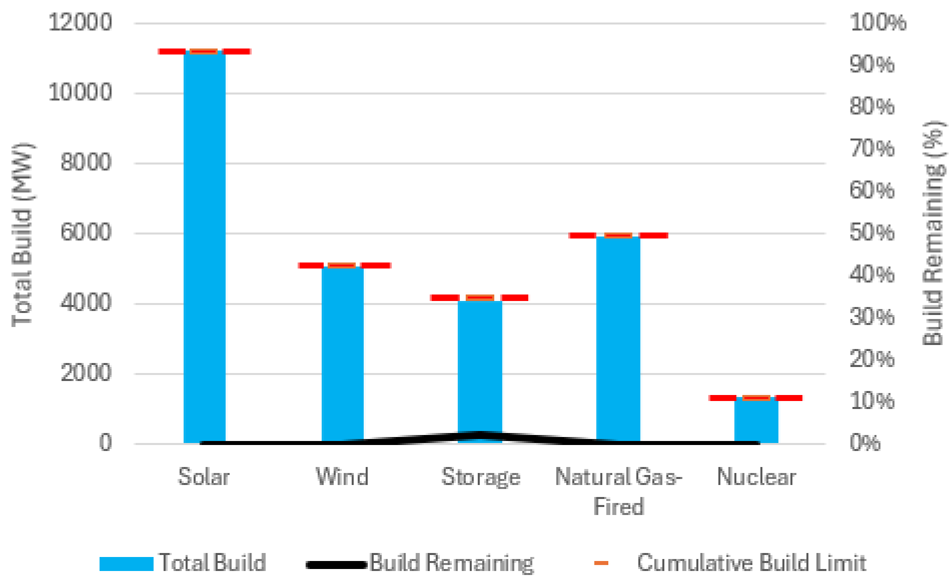
154 U.S. Department of Energy. *Report on Evaluating U.S. Grid Reliability and Security.* Washington, DC: U.S. Department of Energy, July 2025.

sharp spikes in capacity prices PJM-wide,[155] and failure to clear sufficient generating capacity in the Dominion zone to meet its reliability requirement in the 2025/2026 PJM Capacity Auction.[156]

This is further reflected in Dominion's 2025 Integrated Resource Plan, the long-term strategic planning document required by Virginia law to evaluate the need for additional generating resources. Dominion's IRP contemplates substantial investment to meet growing load demand: including 5.9 GW of natural gas, 12 GW of solar, 1.3 GW of small modular nuclear reactors, 4.1 GW of energy storage, 60 MW of onshore wind, and 2.6 GW OSW additional to its ongoing 2.6 GW CVOW project.

Most critically, as shown in Figure 3-7, Dominion proposes to develop all resources at their maximum annual build limits, with the exception of solar distributed energy (DERs) and storage resources which have minimal room for additional growth. These build limits represent the amount of a generation type that Dominion deems possible to build in a specific year given land, labor, capital, and supply chain constraints.

Figure 3-7: 2024 Dominion Integrated Resource Plan for 2029-2039



By relying on existing technologies alone – principally solar, storage, natural gas – Dominion would be unable to maintain reliability under this pace of load growth. Even with the meaningful build-out charted in Dominion's IRP, which includes additions of OSW and next-generation nuclear technology, Dominion still anticipates a shortfall of firm capacity, requiring up to 3.3 GW

155 PJM. *2026/2027 Base Residual Auction Report*. July 22, 2025. For public use. PJM. Accessed August 18, 2025. https://www.pjm.com/-/media/DotCom/markets-ops/rpm/rpm-auction-info/2026-2027/2026-2027-bra-report.pdf.

156 PJM. *2025/2026 Base Residual Auction Report*. July 22, 2025. For public use. PJM. Accessed August 18, 2025. https://www.pjm.com/-/media/DotCom/markets-ops/rpm/rpm-auction-info/2025-2026/2025-2026-base-residual-auction-report.pdf.

of annual capacity purchases from the PJM market or bilateral contracts. Without additional phases of CVOW, that requirement could rise to 3.98 GW, a 20% increase above Dominion's stated planning cap.[157] A capacity purchase means that Dominion would acquire the capacity needed to maintain the resource adequacy of its system from a third-party, either within the PJM capacity market or through a bilateral contract. These results indicate that the most aggressive feasible build-out of traditional resources alone could not reliably support the level of growth.

This underscores the challenges of meeting modern load growth, driven by electrification, data centers, and industrial reshoring, with legacy technologies alone. **OSW** – **working in concert with natural gas, storage, and nuclear** – **represents a promising new pathway reliability and affordability.** It is not a replacement for legacy resources, but without it, Dominion's system would face a widening reliability gap and rising dependence on external capacity purchases. Next, we provide a detailed review of the resource adequacy outlook of markets across the country and describe the role that OSW can play in solving these challenges.

Examining the resource adequacy contributions of OSW by the market

This section reviews the resource adequacy outlook of key American and international wholesale electricity markets, focusing on recent and projected load growth, and shifts in resource mix. We then quantify the potential contribution of OSW to meeting these reliability needs.

4.1 PJM

Load growth and future resource outlook

PJM is currently facing significant resource adequacy challenges that are expected to increase, driven by unprecedented load growth and a structural shift in when system risk occurs. According to PJM's 2025 Load Forecast Report, summer peak demand is expected to increase by 55 GW and winter peak by 62 GW over the next decade.[158] This projected load growth is among the highest in the United States, with the majority attributed to large-scale data center development, particularly in Northern Virginia, supplemented by industrial load growth and electrification. Data center loads are characterized by significant demand levels relative to other large customers (e.g., hundreds to thousands of MWs for each data center), high load factors (i.e., near-constant demand at maximum levels), and stringent reliability requirements to support

157 Ibid.

158 PJM Interconnection, *2025 Long-Term Load Forecast Report*, Valley Forge, PA: PJM, January 2025, Retrieved from PJM website, https://www.pjm.com/-/media/DotCom/library/reports-notices/load-forecast/2025-load-report.pdf.

operations, many of which are critical to health and safety such as healthcare administration, air traffic control, and financial services.

Compounding resource adequacy concerns, PJM has recently experienced thermal resource retirements due to economics, age, and public policy. The PJM region has struggled to develop new resources that possess the operating characteristics necessary to replace the essential reliability properties provided by the retired resources. Between 2012 and 2022, 47.2 GW of resources retired from the system. Almost all of these resources were dispatchable resources like coal, diesel, and natural gas.[159] Entry from new generation resources has been slower than expected and has not kept pace with retirements, particularly on an accredited capacity basis.

Further, the pipeline of new resources in the generator interconnection queue is heavily skewed toward intermittent and energy-limited technologies: 94% of resources in PJM's interconnection queue are solar or battery storage. PJM also continues to face a long and growing interconnection queue – the slowest among all US RTOs/ISOs.[160] However, PJM has adopted reforms to prioritize resources which are farther along in the development project (i.e., transitioning from "first-come, first-served" to "first-ready, first-served" and adopted cluster interconnection studies to streamline engineering analysis).[161] PJM also created one-time fast track to bring high ELCC resources on to the system quickly to reliably accommodate the near-term load growth.[162]

Emerging resource adequacy challenges and risks

Although PJM has reformed its queue process and prioritized reliability-critical projects, the emerging grid tightness, including a potential for shortfalls, has raised red flags. PJM's Board of Governors published a letter highlighting concerns around the pace of load growth and resulting resource adequacy concerns.[163]

Due to these tightening supply demand conditions, PJM's capacity prices have seen a sharp uptick in recent years (shown in Figure 4-1). PJM's July 2025 capacity auction cleared at a

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159 PJM Interconnection, *Energy Transition in PJM: Resource Retirements, Replacements, and Risks*, Valley Forge, PA: PJM, August 2023, Retrieved from the PJM website: *Energy Transition in PJM: Resource Retirements, Replacements, and Risks* (2023), https://www.pjm.com/-/media/DotCom/library/reports-notices/special-reports/2023/energy-transition-in-pjm-resource-retirements-replacements-and-risks.ashx.

160 Bolinger, M., Seel, J., & Wiser, R. *Queued Up: 2024 Edition*, Berkeley, CA: Lawrence Berkeley National Laboratory, April 2024, Retrieved from the Lawrence Berkeley National Laboratory website https://emp.lbl.gov/sites/default/files/2024-04/Queued%20Up%202024%20Edition_1.pdf.

161 Federal Energy Regulatory Commission, *Order Accepting Tariff Revisions Subject to Condition, PJM Interconnection, L.L.C.*, Docket Nos. ER22-2110-000 and ER22-2110-001 (issued November 29, 2022), Accession No. 20221129-3092.

162 Federal Energy Regulatory Commission, *Order Approving Fast-Track Interconnection Proposals (Reliability Resource Initiative, Docket No. ER25-712-000)*, issued February 11, 2025 (reported in *Utility Dive*, February 12, 2025).

163 PJM, *Reimplementation of Critical Issue Fast Path Process of Large Load Additions*, 20250808-pjm-board-letter-re-implementation-of-critical-issue-fast-path-process-for-large-load-additions.pdf.

historically high price, which was an administratively determined price cap.[164] In the prior auction, two zones, Baltimore Gas & Electric and Dominion, marginally failed to meet their resource adequacy requirement[165] and cleared at the maximum price, $466.35 and $444.26 /MW-day, respectively.[166] The fact that these zones cleared at a higher prices than the rest of PJM revealed transmission constraints that limited their ability to import electricity from the broader market.

Reinforcing these concerns, the US Department of Energy (DOE)'s July 2025 reliability study identified PJM as being at elevated risk of load shedding, with Virginia and Maryland particularly exposed.[167] The assumptions underlying this study have been debated, with various experts arguing that the DOE's analysis may have overstated future load growth and/or understated the grid's ability to interconnect new resources – particularly in light of recent emergency measures taken by PJM,[168] MISO,[169] and other system operators.[170] Nonetheless, both the report and subsequent commentary highlight several key points regarding the emerging resource adequacy challenges: load growth is placing increasing stress on resource adequacy, PJM faces greater strain than many other regions, and these challenges can be addressed only if new generating resources (e.g., natural gas, OSW, onshore wind, solar, and storage etc.) are added to the system at a pace that keeps up with demand growth.

164 Report PJM Interconnection, *2025/2026 Base Residual Auction Report*, July 30, 2024, PJM Interconnection, Public Use.

165 PJM Interconnection, "PJM Capacity Auction Procures Sufficient Resources to Meet RTO Reliability Requirement," *PR Newswire*, July 30, 2024.

166 PJM Interconnection, *2025/2026 Base Residual Auction Report* (July 30, 2024).

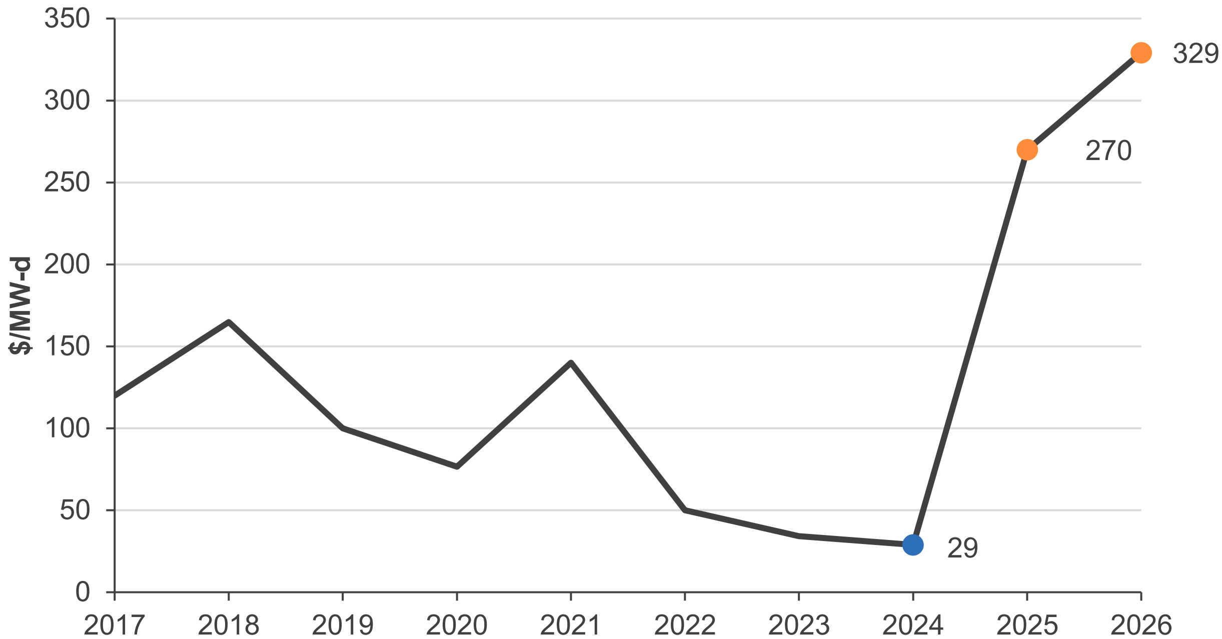
167 U.S. Department of Energy, 2025, *Report on Evaluating U.S. Grid Reliability and Security, DOE final report*, July 7, 2025, (Washington, DC: U.S. Department of Energy).

168 PJM Interconnection, "PJM Chooses 51 Generation Resource Projects To Address Near-Term Electricity Demand Growth," news release (Valley Forge, PA, May 2, 2025), PJM Inside Lines, https://insidelines.pjm.com/pjm-chooses-51-generation-resource-projects-to-address-near-term-electricity-demand-growth/ .

169 Midcontinent Independent System Operator, Inc., *"In Our ERAS Era: MISO Launches Temporary Process to Accelerate Critical Power Projects,"* MISO Matters (media blog), August 7, 2025.

170 Matthias Fripp and Brendan Pierpont, "Energy Department's Flawed Grid Study Props Up Expensive, Zombie Power Plants," Utility Dive (opinion), July 24, 2025

Figure 4-1: PJM Capacity Prices[171]



In light of these challenges, PJM recently reformed its approach to capacity accreditation to better incentivize and reward generators which can solve the emerging challenges. PJM adopted a marginal ELCC accreditation approach, switched its planning metric from LOLE to EUE, and began explicitly modeling cold-weather outages in its ELCC evaluations. As a result, from these reforms and higher load growth in winter months, PJM's resource adequacy risks are shifting from summer to winter. In one July 2024 LOLE study, winter months accounted for 87% of the EUE risk.[172] This dynamic was illustrated in December 2022 during winter storm Elliott. During this storm, extreme cold and rapid temperature swings drove simultaneous spikes in load and widespread generator outages. Although PJM avoided load shedding during the event, the system was severely stressed, and PJM had to rely on emergency procedures to maintain reliability.[173] Winter storm Elliott revealed the grid's vulnerability to common-mode failures, such as natural gas supply constraints and cold weather-related mechanical failures and underscored the need to address the system's winter resource adequacy risks.

171 PJM *2026/2027 Base Residual Auction Report*, https://www.pjm.com/-/media/DotCom/markets-ops/rpm/rpm-auction-info/2026-2027/2026-2027-bra-report.pdf.

172 PJM Interconnection, LLC, *ELCC Education:* Presentation to the ELCC Stakeholder Task Force, December 5, 2024, https://www.pjm.com/-/media/DotCom/committees-groups/task-forces/elccstf/2024/20241205/20241205-item-07---informational-only-posting---data-transparency---elcc-education-from-special-planning-committee-sessions-on-february-16-and-21-2024.pdf.

173 PJM Interconnection, *Winter Storm Elliott: Event Analysis and Recommendation Report*, July 17, 2023, accessed July 9, 2025, https://www.pjm.com/-/media/DotCom/library/reports-notices/special-reports/2023/20230717-winter-storm-elliott-event-analysis-and-recommendation-report.ashx.

How OSW can support resource adequacy in PJM

OSW is well-positioned to help address some of PJM's capacity shortages, particularly in the eastern zones; though, the level of load growth in PJM likely outsprings the ability of any single technology, including OSW, to solve. OSW off the mid-Atlantic seaboard offers strong performance over the entire year, but its highest generation is during evening and winter hours,[174] the periods of greatest stress identified in PJM's indicative ELCC studies.[175]

This shift toward winter reliability risk is driven largely by natural gas supply constraints during extreme cold periods, growing winter load, and the effective contribution of solar generation. OSW production is at its greatest during these same periods, creating a complementary relationship between OSW and natural gas units. By drawing on alternative fuel sources OSW can mitigate the risk of natural gas outages in winter. Natural gas resources can generate electricity when OSW generation is low or unavailable. As such, OSW and natural gas resources can offset each other's availability gaps and improve resilience by increasing fuel diversity.

As a result of this steady annual performance and peak winter performance, OSW has been assigned high ELCC values in the most recent PJM auction. In PJM's July 2025 capacity auction for 2026/2027 (See Figure 4-2), it received a **69% ELCC value**, outpacing some dispatchable resources.[176] OSW's accreditation surpassed the that of 4-hour (50%), 6-hour (58%), and 8-hour (62%) storage. Among storage resources, only 10-hr storage (72%) surpassed the accreditation given to OSW.

OSW's accreditation surpassed the 60% ELCC value assigned to gas-only combustion turbines (CTs). While these CTs have historically been relied on to meet system peaks, they face growing vulnerabilities due to a shift to system tightness in the winter months, when natural gas may be unavailable due to pipeline constraints or competition for fuel from space heating demand and service disruptions on gas pipelines.

OSW's ELCC value was also relatively competitive with other types of thermal resources – 93% that of gas combined cycle (CC) turbines and 88% that of CTs with dual-fuel capability. However, it has a substantially lower accreditation when compared to nuclear (ELCC of 95%) and coal (ELCC 83%), but these types of resources are not being meaningfully explored as

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174 Rosencrans, David, Julie Lundquist, Mike Optis, Alex Rybchuk, Nicola Bodini, and Michael Rossol, "Seasonal Variability of Wake Impacts on US Mid-Atlantic Offshore Wind Plant Power Production," *Wind Energy Science* 9, no. 3 (2024): 555–83, https://doi.org/10.5194/wes-9-555-2024.

175 PJM Interconnection, LLC, *ELCC Education (February 2024)*, *Presentation to the ELCC Stakeholder Task Force*, December 5, 2024, https://www.pjm.com/-/media/DotCom/committees-groups/task-forces/elccstf/2024/20241205/20241205-item-07---informational-only-posting---data-transparency---elcc-education-from-special-planning-committee-sessions-on-february-16-and-21-2024.pdf.

176 PJM Interconnection, LLC., *2026/2027 BRA ELCC Class Ratings,* July 2024, https://www.pjm.com/-/media/DotCom/planning/res-adeq/elcc/2026-27-bra-elcc-class-ratings.pdf.

near-term new capacity resources nationally or in PJM. Collectively, they represent less than 1% of resources in national interconnection queues.[177] While nuclear is likely to expand as small modular reactors become commercially viable in the late 2020s to mid-2030s,[178] this timing is later than needed to support much of the data center growth, which is concentrated before 2030.[179]

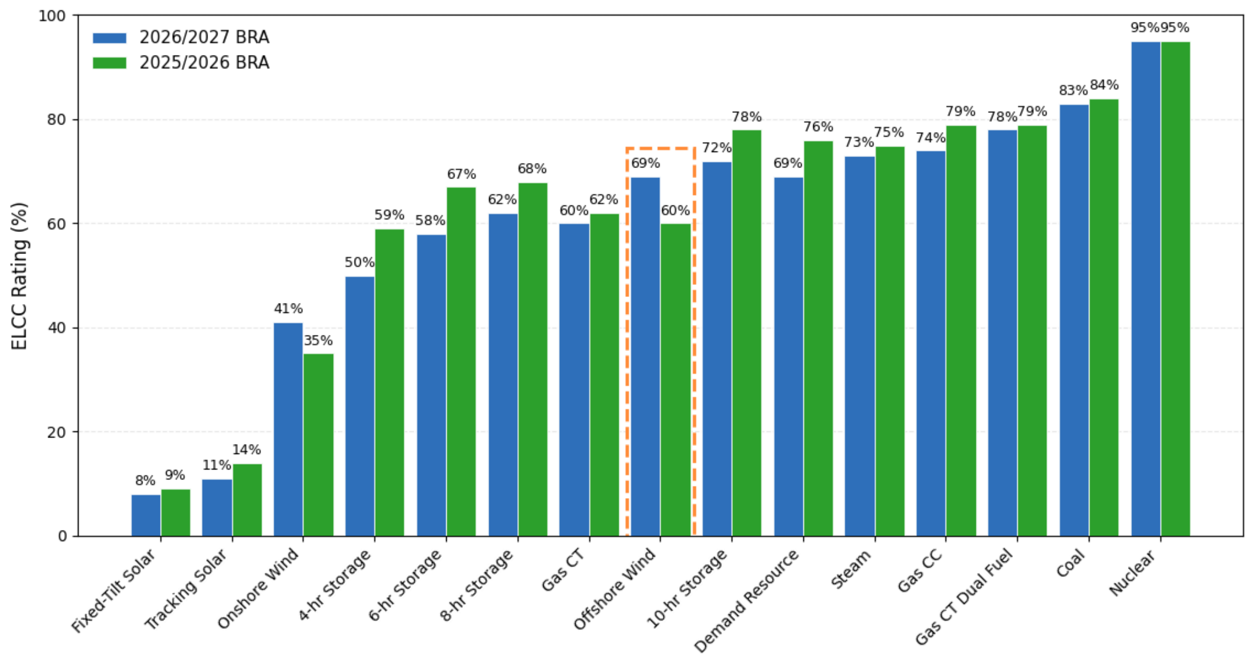
Onshore and offshore wind were the only resource classes to see an ELCC increase between the last two capacity auctions (i.e., the 2025/2026 to the 2026/2027 auctions), while ELCCs for all other resource types either remained flat or declined. The steepest drops occurred for solar, and 4-hour battery storage indicating that these resources have largely met daytime needs in the summer. Solar resources have successfully shifted the most critical risk periods to late summer evenings and the winter. Both onshore and offshore wind, which produce during these emerging high-risk hours, saw its ELCC rise by more than 15% between the two capacity auctions. This further highlights the need to bring resources with strong cold-weather generation, particularly those that can complement the natural gas fleet.

177 David Rosencrans, Julie Lundquist, Mike Optis, Alex Rybchuk, Nicola Bodini, and Michael Rossol, "Seasonal Variability of Wake Impacts on US Mid-Atlantic Offshore Wind Plant Power Production" *Wind Energy Science* 9, no. 3 (2024): 555–83, https://doi.org/10.5194/wes-9-555-2024.

178 U.S. Department of Energy, *Advanced Small Modular Reactors (SMRs),* Office of Nuclear Energy, accessed August 17, 2025.

179 PJM Interconnection, *2025 Long-Term Load Forecast Report,* Prepared by the Resource Adequacy Planning Department, January 24, 2025.

Figure 4-2: PJM ELCC Ratings[180]



In addition to relatively high ELCC values, OSW offers important locational benefits. OSW resources are concentrated along the Atlantic coast, near some of PJM's most constrained and rapidly growing load centers. Currently, the only OSW project in the interconnection queue in PJM is the **Coastal Virginia Offshore Wind** (CVOW) project, being developed by Dominion Energy to serve customers in the Dominion zone.[181] Other projects are being developed and/or planned in Maryland[182] and New Jersey,[183] but have not yet cleared the interconnection queue.

As described above, Dominion is among the most stressed in PJM due to substantial load growth, primarily from data centers. In Dominion Energy Virginia's most recent Integrated Resource Plan, it planned to build all generating types near the build limits – the amount of a given resource type Dominion deemed feasible to build in a single year – for almost all technology types.[184] This indicates Dominion is counting on all technology types, including OSW, to meet its growing energy and capacity needs, and any delay of bringing a new resource would

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180 PJM, *ELCC Class Ratings for the 2025/2026 Base Residual Auction*, https://www.pjm.com/-/media/DotCom/planning/res-adeq/elcc/2025-2026-bra-elcc-class-ratings.pdf.

181 Augustine, Chad, Lea Bilenky, Erin Baker, John F. Bistline, Wesley Cole, and Paul Donohoo-Vallett, *Offshore Wind Resource, Cost, and Energy Modeling for the National Transmission Needs Study,* (Golden, CO: National Renewable Energy Laboratory (NREL), February 2024), https://docs.nrel.gov/docs/fy24osti/90525.pdf.

182 Offshore Wind Maryland. "Home – Offshore Wind Maryland: Powering Maryland with Offshore Wind." Accessed October 2025. https://offshorewindmaryland.org/

183 Offshore Wind NJ. "Home – Offshore Wind NJ." Accessed October 2025. https://www.offshorewindnj.org/

184 Dominion Energy, *2024 Integrated Resource Plan* (Richmond, VA: Dominion Energy, 2024), https://www.dominionenergy.com/-/media/content/about/our-company/irp/pdfs/2024-irp-w_o-appendices.pdf.

create capacity shortfalls.[185] By delivering clean, highly-accredited generation capacity directly into a high-demand region, CVOW is well-positioned to provide multiple benefits to the Dominion zone: contributing to resource adequacy in the zone and region, supporting economic development, and supporting state policy objectives and customer-driven decarbonization targets.

One potential concern for investing in OSW is the potential for the ELCC value to decline over time. PJM published informational ELCC forecasts for OSW, showing a decline from 56% in the 2027/2028 delivery year to 20% by the 2034/2035 delivery year.[186] These forecasts are useful indications of the directional trends of ELCCs and are used by many resource planners during their Integrated Resource Planning and other planning efforts. However, they must be evaluated carefully when assessing and projecting the reliability value of many resources, including OSW, to the system.

PJM uses a marginal ELCC methodology, rather than an average ELCC approach, to send forward-looking market signals about which technologies are best positioned to address emerging reliability risks. Because PJM employs a marginal ELCC approach to capacity accreditation, most technologies – including OSW – are projected to have lower accreditation as their penetration grows. Importantly, such declines reflect a declining contribution of additional resources, rather than a decline in reliability benefit of existing resources. Further, such declines in marginal ELCC only occur if significant OSW capacity is actually built and succeeds in mitigating the PJM' periods of system stress; absent this build-out, marginal ELCC values for OSW will likely remain relatively high.

Additionally, PJM's ELCC forecasts for 2034/35 delivery year are derived from its 2024 load forecast and an assumed future resource mix that may not materialize or align with the system's future reliability needs. Since the time of this ELCC study, PJM has significantly increased its load forecast – particularly in response to widespread data center development. Even under the older, lower load assumptions, PJM had to further reduce the load forecast used in this ELCC study in order for its assumed resource mix to achieve the desired "1-in-10" loss of load expectation baseline. As such, PJM's study projected an 8.2 GW capacity shortfall in 2034/2035. This suggests that the modeled system was already short capacity, even under this lower level of load growth. If a meaningful capacity shortfall like this were to occur, all

185 Oliver Stover, *Direct Testimony of Oliver Stover on Behalf of Microsoft Corporation, In re: Virginia Electric and Power Company's Integrated Resource Plan Filing Pursuant to Va. Code § 56-597 et seq., Case No. PUR-2024, 00184,* Commonwealth of Virginia State Corporation Commission, February 28, 2025, https://www.scc.virginia.gov/docketsearch/DOCS/865t01!.PDF.

186 PJM Interconnection, LLC, *Supplementary Information: ELCC Class Ratings,* Planning Committee Meeting, August 6, 2024, https://www.pjm.com/-/media/DotCom/committees-groups/committees/pc/2024/20240806/20240806-item-08---supplementary-information---elcc-class-ratings.pdf.

resources including OSW would likely have higher resource adequacy contributions than are reflected in the projected ELCC values.

In summary, PJM faces emerging reliability challenges in meeting substantial and near-term load growth. Addressing these challenges will require a diverse portfolio of resources capable of delivering in both summer and winter. OSW aligns closely with PJM's evolving risk profile. It can support the mitigation of natural gas generator outage risks in winter, deliver strong winter performance and moderate but still material summer performance, and offers strategic siting advantages near high-growth coastal load centers. OSW's ELCC value lead among non-dispatchable resources and is competitive with many dispatchable resources, particularly those that can be developed in the near-term. While its marginal ELCC value is projected to decline as more wind is deployed, such a decline simply reflects the diminishing incremental benefit of additional capacity, not a reduction in the reliability value of existing OSW resources. Further, these declines will only occur if OSW is built at meaningful scale and successfully shift system risk into periods of lower output.[187]

As PJM navigates rapid load growth, interconnection bottlenecks, and rising winter risks, OSW is well positioned to play a central role in maintaining reliability. Failure to bring new resources, including OSW, onto the system at scale will likely leave PJM exposed to growing capacity shortfalls. Through CVOW and subsequent OSW projects, OSW working in concert with broader generation and transmission investments can play a decisive role in ensuring PJM can reliably and affordably accommodate substantial near- and medium-term load growth.

4.2 NYISO

Load growth and future resource outlook

NYISO is also in the midst of a structural shift in its periods of reliability risk. While New York has historically been a summer-peaking system, electrification of heating is driving rapid growth in winter demand. In its load forecast documented in the 2025 Gold Book,[188] NYISO projects the current summer peak of 31 GW to shift to a winter peak approaching 50 GW by 2050, adding roughly 19 GW of new demand, most of it in the winter months. As a result, NYISO is projected to transition from a summer-peaking, summer-constrained system to a winter-peaking, winter-constrained system. This shift will require a reassessment of the resource mix to ensure reliable

[187] The exact penetration of offshore wind is not reported by PJM.

[188] New York Independent System Operator, *2025 Load & Capacity Data Report (Gold Book)* (NYISO, 2025), PDF, https://www.nyiso.com/documents/20142/2226333/2025-Gold-Book-Public.pdf.

performance during prolonged cold periods, particularly considering fuel availability risks for natural gas-fired generation during severe weather.[189]

The transition toward winter load is driven by electrification of heating and transportation, jointly driven by consumer preference and in pursuit of goals set by New York's Climate Leadership and Community Protection Act (CLCPA).[190] The CLCPA mandates an 85% reduction in statewide greenhouse gas emissions and has spurred a range of policy actions to support decarbonization. One such policy is the All-Electric Buildings Act, which requires new buildings to use electric energy sources instead of fossil fuels—helping to accelerate the transition envisioned by the CLCPA.[191] As a result of these policy-driven dynamics, Downstate New York—particularly New York City (Zone J), Long Island (Zone K) and the Lower Hudson Valley (Zones G through I)—is expected to see the fastest load growth in the state, reflecting both higher population density and higher rates of heat pump and EV adoption. These regions already have transmission import constraints and have limited available feasible sites for large-scale onshore renewables, amplifying the need for local, winter-capable capacity.[192]

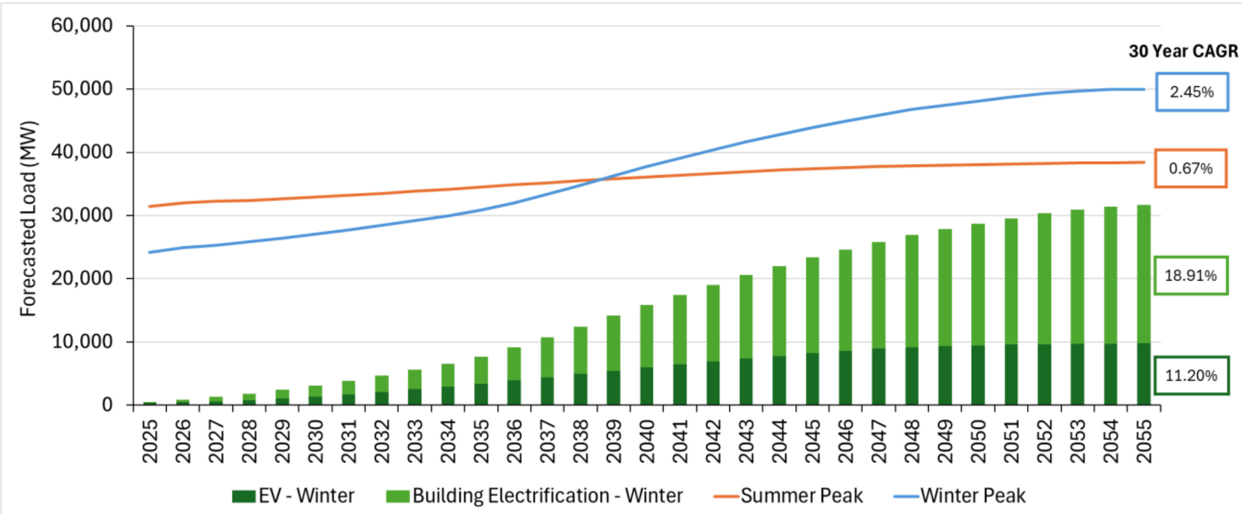
189 New York Independent System Operator, *New York's Winter Grid Reliability Challenges: Changing conditions impacting supply and demand*, https://www.nyiso.com/documents/20142/23494579/NYs-Winter-Grid-Reliability-Challenges-10-29-24.pdf/882ca1e6-f07e-fd97-fc66-fd66c4832828?t=730236889655.

190 *Climate Leadership and Community Protection Act,* N.Y. State S.6599/A.8429, 2019 Leg., Reg. Sess. (N.Y. 2019)S.6599/A.8429 (2019), codified at N.Y. Envtl. Conserv. Law § 75-0101 et seq. and N.Y. Pub. Serv. Law § 66-p., https://climate.ny.gov/Our-Climate-Act.

191 New York State, *All-Electric Buildings Act,* S.9405-A/A.10439-A, 2022 Leg., Reg. Sess. (N.Y. 2022) (codified in part at N.Y. Energy Law § 11-109), https://www.nysenate.gov/legislation/bills/2021/S9405.

192 New York State Public Service Commission, *Order on Energy Storage Deployment Program Review*, Case 18-E-0130, Albany, NY: New York State Public Service Commission, December 19, 2024.

Figure 4-3: NYISO Forecasted Summer and Winter Peak Demand with Electrification Impacts (2025–2055)[193]



Emerging resource adequacy challenges

The current NYISO system is resource adequate with a 2025 Installed Reserve Margin (IRM) of 24.4%.[194] However, sustaining reliability in the face of projected load growth, particularly during winter, will require the addition of new capacity resources. Like other ISOs, NYISO faces persistent challenges in delivering planned projects to commercial operation due to generator interconnection queue bottlenecks, permitting timelines, and supply chain constraints. Through August, only 12 new projects have entered NYISO's interconnection queue in 2025, while 103 projects have been withdrawn. This imbalance underscores the risk that planned resources may not materialize at the scale or pace required to maintain resource adequacy.[195]

NYISO's resource mix is also transitioning. The current queue composition is 48% battery storage, 22% solar, and just 10% OSW.[196] To fill the emerging gap of dispatchable resources, NYISO plans to replace the reliability attributes of fossil-fuel generators slated for retirement to meet zero-emissions goals with group of technologies known as Dispatchable Emissions-Free Resources (DEFRs). NYISO identified long-duration batteries, small modular nuclear reactors,

[193] NYISO (New York Independent System Operator), 2025 Gold Book: Public (Albany, NY: NYISO, 2025), https://www.nyiso.com/documents/20142/2226333/2025-Gold-Book-Public.pdf.

[194] New York State Reliability Council, *NYCA Installed Capacity Requirement for the Period May 2025 through April 2026: Technical Study Report* (December 6, 2024), PDF, https://www.nysrc.org/wp-content/uploads/2024/12/2025-IRM-Study-Technical-Report_Final_12062024_clean.pdf.

[195] New York Independent System Operator, *NYISO Interconnection Queue* [Excel spreadsheet], accessed August 11, 2025, https://www.nyiso.com/documents/20142/1407078/NYISO-Interconnection-Queue.xlsx/ff0e2005-e8d3-e75d-3e81-fa7027a52685.

[196] New York Independent System Operator, *NYISO Interconnection Queue* [Excel spreadsheet], accessed August 11, 2025, https://www.nyiso.com/documents/20142/1407078/NYISO-Interconnection-Queue.xlsx/ff0e2005-e8d3-e75d-3e81-fa7027a52685.

hydrogen-powered generators, and fuel cells as potential DEFRs. While these technologies are promising, they are not yet commercially available and thus have meaningful uncertainty around their timeline and cost to bring onto the grid.[197] Given these emerging challenges, NYISO's future resource mix may warrant closer review to assess whether the future fleet will provide sufficient generation during winter stress periods.

Capacity prices & transmission constraints

While NYISO capacity prices have remained stable, zonal pricing shows significant divergence. In the Summer 2025 Strip Auction,[198] New York City capacity cleared at $13.38/kW-month - nearly three times the rest-of-state price of $4.70/kW-month. This price spread reflects interzonal transmission constraints and localized reliability stress in the downstate zones. This localized stress in downstate zones may worsen in the near-term. Much of the generation in these zones is fossil-fueled,[199] and retirements driven by state environmental policies and load growth are both concentrated in these regions. These factors will only tighten capacity conditions further.

To mitigate resource adequacy risks and meet the state's decarbonization mandates, New York is pursuing major transmission investments. For example, the $4.5 billion Champlain-Hudson Power Express (CHPE), a 1,200 MW HVDC line, will bring clean hydropower from Québec into Astoria by 2026. However, this investment is likely insufficient to resolve downstate transmission constraint alone. NYISO is evaluating further transmission projects to resolve these constraints. Even with these projects, transmission congestion is likely to remain a key challenge in maintaining the reliability of the downstate portion of the system.

State policy driven retirements

Downstate zones face heightened reliability risk as aging peaker plants retire in response to state regulations -1,027 MW were retired by mid-2023, with another 590 MW scheduled to go offline in 2025.[200] About 500 MW from four units have been extended to 2027 to maintain summer reliability, but winter will be more materially impacted. In a dynamic similar to PJM, NYISO's Gas Constraints Study found that lower temperatures during extreme cold weather could reduce gas-fired generation availability by as much as 8.6 GW, shifting 81% of reliability

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197 NYISO, *2023–2042 System & Resource Outlook* (Rensselaer, NY: NYISO Electric System Planning Working Group, July 2024), accessed August 15, 2025, https://www.nyiso.com/documents/20142/46037414/2023-2042-System-Resource-Outlook.pdf.

198 New York Independent System Operator, *Capability Period (Strip) Auction Results*, 2025, http://icap.nyiso.com/ucap/public/auc_view_strip_detail.do.

199 New York Independent System Operator, *2025 Load & Capacity Data Report (Gold Book)* (NYISO, 2025), PDF, https://www.nyiso.com/documents/20142/2226333/2025-Gold-Book-Public.pdf.

200 New York Independent System Operator, *NYC Reliability Solution Fact Sheet*, Albany, NY: NYISO, November 2023, PDF file, accessed August 11, 2025, https://www.nyiso.com/documents/20142/39103148/NYC-Reliability-Solution-Fact-Sheet.pdf/169f336c-730f-6bd3-67c2-22037fcee56f?t=1700503745709.

risk to the winter months. [201] This underscores the importance of replacing retiring capacity with resources that can generate electricity in winter, particularly during extreme cold periods.

Evolving approaches to capacity accreditation

Since 2024, NYISO has used the Marginal Reliability Improvement (MRI) method to assess the reliability contribution of various resources. While it refers to these accreditation values as Capacity Accreditation Factors (CAFs), they are conceptually equivalent to a marginal ELCC. Under the current framework, only solar, storage, and wind resources receive CAF rating. Thermal resources contribution to resource adequacy is measured by the Equivalent Demand Forced Outage Rate (EFORd) – the measure of unplanned equipment outages including both full outages and partial derates.[202]

In the 2024 State of the Market,[203] the independent market monitor (MMU) raised concerns around NYISO's approach to capacity accreditation. NYISO's MRI model simulates load and renewable generation separately, meaning that it cannot capture that load and renewable generation are driven by the same underlying conditions – weather. Based on this separate treatment, the current modeling approach fails to accurately capture the reliability benefits of solar generation since it does not reflect the correlation of solar generation and demand. The authors extend the concern to wind generation and highlight that neglecting the correlations between wind generation and load likely undervalues wind's contribution during very cold, high load hours.[204]

Similarly, the MMU raised concerns that NYISO was not modeling sufficiently fuel-limitations during cold weather events. NYISO does simulate higher level of outages when load is very high, which could lead to fuel shortages, in its planning reserve margin targets and CAF modeling.[205] As such, these correlated outages are not reflected in thermal accreditation, and the thermal accreditation values used in NYISO overstate their reliability benefit since they do not capture the impact of the correlated outage events.

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[201] New York State Reliability Council (NYSRC), Gas Constraints Modeling Whitepaper: 2024–2025 IRM Study, White paper, ICS Meeting No. 290, June 5, 2024, PDF file, https://www.nysrc.org/wp-content/uploads/2024/06/Gas-Constraints-Modeling-Whitepaper-Final.pdf

[202] North American Electric Reliability Corporation (NERC), *2023 GADS Data Reporting Instructions: Appendix F: Performance Indexes and Equations*, January 2023, accessed August 18, 2025, https://www.nerc.com/pa/RAPA/gads/DataReportingInstructions/Appendix_F_Equations_2023_DRI.pdf.

[203] Potomac Economics, *2024 State of the Market Report for the New York ISO Markets*, Prepared for NYISO Market Monitoring Unit, May 2025, PDF file, accessed August 11, 2025, https://www.potomaceconomics.com/wp-content/uploads/2025/05/NYISO-2024-SOM-Full-Report_5-14-2025-final.pdf.

[204] Synapse Energy Economics Inc., *Charting the Wind: Quantifying the Ratepayer, Climate, and Public Health Benefits of Offshore Wind in New England*, prepared for the Sierra Club, June 3, 2024, https://www.sierraclub.org/sites/default/files/2025-01/synapse-offshore-wind-benefits-in-new-england-20240603.pdf.

[205] New York State Reliability Council, *Gas Constraints Modeling Whitepaper,* June 2024.

Further, neglecting to align cold-weather induced outage events with wind generation undervalues wind resources since it does not capture that wind generation tends to be higher during extreme cold.[206] Without fully accounting for all parameters that affect the reliability contribution of every resource type and accurately modeling real-world correlations, the NYISO capacity market risks misaligning resource accreditation with actual performance, undervaluing the potential reliability contribution of winter-capable clean resources like OSW, and driving inefficient investment decisions. These concerns regarding NYISO's approach to capacity accreditation may and will likely be addressed as the rules evolve.

How OSW can support resource adequacy in NYISO

Given these factors, OSW can play a critical role in addressing emerging winter peak challenges in NYISO and tightening downstate reserve margins. Unlike other renewables in the state's interconnection queue, OSW produces most reliably during cold-weather periods, when space heating and EV charging loads are highest and gas generation faces fuel constraints.

This value is partially reflected in NYISO's current CAFs. Under NYISO's 2025 CAFs, OSW, which does not currently exist at a large scale, would receive an accreditation rating of about **32%** – higher than onshore wind (~18%-20%) and solar (~11%-15%).[207] This is the highest value among renewable generators.

However, this likely understates OSW's full potential contribution to resource adequacy, particularly downstate. In its current CAF modeling, NYISO currently projects almost all system risk to occur during the summer. As a result, the current CAF values reflect only reliability contribution during summer afternoons and evenings.[208] As highlighted by the MMU[209] and NYISO themselves,[210] NYISO's framework does not fully capture the impact of cold-weather outages and capture the shift to winter risk in the process of assigning CAF values. As NYISO's modeling evolves to better capture winter risk, CAF values will change. PJM, which projects

206 Potomac Economics, *2024 State of the Market Report for the New York ISO Markets*, Prepared for NYISO Market Monitoring Unit, May 2025, PDF file, accessed August 11, 2025, https://www.potomaceconomics.com/wp-content/uploads/2025/05/NYISO-2024-SOM-Full-Report_5-14-2025-final.pdf.

207 New York Independent System Operator, *Final Capacity Accreditation Factors for the 2024–2025 Capability Year* (NYISO, [2023 or 2024]), PDF, https://www.nyiso.com/documents/20142/41593818/Final-CAFs-for-the-2024-2025-capability-year.pdf/3efc1e06-c1b0-72d6-f736-22721709c157?t=1708951801025.

208 Jain Pallavi, *2025-2026 Informational Capacity Accreditation Factors for 2025/2026 (CAF) – ICAPWG Presentation,* New York Independent System Operator (NYISO), October 7, 2024, https://www.nyiso.com/documents/20142/47364758/2025-2026%20Informational%20CAFs_ICAPWG_10.07.2024_Final.pdf.

209 Potomac Economics, *2024 State of the Market Report for the New York ISO Markets*, Prepared for NYISO Market Monitoring Unit, May 2025, PDF file, accessed August 11, 2025, https://www.potomaceconomics.com/wp-content/uploads/2025/05/NYISO-2024-SOM-Full-Report_5-14-2025-final.pdf.

210 New York State Reliability Council (NYSRC), *Gas Constraints Modeling Whitepaper,* 2024–2025 IRM Study, White paper, ICS Meeting No. 290, June 5, 2024, PDF file, https://www.nysrc.org/wp-content/uploads/2024/06/Gas-Constraints-Modeling-Whitepaper-Final.pdf.

most of the resource adequacy risk will be experienced in winter months,[211] offers insights into what CAF values may be in the future. Based on trends seen in PJM, offshore and onshore wind's CAF values are likely to increase, possibly meaningfully, in the future to more accurately reflect their contribution during cold-weather periods.

In addition to high CAF values, OSW can be built at scale. The region is targeting 9 GW of OSW by 2035[212] and has two projects under construction - Empire Wind 1 (810 MW) and Sunrise Wind (924 MW).[213] The region has faced challenges developing some OSW projects due to changing economic conditions, supply-chain challenges, and technical complexities. Some projects have been delayed or cancelled including Empire Wind 2 (1,260 MW), Attentive Energy One (1,404 MW), Community Offshore Wind (1,314 MW), and Excelsior Wind (1,314 MW).[214] Developers may return to some of projects – particularly Empire Wind 2[215] – in the future though the technical details and offtake agreements may evolve to capture current conditions and learnings as domestic OSW capabilities mature.

OSW can also be targeted to directly interconnect to high stress regions – particularly where onshore transmission or pipeline investments are challenging due to population density or permitting hurdles or prohibitively expensive. For example, the Propel NY Energy project is planned to deliver 3,000 MW OSW energy in the Atlantic off the coast of Long Island into New York City and Long Island by 2030, delivering energy and capacity to the stressed downstate region[216] where building onshore infrastructure has serious challenges.

This ability to deliver in constrained load pockets is further demonstrated by South Fork Wind (132 MW), placed in service in March 2024.[217] Built to meet rising demand on Long Island's South Fork – where limited natural gas deliverability drove regulators to seek alternatives – it

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211 PJM Interconnection, LLC., *ELCC Education: Data Transparency and ELCC Study Results (February 2024)*, Presentation to the ELCC Stakeholder Task Force, December 5, 2024, https://www.pjm.com/-/media/DotCom/committees-groups/task-forces/elccstf/2024/20241205/20241205-item-07---informational-only-posting---data-transparency---elcc-education-from-special-planning-committee-sessions-on-february-16-and-21-2024.pdf.

212 New York State Energy Research and Development Authority. *2022 Offshore Wind Solicitation (Closed).* Albany, NY: NYSERDA, 2022. https://www.nyserda.ny.gov/All-Programs/Offshore-Wind/Focus-Areas/Offshore-Wind-Solicitations/2022-Solicitation

213 The New Bedford Light. "Our Offshore Wind Tracker: What's New with Wind Projects off Massachusetts and Beyond?" *The New Bedford Light*, accessed October 26, 2025. https://newbedfordlight.org/offshore-wind-tracker-whats-happening-to-massachusetts-projects/

214 New York State Energy Research and Development Authority. "2022 Offshore Wind Solicitation (Closed)." *Offshore Wind — Focus Areas*, January 26, 2023 (last updated). Accessed October 27, 2025. https://www.nyserda.ny.gov/All-Programs/Offshore-Wind/Focus-Areas/Offshore-Wind-Solicitations/2022-Solicitation

215 Equinor ASA. "Empire Wind 2 Offshore Wind Project Announces Reset, Seeks New Offtake Opportunities." *Empire Wind*, January 3, 2024. https://www.empirewind.com/2024/01/03/empire-wind-2-offshore-wind-project-announces-reset-seeks-new-offtake-opportunities/

216 New York Independent System Operator, *NYISO Board Decision: Long Island Offshore Wind Export Public Policy Transmission Need*, Board Decision, June 13, 2023, https://www.nyiso.com/documents/20142/38388768/.../Board-Decision-Long-Island-2023-06-13.pdf.

217 Welcome to South Fork Wind" n.d. Southforkwind.com. https://southforkwind.com/.

delivers fuel-free generation directly into a constrained local grid, enhancing resilience through greater fuel diversity and deferring costly transmission upgrades.[218] It generated at 46.4% capacity factor during its first year of operation, but provided its greatest contribution during the winter months.[219] By generating most strongly during winter and overnight hours, when pipelines and gas units are under the greatest strain, South Fork illustrates how OSW can complement existing gas assets, ease local bottlenecks, strengthen reliability in areas with limited infrastructure alternatives, and defer or minimize onshore transmission expansion in regions where new construction is challenging.[220]

In summary, NYISO's evolving resource adequacy challenges are increasingly shaped by cold-weather risks, downstate transmission and capacity constraints, and policy-driven fossil retirements. These are precisely the factors that OSW can help to address. Among other renewable resources, it stands out as a scalable, relatively highly accredited resource that can both deliver directly into these stressed load pockets and perform reliably during cold-weather peaks. OSW's development has faced hurdles in NYISO, but the region is relying on its pipeline of OSW – including South Fork (currently in operation), Empire Wind (under construction), and Sunrise Wind (under construction) – to provide energy and capacity into constrained downstate load pockets. While its current CAF value is higher than other renewables, it is likely to grow over time as NYISO better captures emerging winter risk in its reliability modeling.

4.3 ISO New England

Load growth and future resource outlook

Like NYISO, ISO-NE has historically been a summer-peaking system and summer-constrained system, but electrification of heating, growing EV adoption, and policy-driven fossil retirements are shifting resource adequacy risks toward the winter months (see Figure 4-4). According to ISO-NE's 2025 Capacity, Energy, Load, and Transmission (CELT) report documenting the ISO's load forecast and resource adequacy outlook,[221] summer peak demand is expected to grow modestly from 26.5 GW in 2025 to 28.7 GW by 2034 (a compound annual growth rate (CAGR) of 0.9%). In contrast, winter peak demand is projected to surge from 20.0 GW to 26.4

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218 PSEG Long Island. *2015 South Fork Resources Request for Proposals*. June 24, 2015. https://www.psegliny.com/aboutpseglongisland/proposalsandbids/2015southforkrfp

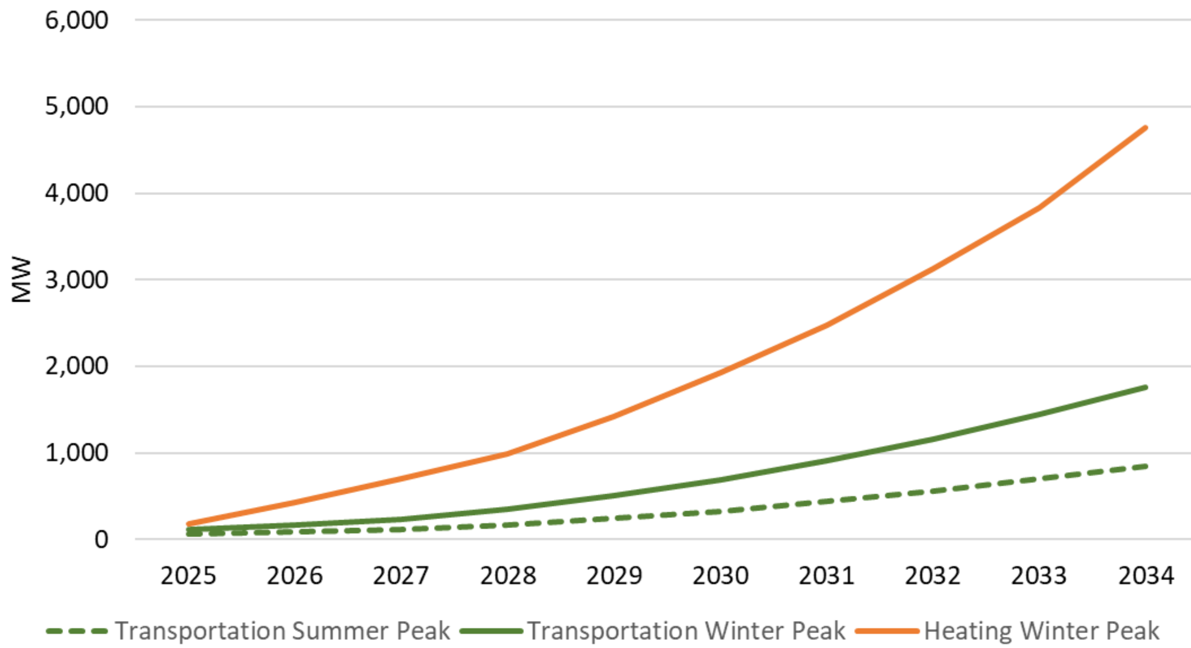
219 Ørsted. *One Year of South Fork Wind: Energy That Works.* Ørsted U.S. Offshore Wind, 2025. https://us.orsted.com/renewable-energy-solutions/offshore-wind/south-fork-wind-report

220 Long Island Power Authority. "South Fork RFP: Board Materials for the LIPA Board of Trustees." January 25, 2017. https://www.lipower.org/wp-content/uploads/2019/02/2017-01-South-Fork-Board-Material.pdf

221 ISO New England, *2025 CELT Report—2025-2034 Capacity, Energy, Loads, and Transmission Forecast* (Excel file, May 24, 2025), https://www.iso-ne.com/static-assets/documents/100023/2025_celt.xlsx.

GW—a much higher CAGR of 3.1%. This growth in winter loads warrants increased scrutiny in ISO-NE given the region's acute winter fuel security risks.[222]

Figure 4-4: ISO-NE Electrification Forecast, 2025[223]



In addition to growing load, ISO-NE is navigating a transition toward increasing renewable generation, primarily driven by state renewable energy mandates. This trend is reflected in ISO-NE's generator interconnection queue, which is presently comprised of approximately 51% battery storage,[224] 40% wind (primarily offshore), and 8% solar. Meanwhile, due to decarbonization policy, age, and other factors, natural gas generation is projected to decline sharply, from about 45% of electricity production in 2022 to just 12% by 2040.[225] While the composition of the queue is dynamic and subject to change, it clearly signals New England's pathway toward a grid with more renewables, less dispatchable resources, and more winter stress.

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222 Stephen George, "Opening Presentation: Winters 2023/2024 and 2024/2025 in New England and the Role of Everett," presentation to the New England Winter Gas-Electric Forum, 2023 Winter Gas-Electric Forum, published on ISO-New England website, https://www.ferc.gov/media/iso-ne-opening-presentation.

223 ISO New England, *2025 CELT Report—2025-2034 Capacity, Energy, Loads, and Transmission Forecast* (Excel file, May 24, 2025), https://www.iso-ne.com/static-assets/documents/100023/2025_celt.xlsx.

224 ISO New England, *ISO New England Interconnection Workshop*, October 2024, https://www.iso-ne.com/static-assets/documents/100017/iso_ne_interconnection_workshop_october_2024_final.pdf.

225 Gordon van Welie, President & CEO, "New England's Changing Resource Mix and Planning for the Future Grid," keynote presentation to the Northeast Public Power Association 2023 Annual Conference, August 21, 2023, Groton, CT, published on the ISO-NE website, PDF, https://www.iso-ne.com/static-assets/documents/2023/08/8-21-neppa-keynote-gvw-isone.pdf.

Emerging resource adequacy challenges

New England's reliability outlook is shaped by four converging challenges: the retirement of natural gas generation, the shift to a winter-peaking demand profile, strain on existing natural fuel system, and the operational limits of battery storage. Natural gas infrastructure is uniquely stressed in New England. The Northeast Power Coordinating Council (NPCC) has warned that pipelines in New England operate at or near maximum throughput during extreme cold, posing "severe threats to reliability" because this limits the amount of natural gas that can be delivered to gas power plants.[226] NERC, likewise, has recommended that more gas pipelines and storage are needed to enhance deliverability as the electric system increasingly relies on natural gas.[227] Further, the gas generators in the region will have to retire or switch to emission-free fuels due to a combination of clean energy policy goals, market economics, and the age and inefficiency of existing units, which will reduce the region's supply of firm, dispatchable capacity. While retiring generation would likely ease burdens on the gas infrastructure, it has implications for the resource adequacy of the electric grid.

At the same time, electrification of heating and transportation is pushing winter peaks higher, creating periods of sustained electric demand that could coincide with low wind and solar output. The 2021 ISO-NE Future Grid Reliability Study[228] found that in winter conditions resembling 2019, large-scale battery energy storage systems would often become fully depleted during multi-day cold-weather-induced high-demand events with insufficient recharge opportunities. Because current market tools tend to optimize for short-term price arbitrage rather than multi-day resource adequacy, the study concluded that batteries alone could not reliably replace dispatchable resources in a future winter-peaking grid. Market reforms may help mitigate these challenges as storage penetration grows, but they also underscore a fundamental limitation: storage resources depend on sufficient surplus generation to recharge during multi-day high-load to successfully maintain reliability on the grid.

Evolving approaches to capacity accreditation and market design

Presently, ISO-NE does not utilize an ELCC-type approach to capacity accreditation. Instead, it currently relies on historical performance and does not rely on probabilistic modeling. Like other wholesale markets, ISO-NE plans to reform its approach to capacity accreditation and resource adequacy models. ISO-NE plans to adopt the Resource Capacity Accreditation (RCA)

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226 Northeast Power Coordinating Council. 2025. *Northeast Gas/Electric System Study: Public Version*. January 21. Boston: Levitan & Associates, Inc. https://www.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7B70601B99-0000-C027-B1CF-31983983DAA0%7D

227 Cooperative.com. 2023. "NERC Warns of Electricity Shortages in Winter Reliability Assessment." *Cooperative.com*, 2023. https://www.cooperative.com/news/Pages/NERC-Warns-of-Electricity-Shortages-in-Winter-Reliability-Assessment.aspx

228 ISO New England, *2021 Economic Study: Future Grid Reliability Study, Phase 1 (Report*, PDF file), July 29, 2022, https://www.iso-ne.com/static-assets/documents/2022/07/2021_economic_study_future_grid_reliability_study_phase_1_report.pdf.

framework[229] to accredit each resource based on its expected contribution during peak risk periods. Using a marginal-ELCC type metric and EUE for the planning risk metric, the RCA framework will calculate the marginal reliability improvement of each resource by incorporating several resource-specific factors, such as seasonal performance, fuel supply risks, and energy limitations. ISO-NE is currently planning to implement this framework in the capacity auction planned for February 2028.[230] The RCA framework is part of a broader set of capacity market reforms that also include moving toward a prompt, seasonal capacity market.

How OSW can support resource adequacy in ISO-NE

The regional OSW pipeline is advancing, with roughly 7 GW of projects under various stages of construction and permitting across Massachusetts, Rhode Island, and Connecticut. Vineyard Wind 1 (800 MW), the nation's first utility-scale OSW farm, began partial operations in 2024 and is expected to reach full commercial operation in 2025.[231,232] Revolution Wind (704 MW) is also under construction, serving Rhode Island and Connecticut, while South Coast Wind (2,400 MW) and New England Wind 1 and 2 (up to 2,600 MW) are moving through permitting and power purchase agreement finalization.[233] Collectively, these projects could provide substantive installed – and accredited – capacity and energy to high population coastal load pockets, significantly strengthening winter adequacy and easing natural gas constraints near Boston and southeastern New England.

OSW development in ISO-NE has not been without challenges. Rising project-financing costs, supply-chain bottlenecks, and regulatory uncertainty have created headwinds for the industry nationwide including federal stop-work order temporarily halting work on Revolution Wind in 2025.[234]

One OSW project is already online in the region, Block Island Wind Farm. The site is relatively small, with only 30 MW of installed capacity, but it delivers power directly into a constrained

229 ISO New England Inc., *Overview of Detailed Design: Resource Capacity Accreditation in the Forward Capacity Market,* presentation to NEPOOL Markets & Reliability Committees, December 12–14, 2023, accessed August 13, 2025.

230 ISO New England Inc. and NEPOOL Participants Committee, *Revisions to Further Delay the Nineteenth Forward Capacity Auction and Related Capacity Market Activities* (transmittal letter to FERC, April 5, 2024), accessed August 13, 2025.

231 Massachusetts Executive Office of Energy and Environmental Affairs, "*Vineyard Wind, America's First Large-Scale Offshore Wind Farm, Delivers Full Power from 5 Turbines to the New England Grid*," press release, February 22, 2024, https://www.mass.gov/news/vineyard-wind-americas-first-large-scale-offshore-wind-farm-delivers-full-power-from-5-turbines-to-the-new-england-grid.

232 Lennon, A. E. "*Vineyard Wind Nears 30% Power Production*." *The New Bedford Light*, July 23, 2025. https://newbedfordlight.org/vineyard-wind-nears-30-power-production/

233 The New Bedford Light. "Our Offshore Wind Tracker: What's New with Wind Projects off Massachusetts and Beyond?" *The New Bedford Light*, accessed October 26, 2025. https://newbedfordlight.org/offshore-wind-tracker-whats-happening-to-massachusetts-projects/

234 U.S. Department of the Interior, Bureau of Ocean Energy Management. "Director's Order to Revolution Wind, LLC (Aug. 22, 2025)." Washington, DC: BOEM, 2025. https://www.boem.gov/sites/default/files/documents/renewable-energy/Director%26%23039%3BsOrder-20250822.pdf?VersionId=Y674sNo8zi7jLu3VWRvq2hFb_8KtMldc

island load pocket and has enabled the island to shut down expensive and environmentally burdensome diesel generators. Though Block Island has experienced unanticipated maintenance events,[235] it has served as a proof of concept for how OSW can deliver power to constrained coastal areas and harden the existing grid.[236,237]

However, further investment in OSW in ISO-NE lies not only in its emission-free output but also in its ability to generate during the hours that are becoming increasingly risky cold winter periods when demand is high, natural gas fuel supplies are limited due to pipeline constraints and competing demand for building heating, and solar output is low. This winter availability makes OSW a resource that can mitigate ISO-NE's winter resource adequacy risks, particularly during extended cold periods.

This is reflected in recent capacity accreditation studies performed by the ISO. While these accreditation values have not yet been adopted in ISO-NE's capacity auction, they are indicative of likely results when the RCA framework is implemented. One study, the ISO-NE May 2024 Impact Analysis Sensitivity Results study,[238] compared three scenarios with various future resource mixes. See a summary of these scenarios in Table 4-1.

235 The Providence Journal. "Block Island Offshore Wind Farm Offline Two Months Due to Maintenance and Safety Concerns." *The Providence Journal*, August 14, 2021. https://www.providencejournal.com/story/news/2021/08/14/block-island-offshore-wind-farm-offline-two-months-due-to-maintenance-and-safety-concerns/8122841002/

Ørsted. "Block Island Wind Farm – Renewable Energy Solutions / Offshore Wind." Ørsted U.S. Offshore Wind. Accessed October 26 2025. https://us.orsted.com/renewable-energy-solutions/offshore-wind/block-island-wind-farm

237 The New York Times. "Offshore Turbines Let Block Island Shut Down Soot-Spewing, Earsplitting Diesel Generators … There Were Other Benefits, Too." *New York Times*, September 22, 2025. https://www.nytimes.com/2025/09/22/climate/block-island-rhode-wind-turbines.html

238 ISO New England, *Impact Analysis Sensitivity Results – May 2024*, presentation to the NEPOOL Markets Committee, Milford, MA, May 7–8, 2024, https://www.iso-ne.com/static-assets/documents/100011/a02c_mc_2024_05_07_08_impact_analysis_sensitivity_results_may2024.pdf.

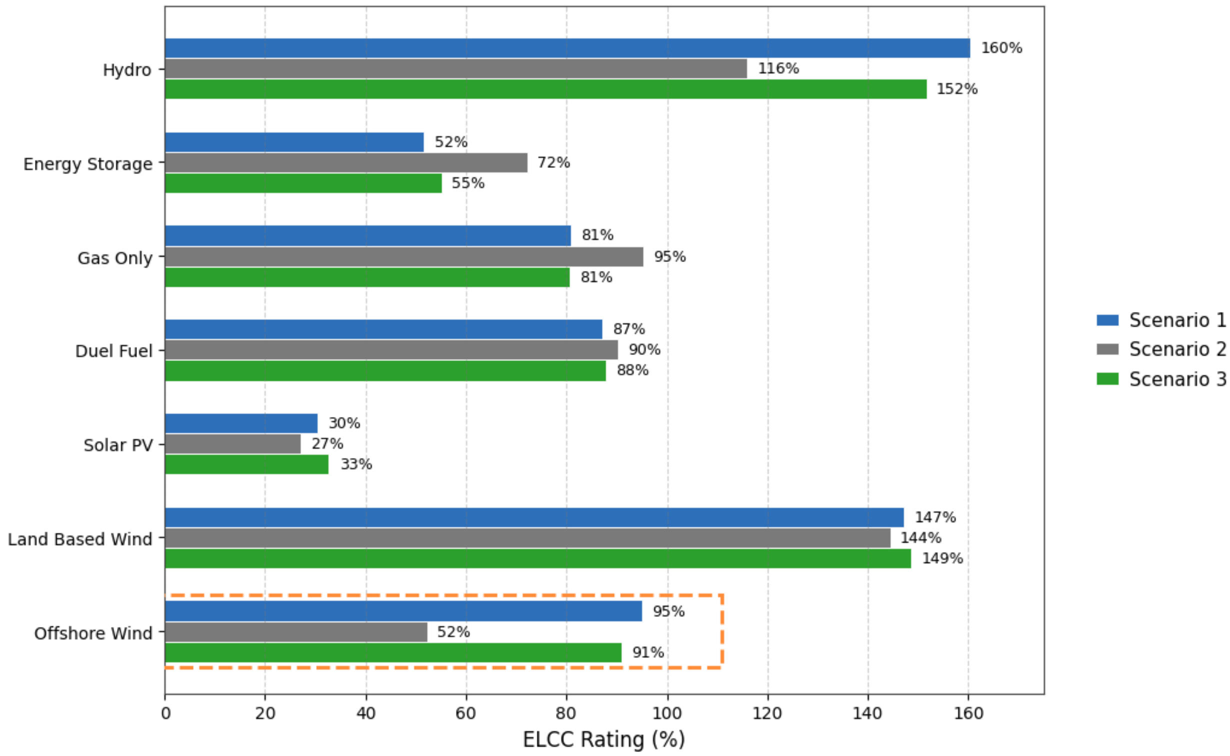
Table 4-1: ISO-NE Accreditation Scenarios[239]

Scenario	Retirements	Resource Additions
Scenario 1	438 MW coal	2 GW solar, 0.3 GW onshore wind,1 GW offshore wind, 0.2 GW 4-hour storage
Scenario 2	1.3 GW oil	6.5 GW solar, 1 GW onshore wind, 3.3 GW offshore wind, 0.8 4-hour storage
Scenario 3	None	2 GW solar, 0.3 GW onshore wind,1 GW offshore wind, 0.2 GW 4-hour storage

The three scenarios assess multiple future generator resource mixes. The first Scenario retired coal capacity and added onshore wind, solar, storage, and about 1 GW of OSW. The second Scenario only retired oil resources and added higher amounts of onshore wind, solar, storage, and onshore wind (about 3 GW). The third scenario had no thermal retirements and had the same wind, solar, storage, and OSW additions as Scenario 1.

239 Ibid.

Figure 4-5: Average Capacity Rating Across Scenarios in ISO-NE[240]



The average capacity rating for each technology is shown in Figure 4-5. Across all three scenarios, OSW offered a consistently strong reliability contribution. In Scenarios 1 and 3, it achieves winter capacity accreditation ratings above 90%, placing it on par with, and in some cases exceeding, the reliability contribution of thermal resources (87-97% range), while far outperforming solar PV (approximately 13%) and short-duration storage (28-29%) during critical winter periods.

However, OSW's accreditation fell significantly in Scenario 2 (51%), resulting in a rating meaningfully lower than energy storage and thermal resources. This decline is driven by the assumption of a substantially higher levels of OSW deployment in Scenario 2. At these higher penetrations, OSW reshapes the net load and successfully shifts the periods of greatest reliability risk into hours when its output is lower. Importantly, this reduction reflects the mechanics of marginal accreditation: once a significant tranche of OSW has been added, each additional megawatt has a smaller incremental reliability contribution than earlier investments. As such, the decline is not an accurate reflection of the first 1-3 GW of offshore wind assumed

240 ISO New England, *Impact Analysis Sensitivity Results – May 2024*, (Milford, MA, presentation to the NEPOOL Markets Committee, May 7–8, 2024), https://www.iso-ne.com/static-assets/documents/100011/a02c_mc_2024_05_07_08_impact_analysis_sensitivity_results_may2024.pdf.

in the scenario, but rather a reflection of diminishing marginal reliability benefits beyond this initial tranche of OSW investment.

Unlike other regions, ISO-NE's accreditation values do not show a strong benefit of OSW relative to onshore wind. This high accreditation value for onshore wind is likely due to the lower penetration of onshore wind assumed in New England (a third of that assumed for offshore) and relatively strong onshore wind in New England, particularly in regions like Northern Maine.[241] However, OSW may have locational benefits relative to onshore due to its closer proximity to population centers, like Boston, and its ability to avoid high land costs.[242] OSW also may require less transmission investment, as measured by length, than onshore wind. ISO-NE's 2010 *Economic Study*[243] found that for equivalent amounts of onshore and offshore wind additions, integrating OSW requires significantly less new transmission in terms of milage because projects are located closer to major coastal load centers. This proximity reduces system upgrade needs and can enable faster deployment compared to onshore wind. However, further analysis is needed to perform direct cost comparisons due to the higher per mile cost of the submarine transmission required to interconnect OSW.

Why OSW has high ELCC values in ISO-NE

The first gigawatt of OSW in New England delivers its strongest output during high-risk winter hours - the same periods when natural-gas resources are most stressed, and existing and growing heating demand is highest. This alignment gives OSW exceptionally high initial ELCC values, often comparable to thermal resources.

As penetration increases to roughly 3.5 GW, OSW shifts remaining reliability risks risk to lower wind hours. As such, Its ELCC declines. In effect, the first wave of OSW provides the greatest reliability gain per megawatt added, directly targeting the system's most critical hours of need.

Collectively, these factors underscore the material role that OSW can play in addressing ISO-NE's emerging winter reliability challenges. OSW can play a critical role in easing stress on the natural gas fuel system by delivering fuel-free, consistent winter generation. At current and near-term penetration levels, OSW provides high accredited capacity, on par with or exceeding

241 Canary Media, 2025, "Is Wind Power Finally Coming to Maine's Remote North?" *Canary Media*, July 7, 2025, accessed August 17, 2025, https://www.canarymedia.com/articles/wind/maine-aroostook-clean-power-transmission.

242 Luran Dong, Vasundhara Gaur, and Corey Lang, "Property value impacts of onshore wind energy in New England: The importance of spatial heterogeneity and temporal dynamics," *Energy Policy* 179 (2023): 113643.

243 ISO New England, *New England 2030 Power System Study: 2009 Economic Study: Scenario Analysis of Renewable Resource Development (*report to the New England Governors, February 2010, 14–15) https://www.iso-ne.com/static-assets/documents/committees/comm_wkgrps/prtcpnts_comm/pac/reports/2010/economicstudyreportfinal_022610.pdf.

traditional thermal resources. Even as marginal accreditation values decline at higher penetrations, the first wave of OSW projects delivers meaningful capacity value precisely when the system is increasingly at risk -during cold winter periods with high heating demand and constrained gas supplies. Furthermore, the geographic siting advantages of OSW, its proximity to coastal load centers and reduced reliance on extensive new onshore transmission compared to remote onshore wind, position it as a resource capable of being deployed at scale in New England's constrained system. As ISO-NE transitions to its Reliability Contribution Accreditation framework, OSW is likely to be recognized not only for its clean energy output, but also for its ability to provide firm, accredited capacity that directly mitigates the region's most acute reliability risks.

4.4 CAISO

Load growth future resource outlook

CAISO is facing emerging resource adequacy challenges as it manages the combined effects of accelerating load growth, the retirement of thermal resources, and a rapidly evolving generation mix dominated by renewables and battery storage. California has implemented ambitious decarbonization targets via SB 100 which mandates raising the share of renewable energy to 60% by 2030 and 100% by 2045.[244] Battery storage mandates in California and other factors led to the development of 5.8 GW of battery storage as of December 2024 in CAISO.[245] At the same time, peak demand in the CAISO footprint is projected to grow substantially, from 46.1 GW in 2025 to 52.9 GW by 2030,[246]driven by electrification and increasing data center development.

Given these factors, CAISO has projected to add substantial renewable energy and battery storage resources to the system. In its 20-Year Transmission Outlook, CAISO called for 165 GW of new resources by 2045 including: 69 GW of utility scale solar, 32 GW of onshore wind (with 3 GW coming from in-state and the remainder coming from out of state resources), and 20 GW of OSW.[247]

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244 California State *Senate Bill 100 (2018), 100 Percent Clean Energy Act of 2018*, (enacted September 10, 2018), (Codifies the policy that eligible renewable energy and zero-carbon resources supply 100 percent of retail electricity sales in California by December 31, 2045).

245 California Independent System Operator (CAISO), *2024 Special Report on Battery Storage,* Issued May 29, 2025, https://www.caiso.com/documents/2024-special-report-on-battery-storage-may-29-2025.pdf.

246 California Independent System Operator, *Summer Loads and Resources Assessment 2025*, Folsom, CA: California ISO, 2025, https://www.caiso.com/content/summer-loads-resources-assessment/2025/index.html#:~:text=From%202014%20to%202024%2C%20CAISO's,Probabilistic%20assessment.

247 California Independent System Operator (CAISO), *2024 20-Year Transmission Outlook* (July 31, 2024), https://www.caiso.com/documents/2024-20-year-transmission-outlook-jul-31-2024.pdf.

CAISO also expects to retire roughly 8 GW of natural gas and coal generation by 2030—a 77% reduction in installed thermal capacity -further increasing reliance on intermittent resources and energy-limited battery storage.[248]

Emerging resource adequacy challenges

CAISO is facing resource adequacy challenges primarily due to thermal resource retirements, an evolving and increasingly intermittent and energy-limited generation mix, and increased exposure to climate-related risks such as severe heat waves, droughts, and wildfires, impacting both supply and demand-side needs. Due to its high penetration of solar generation, CAISO also faces challenges due to sharp increases in the net load (i.e., total demand less renewable generation) in the evening hours as solar generation declines. This is referred to as the "duck curve" phenomena[249] and has led the creation of the Flexible Ramping Product (FRP).[250]

Unlike the Northeastern United States, CAISO has not seen the trend of higher load growth and tightening system risk in the winter months. Rather, CAISO's load and risk profile are projected to remain in summer months. CAISO's summer risk was highlighted during a recent rolling blackout event in August 2020[251] and near-misses in September 2022. These events have further raised concerns on the CAISO's system's resource adequacy.[252]

To address these emerging resource adequacy concerns, the CPUC adopted the Slice-of-Day capacity resource accreditation framework in 2020 and implemented this framework in 2025. This framework replaced an approach that accredited resources based on a single peak hour each month. Slice of Day uses hourly Net Qualifying Capacity (NQC) profiles,[253] reflecting availability across the 24-hour period of the "worst day" in the month (the day containing the hour of highest coincident peak demand).[254]

By considering 24-hour expected generation profiles, the Slice-of-Day framework increasingly values resources that provide reliable capacity during the *tightest* hours of the day in each month when resource adequacy risks are highest. This accreditation method will place greater

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248 State of California, California Independent System Operator, *2023–2024 Transmission Plan (Draft)*, (Folsom, CA: California Independent System Operator, April 1, 2024), accessed August 13, 2025.

249 U.S. Energy Information Administration, "As Solar Capacity Grows, Duck Curves Are Getting Deeper in California," *Today in Energy*, June 21, 2023, https://www.eia.gov/todayinenergy/detail.php?id=56880.

250 California Independent System Operator, *Flexible Ramping Product Performance,* March 29, 2022, https://www.caiso.com/Documents/Report-FlexibleRampingProductPerformance.pdf.

251 *California Public Utilities Commission, 2025 Resource Adequacy and Slice of Day Guide, Issued September 25, 2024, accessed September 15, 2025,* https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/resource-adequacy-homepage/resource-adequacy-compliance-materials/guides-and-resources/2025-ra-slice-of-day-filing-guide.pdf.

252 Kavya Balaraman, "California ISO Narrowly Avoids Rolling Outages as Peak Demand Hits Record 52 GW," *Utility Dive*, September 7, 2022.

253 California Public Utilities Commission, *CPUC Slice of Day Resource Adequacy Whitepaper*; January 2024.

254 California Public Utilities Commission, *2025 Resource Adequacy and Slice of Day Guide,* September 2024.

capacity value on resources that can perform during these nighttime tight hours, such as dispatchable resources (i.e., longer duration energy storage, geothermal) and OSW.[255]

How OSW can support resource adequacy

Based on the plans charted in the 20-Year Transmission plan,[256] CAISO expects OSW to play a meaningful role in the future grid from both decarbonization and resource adequacy perspectives. CAISO has not yet reported the impact of OSW in its ongoing slide-of-day modeling, but insights can be drawn from other markets to evaluate OSW's potential role in CAISO. Offshore wind facilities are expected to have higher capacity factors than onshore wind, ranging from 29-52% across all seasons, compared to 23-44% performance by onshore wind (See Figure 4-6).[257] In addition, generation at coastal or offshore wind sites are generally less correlated to solar output and provide complementary benefits due to late afternoon and evening sea breezes.[258]

Like other regions, California's OSW production is higher at night, which will enable offshore wind to play a complementary role to CAISO's substantial solar generation fleet. Unlike other regions, California's OSW resources are expected to generate the most electricity during the summer, which aligns with CAISO's periods of greatest risk.[259]

One study by the Berkeley Policy School[260] found that installing 50 GW of OSW reduced the amount of solar capacity need by 77 GW and the amount of storage capacity needed by 44 GW without harming resources adequacy – a net reduction 70 GW in the overall installed capacity. This is because OSW has significant synergies – with solar and storage resource in CAISO. It has a complementary shape with solar generation with its period of strongest generation at night. OSW can also provide cheap energy to charge storage resources during periods of strong

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255 California Independent System Operator (CAISO), *CAISO RA Processes and CPUC's Slice of Day* (white paper, January 9, 2024), https://stakeholdercenter.caiso.com/InitiativeDocuments/White-Paper-ResourceAdequacyProcesses-CPUC-Slice-of-Day-Jan09-2024.pdf.

256 State of California, California Independent System Operator, *2024–2025 Transmission Plan (Draft)*, (Folsom, CA: California Independent System Operator), May 14, 2025, accessed August 13, 2025.

257 IEA (2019), *Offshore Wind Outlook 2019*, (Paris, IEA), https://www.iea.org/reports/offshore-wind-outlook-2019, (Licence: CC BY 4.0.

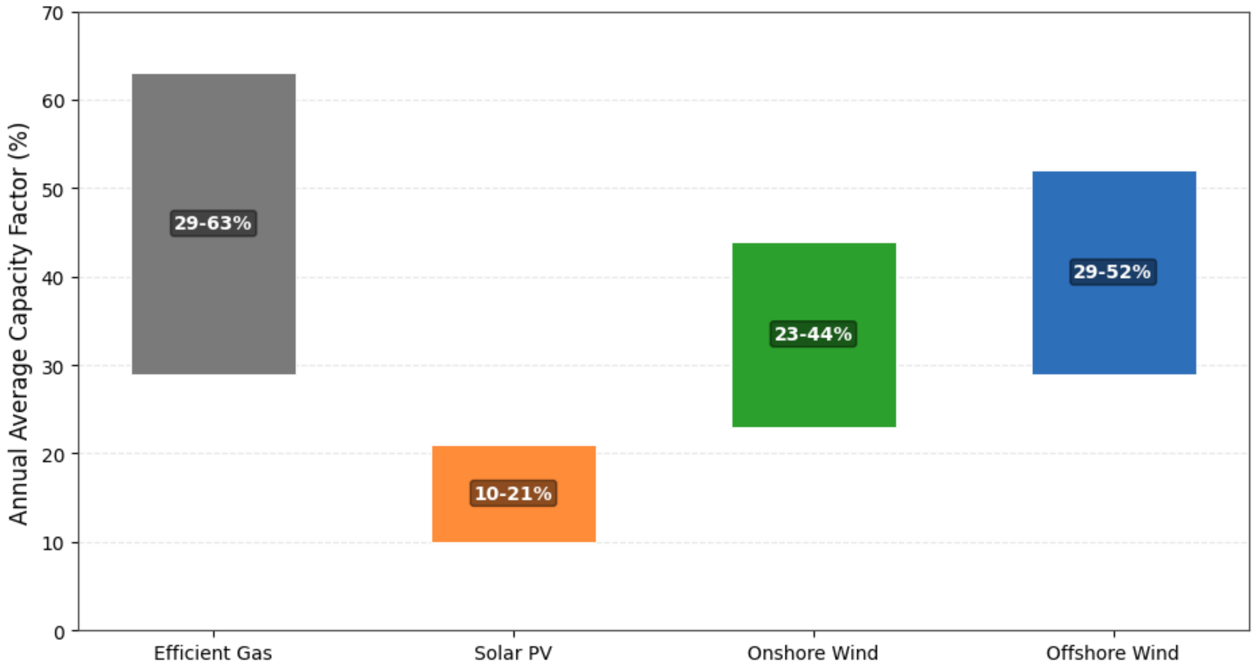
258 Amul Sathe, Andrea Romano, Bruce Hamilton, Debyani Ghosh, and Garrett Parzygnot (Guidehouse), *Research and Development Opportunities for Offshore Wind Energy in California,* California Energy Commission, August 2020, Publication No. CEC-500-2020-053, https://www.energy.ca.gov/sites/default/files/2021-05/CEC-500-2020-053.pdf.

259 M. Severy, C. Ortega, C. Chamberlin, and A. Jacobson, *Wind Speed Resource and Power Generation Profile Report,* In *California North Coast Offshore Wind Studies*, edited by M. Severy et al. (Arcata, CA: Schatz Energy Research Center, September 2020), accessed August 13, 2025.

260 Paliwal Umed, Nikit Abhyankar, David Wooley, and Amol Phadke, *The Offshore Report: California—Plummeting Offshore Wind Costs Can Accelerate a Diverse Net-Zero Grid,* Working Paper #1, Center for Environmental Public Policy, Goldman School of Public Policy, University of California, Berkeley, December 2022, https://gspp.berkeley.edu/assets/uploads/page/CA_OSW_Assessment_Working_Paper_CEPP.pdf.

generation, and storage resources can provide needed generation during periods of lower solar and wind generation.

Figure 4-6: Annual average capacity factor across technology types (2018)[261]



4.5 ERCOT

Load growth and future resource outlook

ERCOT is forecasting some of the highest load growth in the country and a transition to a winter-peaking system by 2038. Peak demand is expected to grow from 95 GW in 2026 to 183 GW by 2044 -a compound annual growth rate of 3.8%. Most of this growth is due to rapid additions of large, electricity-intensive loads such as data centers and cryptocurrency mining.[262] Unlike traditional load, data centers operate at a high capacity factor, flattening intra-day load curves and maintaining elevated demand across all seasons. Some of the load growth is offset due to the relatively large share driven by cryptocurrency miners. Cryptocurrency miners provide a significant amount of demand response in ERCOT and can interrupt their load when

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261 IEA (2019), *Offshore Wind Outlook 2019: World Energy Outlook Special Report*, (Paris, IEA, Licence: CC BY 4.0) https://www.iea.org/reports/offshore-wind-outlook-2019,.

262 ERCOT, *2025 ERCOT System Planning Long-Term Hourly Peak Demand and Energy Forecast,* 2025, https://www.ercot.com/files/docs/2025/04/08/2025-LTLF-Report.pdf.

price spikes.[263] However, new, cheap energy is needed to accommodate growing investment in the state.

Emerging resource adequacy challenges

Like many other systems, ERCOT currently experiences the greatest stress in the summer, but winter risks are growing. Recent events, such as Winter Storm Uri, have further highlighted growing winter risks due to natural gas supply disruptions.

Similar to other wholesale markets like MISO, ERCOT is also seeing reliability pressures in the shoulder months, when volatile spring and fall weather can bring unseasonably hot or cold conditions that coincide with planned maintenance outages. In these periods, reserve margins can approach summer-like lows as aging thermal units undergo maintenance and demand from around-the-clock loads remains high.[264,265]

ERCOT's most recent Capacity, Demand, and Reserves (CDR)[266] report projects tightening reserve margins in the coming years, with several scenarios showing potential shortfalls under extreme weather or high outage conditions. While the CDR points to real capacity shortage risks, some stakeholders have raised questions about certain assumptions, related to demand growth and thermal resource availability.[267]

How OSW can support resource adequacy in ERCOT

OSW faces development challenges in ERCOT relative to PJM, NYISO and other coastal regions. The seabed is deeper and silty; as a result, ERCOT would require higher cost hurdles to installing OSW.[268,269] Offshore wind speeds are also lower off the Texas coast compared to

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263 Potomac Economics, *2024 State of the Market Report*, June 2025, https://www.potomaceconomics.com/wp-content/uploads/2025/06/2024-State-of-the-Market-Report.pdf.

264 ERCOT, *Report on the Capacity Demand Reserves (CDR) in the ERCOT Region 2026-2030*, May 2025, (2026 and 2026/27 Winter Morning and Evening ELCC values), https://www.ercot.com/files/docs/2025/05/16/CapacityDemandandReservesReport_May2025_Revised.pdf.

265 Aurora Energy Research, *The US Reliability Challenge and the Value of Flexibility*, June 2025, https://go.auroraer.com/l/885013/2025-06-09/phvkq/885013/17494806532yw0P8mp/060625_Aurora_DR_and_Reliability_Assessment.pdf.

266 ERCOT, *Report on the Capacity Demand Reserves (CDR) in the ERCOT Region 2026-2030*, May 2025, (2026 and 2026/27 Winter Morning and Evening ELCC values), https://www.ercot.com/files/docs/2025/05/16/CapacityDemandandReservesReport_May2025_Revised.pdf.

267 Potomac Economics, *2024 State of the Market Report for the ERCOT Electricity Markets* (Independent Market Monitor for ERCOT, May 2025), accessed August 11, 2025, https://www.potomaceconomics.com/wp-content/uploads/2025/06/2024-State-of-the-Market-Report.pdf.

268 Tim McDonnell, "Why the First Auction for Offshore Wind in the Gulf of Mexico Was a Bust," *Semafor*, (Semafor.com, August 30, 2023), https://www.semafor.com/article/08/30/2023/offshore-wind-gulf-of-mexico-bust.

269 Robert Mecarini, "Geotechnical Studies for Offshore Applications" *Wind Systems Magazine*, March 6, 2012, https://www.windsystemsmag.com/geotechnical-studies-for-offshore-applications/.

regions off the Eastern and Western coats.[270] As such, there are no current OSW projects underway, but it may play a role longer term as OSW technology evolves.

Coastal wind follows meaningfully different patterns than wind in other parts of the state. It has stronger generation during the day while other parts of the state produce more at night.[271] As such, wind sited off the Texas coast could provide critical diversity to the rest of Texas wind generation.

While ERCOT does not have a capacity market, ERCOT performs ELCC studies to assess the reliability contribution of varying resources. Currently, ERCOT does not include OSW in its studies, but does include onshore wind. In ERCOT's ELCC studies, wind resources are modelled as either Coastal, Panhandle or Other (there is currently no OSW in Texas). The ELCC values for Coastal wind can provide insights into the possible accreditation which will be assigned to OSW as it develops in the Gulf coast. Currently, Coastal wind has the highest average ELCC values for non-dispatchable resources across both summer evenings and winter mornings. ELCCs for OSW would likely be even higher, given the ability of OSW resources to access higher wind speeds at higher hub heights.[272]

OSW can also play a synergistic role with storage. Storage resources currently receive the highest non-thermal ELCC values. While these are expected to decline with higher penetration, its effectiveness depends on having sufficient excess energy in low-risk periods to recharge—a role coastal wind and other renewables can help fill. Based on the 2022 ELCC study, higher penetration of solar and wind resources will result in higher ELCC values for storage resource.[273]

OSW also shows modest locational benefits. Some coastal cities such as Brownsville and Corpus Christi are experiencing load growth from economic development, population growth, and EV adoption. However, the fastest load growth is projected in inland hubs such as Dallas – Fort Worth, Austin, and Houston, limiting OSW locational advantage compared to its role in PJM and NYISO, where wind more directly serves constrained load pockets.

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270 Musial, Walt, Donna Heimiller, Philipp Beiter, George Scott, and Caroline Draxl. ***2016 Offshore Wind Energy Resource Assessment for the United States.*** NREL Technical Report NREL/TP-5000-66599. Golden, CO: National Renewable Energy Laboratory, September 2016. https://docs.nrel.gov/docs/fy16osti/66599.pdf

271 Yih-huei Wan, *Analysis of Wind Power Ramping Behavior in ERCOT*, National Renewable Energy Laboratory (NREL), (Golden, CO, Technical Report: NREL/TP-5500-49218, March 2011), https://docs.nrel.gov/docs/fy11osti/49218.pdf.

272 Astrapé Consulting, *Effective Load Carrying Capability Study: Final Report Revised,* 2025, (prepared for Electrical Reliability Council of Texas (ERCOT), December, 7, 2025, https://www.ercot.com/files/docs/2025/02/12/2024_ERCOT_ELCC_Study_Final_Report_Revised.pdf.

273 Astrapé Consulting, *Effective Load Carrying Capability Study: Final Report* (prepared for the Electric Reliability Council of Texas), December 7 2022, accessed August 12, 2025, https://www.ercot.com/files/docs/2022/12/09/2022-ERCOT-ELCC-Study-Final-Report-12-9-2022.pdf.

4.6 International markets

While the above results demonstrate that OSW can play a meaningful role in meeting America's emerging resource adequacy challenges, these findings may be viewed as theoretical given the limited amount of domestic operating experience. However, the United States operators and regulators can draw on learnings from the extensive operational record in European markets, where OSW is a mature and proven technology. OSW plays a central role in addressing Europe's own adequacy challenges. OSW has also acted as a key hedge against uncertainty in the natural gas markets due to geopolitical instability and war, demonstrating the value in an electricity resource mix with diverse fuel sources. However, OSW's marginal impact has declined as it has been developed at scale.

Throughout Europe, electrification, rapid digitalization, and decarbonization are reshaping demand and supply dynamics. Peak demand is projected to grow, driven by the adoption of electric vehicles, electrified heating, and the growth of data centers and other energy-intensive industries. At the same time, the retirement of coal, nuclear, and other firm thermal capacity - accelerated by climate policy, market economics, and geopolitical tensions -is tightening installed reserve margins. The 2024 European Resource Adequacy Assessment (ERAA) highlights that over 50 GW of fossil-fueled capacity may become economically non-viable by 2030, with significant retirement risks already emerging by 2026. While renewable capacity is expected to grow, ERAA modeling suggests the expected growth will not fully offset the loss of dispatchable generation or meet rising electrification needs by 2035.[274]

The 2022 Russia-Ukraine war further underscored the vulnerability of Europe's energy system, exposing heavy dependence on imported Russian gas and triggering urgent policy shifts to diversify natural gas supply and accelerate renewable deployment. More broadly, interdependencies across interconnected regional European electricity markets mean that regional stress events are becoming more consequential, particularly as extreme weather becomes more frequent. ERAA modeling shows that adequacy risks are concentrated in central and western Europe, with LOLE values projected to exceed reliability standards in several countries by 2035. The Netherlands is expected to have a LOLE of 12.6 hours per year by 2033 well above its standard of 4 hours per year, due to rise in demand and limited firm replacement capacity.[275,276]

Against this backdrop, OSW is increasingly viewed as a cornerstone of European resource adequacy strategies, valued for its strong winter generation profile and potential to displace

274 Entsoe.eu, *ERAA 2024 Edition*, 2024, https://www.entsoe.eu/eraa/2024/.

275 Tennet, *Security of Supply 2025*, May 2025, https://tennet-drupal.s3.eu-central-1.amazonaws.com/default/2025-05/20250515%20TenneT%20Monitor%20Leveringszekerheid%202025%20final.pdf.

276 Milena Giorgi, *The Netherlands Faces Power Supply Risks after 2030: TenneT Calls for Urgent Investment—Strategic Energy Europe*, Strategic Energy: Europe, May 19, 2025, https://strategicenergy.eu/the-netherlands-power-supply-risks-2030-tennet.

retiring firm capacity. Europe's OSW is advanced and proven, with roughly 37 GW installed and supplying power across multiple countries.[277]

European leaders broadly view OSW as a foundation of the future grid and have collective plans to reach about 86 GW by 2030.[278] Yet, despite this general pan-European trend, countries differ in policy frameworks, capacity constructs, and the pace of build-out, producing divergent pathways for meeting rising reliability challenges.

The United Kingdom

In the latest capacity report from the National Energy System Operator (NESO), the UK body responsible for resource adequacy planning and capacity auctions, peak demand under their base case is expected to grow from 58 GW in 2024 to 88 GW by 2040. This substantial growth in peak demand is due to an array of factors including the increased adoption of EVs, electrification of heating, and demand from new loads such as data centers.[279]

In parallel with growing demand, the UK has aggressive decarbonization policies, has retired its last coal plant in 2024,[280] and is aiming to reduce reliance on natural gas following the 2022 natural gas crisis that resulted from the Russian Ukrainian war.[281] These pressures, combined with growing uncertainty in supply and demand across the interconnected electricity markets in the UK and Europe, present a significant resource adequacy challenge.

Going forward, OSW is set to play a crucial role in addressing the UK's resource adequacy needs. The UK government wants to make renewable energy—OSW in particular, a primary driver of the 2030 energy mix.[282] OSW has already achieved scale, with 13.6 GW of capacity in service, the highest worldwide outside of China.[283]

The government's Clean Power 2030 Action report highlights OSW as a key resource for meeting increasing seasonal and volatile electricity demand. As electrification of building

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277 WindEurope, *Wind Energy in Europe: 2024 Statistics and the Outlook for 2025–2030* (February 2025).

278 European Commission, Directorate-General for Energy, *Offshore Renewable Energy,* accessed August 16, 2025, https://energy.ec.europa.eu/topics/renewable-energy/offshore-renewable-energy_en.

279 National Energy System Operator (NESO), *Electricity Capacity Report 2025* (May, 2025), https://nationalenergyso-emr.my.salesforce.com/sfc/p/#8d000002dUGC/a/J70000005jrg/XjBKzF950LteSxW1CYnAg_HFeT3knfyzOjbobw3bCGE.

280 World Resources Institute, *STATEMENT: UK Eliminates Coal from Power Generation*, 2024, https://www.wri.org/news/statement-uk-eliminates-coal-power-generation.

281 Energy & Climate Intelligence Unit, ECIU, *Two Years of Russia's War on Ukraine: The Gas Crisis, Price Rises and Energy Security*, February 22, 2024, https://eciu.net/insights/2024/two-years-of-russias-war-on-ukraine-the-gas-crisis-price-rises-and-energy-security?.

282 UK Government, *Clean Power 2030 Action Plan: A New Era of Clean Electricity*, December, 2024, https://assets.publishing.service.gov.uk/media/677bc80399c93b7286a396d6/clean-power-2030-action-plan-main-report.pdf.

283 UK Government, *Seizing Our Opportunities: Independent Report of the Offshore Wind Champion*, n.d., April 5, 2023, https://www.gov.uk/government/publications/accelerating-deployment-of-offshore-wind-farms-uk-offshore-wind-champion-recommendations/seizing-our-opportunities-independent-report-of-the-offshore-wind-champion.

heating drives sharp spikes in winter demand, especially on very cold days, OSW's tendency to generate more in the winter can help serve loads in these periods.[284] This contribution of OSW to hedging against winter demand is also reflected in their capacity accreditations (see Figure 4-7) where OSW has consistently received higher Equivalent Firm Capacity (EFC) ratings (similar to ELCC in the US) than onshore wind and solar, reflecting its stronger delivery during at risk periods—winter evening and morning peaks.[285,286] OSW's EFC values are declining as growing capacity leads to more correlated output across sites, reducing the incremental contribution of new OSW capacity to meeting UK's resource adequacy needs. This trend reflects the maturity and scale of the UK's OSW fleet and does not yet apply to US markets, where OSW development is still in its early stages. This trend is important for domestic leaders to consider as they seek to find the right level of OSW development so that each additional resource continues to play a meaningful resource adequacy role. Domestic markets may also consider synergies with storage resources, particularly emerging long-duration storage resources, which may mute the decline of OSW's capacity accreditation observed in UK modeling.

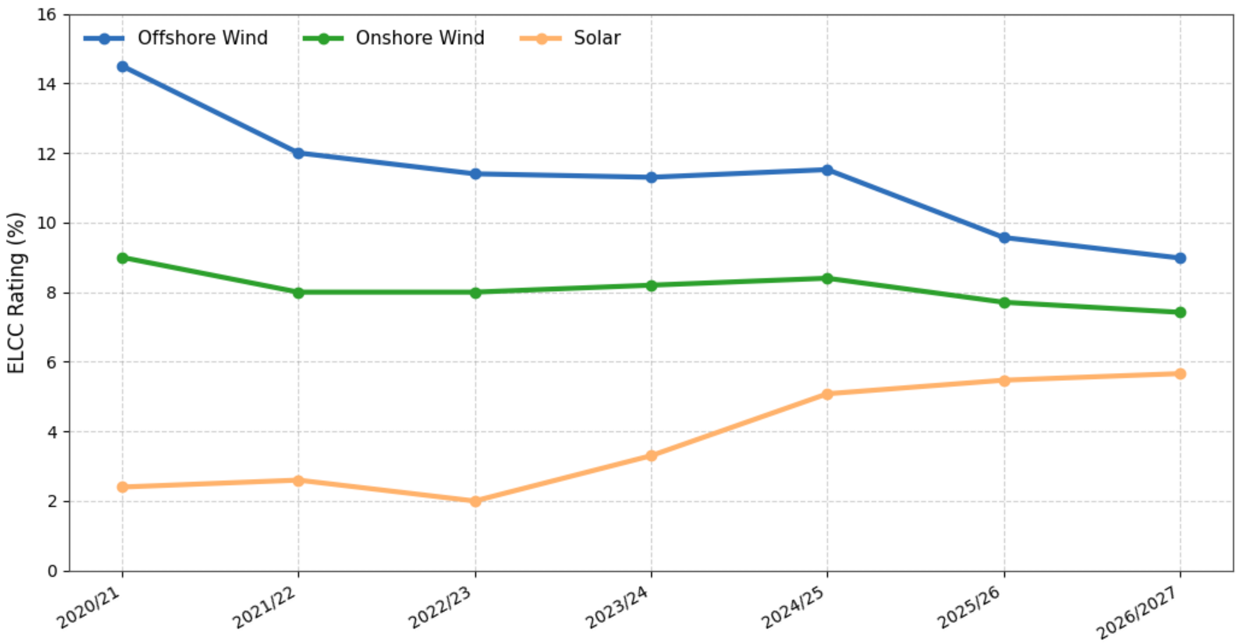
In contrast, solar equivalent firm capacity values are rising as the expansion of short-duration storage shifts some stress events to earlier in the day and high levels of wind generation shifts risk back to high solar periods, allowing more solar generation to contribute during those periods.

284 UK Government, 2024, *Clean Power 2030 Action Plan: A New Era of Clean Electricity*, December, 2024, https://assets.publishing.service.gov.uk/media/677bc80399c93b7286a396d6/clean-power-2030-action-plan-main-report.pdf.

285 National Energy System Operator (NESO), *Electricity Capacity Report,* May, 2025, https://nationalenergyso-emr.my.salesforce.com/sfc/p/#8d000002dUGC/a/J70000005jrg/XjBKzF950LteSxW1CYnAg_HFeT3knfyzOjbobw3bCGE.

286 National Energy System Operator (NESO), Storage & Renewables De-rating Factors (2023), https:/www.emrdeliverybody.com/Capacity%20Markets%20Document%20Library/Storage%20and%20Renewables%20De-rating%20Factors%20Briefing%20Note%202023.pdf.

Figure 4-7: UK Equivalent Firm Capacity Values for Solar, Onshore Wind, and Offshore Wind



Germany

In the most recent European Resource Adequacy Assessment (ERAA) conducted by the European Network of Transmission system Operators for Electricity (ENTSO-E), Germany is projected to have notable resource adequacy risks over the 2025-2035 period, with LOLE reaching up to 9.87 hours per year by 2035 – well above the reliability standard of 2.77 hours. Germany's rising resource adequacy risk is driven not only by growing demand, but also by policy-mandated coal and nuclear retirements and potential further economics-driven decommissioning of fossil-fueled capacity.[287,288] Germany fully retired nuclear generators in 2023 and plans to retire all coal capacity by 2038, further limiting its fuel-assured capacity.[289] Recognizing this emerging capacity gap, the historically energy-only market is exploring a capacity market mechanism for securing resource adequacy in the long term.[290]

287 *European Network of Transmission System Operators for Electricity, European Resource Adequacy Assessment 2024 Edition* ERAA 2024 Edition Annex 5: Country Comments, n.d., accessed July 21, 2025, https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/sdc-documents/ERAA/2024/report/ERAA_2024_Annex_5%20Country_Comments.pdf.

288 Sarah Brown, "German State Awards €317 Million to Loss-Making Coal Plants," *Ember*, December 8, 2020, https://ember-energy.org/latest-insights/german-state-awards-e317-million-to-loss-making-coal-plants/.

289 "Bundesregierung Beschließt Kohleausstiegsgesetz," n.d. Website of the Federal Government | Bundesregierung, https://www.bundesregierung.de/breg-en/service/archive/kohleausstiegsgesetz-1717014.

290 Federal Ministry for Economic Affairs and Climate, *Design Proposal for a Combined Capacity Market*, 19/09/2024, https://www.bundeswirtschaftsministerium.de/Redaktion/EN/Downloads/design-proposal-for-a-combined-capacity-market.pdf?.

Germany is expanding its OSW footprint to help close this capacity gap. The urgency of accelerating OSW development was emphasized following Russia's invasion of Ukraine, which significantly impacted Germany as it had previously relied on Russia for 55% of its natural gas supply.[291]

Denmark

Historically, Denmark has maintained one of the highest levels of electricity supply security among peer countries, averaging fewer than 20 minutes of outage annually – mainly due to network faults rather than capacity shortages.[292] However, in a recent ERAA by ENTSO-E, Denmark is projected to face high resource adequacy risks beginning in 2026.[293] This risk is driven by growing demand from the electrification of transport and heating, the expansion of data centers, and Power-to-X facilities (facilities that convert electrical power, typically from renewables, into other forms of energy such as hydrogen or synthetic fuels).[294] These trends, coupled with the retirement of domestic thermal plants and regional decommissioning across Northwestern Europe, are increasing the risk of future supply shortfalls.[295]

Like Germany, Denmark does not have a formal capacity market where resources are assigned capacity accreditations, but it conducts regular national adequacy assessments through Energinet, the national transmission system operator. While individual resources are not assigned to fixed capacity values, they are all included in the system adequacy modeling framework. Denmark is also evaluating future capacity mechanisms to ensure sufficient generation, alongside efforts to scale demand-side flexibility and strengthen system resilience.[296]

OSW is expected to play a key role in maintaining resource adequacy as firm thermal capacity retires. While not explicitly stated since Denmark does not run formal accreditation studies or have organized capacity markets, OSW is likely to provide stable consistent output, particularly during winter months, and fill in gaps in solar power generation. Recognizing OSW's critical

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291 Norton Rose Fulbright, *Global Offshore Wind: Germany*: *Global* | *Publication* | *July 2023*, (global law firm), https://www.nortonrosefulbright.com/en-us/knowledge/publications/22341fc4/global-offshore-wind-germany.

292 Danish Energy Agency, *Climate Change Agreement Analysis 1 (2022)*, https://ens.dk/media/2124/download.

293 *European Network of Transmission System Operators for Electricity, European Resource Adequacy Assessment 2024 Edition* ERAA 2024 Edition Annex 5: Country Comments, n.d., accessed July 21, 2025, https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/sdc-documents/ERAA/2024/report/ERAA_2024_Annex_5%20Country_Comments.pdf.

294 Danish Energy Agency, *Climate Change Agreement Analysis 1* (2022), https://ens.dk/media/2124/download.

295 "European Network of Transmission System Operators for Electricity, *European, Resource Adequacy Assessment: 2024 Edition: ERAA 2024 Edition: Annex 5: Country Comments*, n.d., accessed July 21, 2025, https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/sdc-documents/ERAA/2024/report/ERAA_2024_Annex_5%20Country_Comments.pdf.

296 "Energinet, Danish Electricity Supply Security 2024-AFRY,2024, Afry.com https://bid3.afry.com/publicpages/publications/client-studies-pages/2025-04-28-energinet-danish-electricity-supply-security-2024.html.

value to cover the emerging resource adequacy gap, Denmark aims to scale OSW capacity from roughly 2.7 GW today to 14 GW by 2030 and up to 52 GW by 2050.[297]

As domestic generation tightens and imports become more critical during periods of regional stress, OSW is increasingly viewed not only as a decarbonization tool but as a strategic resource for reliability, reinforcing Denmark's adequacy position while bolstering resilience across the interconnected North Sea power system. Planned large-scale OSW deployment in the North Sea is expected to enhance Denmark's ability to maintain adequacy by reducing dependence on neighboring systems that are projected to face capacity shortfalls in the near term. These OSW projects are designed not only to meet domestic energy goals, but also to strengthen cross-border flexibility and contribute to regional system reliability. In parallel, Denmark is expanding its interconnector capacity within the North Sea region, enabling deeper integration with neighboring markets and improving mutual support capabilities during periods of stress. This coordinated offshore development aligns with EU-wide adequacy planning and the North Sea Grid corridor targets, positioning Denmark as a key contributor to the region's long-term energy security.[298,299]

Netherlands

The Netherlands is projected to maintain low resource adequacy risks through 2030, but post-2030 resource adequacy risks are projected to increase rapidly. TenneT, the Dutch grid operator, has warned that LOLE could rise to 12.6 hours by 2033—well above the 4-hour reliability standard. Among demand drivers is the growing electricity use from artificial intelligence and the rapid expansion of data centers, both of which have raised concerns from the grid operator.[300,301] TenneT notes that the interdependency between the neighboring countries is rising, with the Netherlands expected to import more energy than in the past.[302] As a result, the Netherlands is increasingly vulnerable to the energy policies and potential energy shortfalls of its neighbors. Ultimately, regional decommissioning across Northwestern Europe and rise in demand, will increase the risk of resource adequacy for the Netherlands.

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297 Offshore Coalition for Energy and Nature (OCEaN), *Denmark: Country Profile — Factsheet (December 2024)*, https://offshore-coalition.eu/wp-content/uploads/2025/03/Denmark_Factsheet_FINAL_country-profile.pdf.

298 European Commission, *Final update of Dan mark's National Energy and Climate Plan for the period 2021-2030*, June 2024, https://commission.europa.eu/document/download/13353c72-43bc-486e-bc82-9e8ea7588734_en?filename=DK_FINAL%20UPDATED%20NECP%202021-2030%20%28English%29.pdf.

299 Adnan Memija, 2025, "Denmark Targets This Autumn for Offshore Wind Tender Reboot with State Support," *Offshore Wind*, May 20, 2025, https://www.offshorewind.biz/2025/05/20/denmark-targets-this-autumn-for-offshore-wind-tender-reboot-with-state-support/.

300 Tennet, *Security of Supply 2025*, May 2025, https://tennet-drupal.s3.eu-central-1.amazonaws.com/default/2025-05/20250515%20TenneT%20Monitor%20Leveringszekerheid%202025%20final.pdf.

301 Milena Giorgi, "The Netherlands Faces Power Supply Risks after 2030: TenneT Calls for Urgent Investment—Strategic Energy Europe," *Strategic Energy Europe*, May 19, 2025, https://strategicenergy.eu/the-netherlands-power-supply-risks-2030-tennet.

302 TenneT, *International Dependency on Security of Electricity Supply Calls for More Cross-Border Coordination*, 2025, https://www.tennet.eu/nl-en/news/international-dependency-security-electricity-supply-calls-more-cross-border-coordination.

With the evolving energy landscape, the grid operator has called for government action, including further research on the introduction of capacity mechanisms and ramping up OSW deployment to meet the capacity gaps.[303]

Conclusions

Across American electricity markets, the nature of reliability risk is evolving. PJM, NYISO, ERCOT, and ISO-NE are each experiencing rapid load growth, increasing seasonal variability, and shifts toward winter-constrained conditions. These season shifts in load demand, driven largely by the electrification of heating and transportation from consumer preference and state policies, are altering the hours in which system risk is concentrated and reshaping the characteristics required of capacity resources. Additionally, markets, particularly PJM and ERCOT, are experiencing a rapid expansion in data centers in their footprints which are driving up demand and created more pressure across all hours and seasons due to their high load factor nature.

OSW has many features which position it to contribute toward meeting these challenges. **OSW delivers high capacity factors, reliable winter generation, near-term deployability, and accredited capacity values that rival – and in some cases exceed – those of traditional thermal resources.** It is also often aligned with most critical risk seasons, winter in most markets and summer in CAISO. Its resource adequacy value is represented in the high accreditation values assigned across the country. In PJM's most recent auction, OSW cleared at a 69% ELCC – the highest of any renewable and competitive with thermal resources. In NYISO and ISO-NE, OSW aligns with emerging winter peaks and coastal transmission constraints. In CAISO, it complements solar by producing in summer evenings, reducing the need for costly additional storage. Though these accreditations will decline at higher penetration, this will likely occur after GWs of investment and reflect a successful shifting of grid risk to lower wind hours.

International experience can provide opportunities for American leaders to understand how modeling will translate into real-world reliability benefits for the American power grid. In the UK and northern Europe, OSW is increasingly being viewed as cornerstone of adequacy planning by European leaders, consistently contributing during periods of highest stress and providing a hedge to disruptions in the natural gas supply However, results in the UK reinforce that OSW can continue to play a role in resource adequacy, but that marginal contribution of additional MWs at high penetrations will be less impactful than initial investments.

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[303] The Netherlands Ministry of Economic Affairs and Climate, *Update on Additional Offshore Wind Energy Roadmap,* 2025, https://english.rvo.nl/sites/default/files/2024-05/Letter-to-Parliament-Update-Offshore-Wind-Energy-Roadmap.pdf.

In the United States, OSW has the potential to be developed at multi-gigawatt scale, often adjacent to the most load-constrained coastal areas, positioning it as a valuable resource for alleviating local grid constraints. Delivering capacity directly into transmission-limited regions such as downstate New York, coastal New England, and mid-Atlantic load centers could reduce reliance on imports, mitigate bottlenecks, strengthen local adequacy where needs are most acute, and free up energy to further support additional load growth inland. Its potential future role is being currently demonstrated in two operational sites – Block Island and South Fork – which have successfully mitigated transmission and fuel limits in constrained regions in New England and New York.

As system risks shift, portfolios will need to balance multiple attributes: firm delivery during periods of highest stress, geographic diversity, and alignment with local transmission and siting realities. OSW, developed alongside complementary resources like natural gas, can play a meaningful role in this strategy – combining high accredited capacity values, scalable deployment potential, and the ability to serve the fastest-growing and most constrained load pockets, particularly those emerging in downstate NYISO, New England, and PJM.

While OSW's stress-aligned characteristics make it a promising resource adequacy tool, realizing its potential will depend on overcoming several material challenges seen in some domestic OSW projects. The cancellation and delay of several projects have illustrated how supply chain disruptions, inflationary pressures, evolving offtake structures, and permitting uncertainty can create substantial barriers to OSW development. Offshore transmission – though potentially requiring shorter total mileage, presenting fewer onshore siting conflicts, and targeted at key, constrained load pockets – may also pose significant cost and logistical hurdles. Finally, as capacity accreditation methods continue to evolve, markets will need to ensure that OSW's contributions are accurately and consistently reflected. Addressing these challenges will be critical to enabling OSW to scale meaningfully. If resolved, market leaders can identify an optimal mix of generation and transmission investments – potentially including OSW – that best balance reliability, affordability, and broader policy goals, including decarbonization.

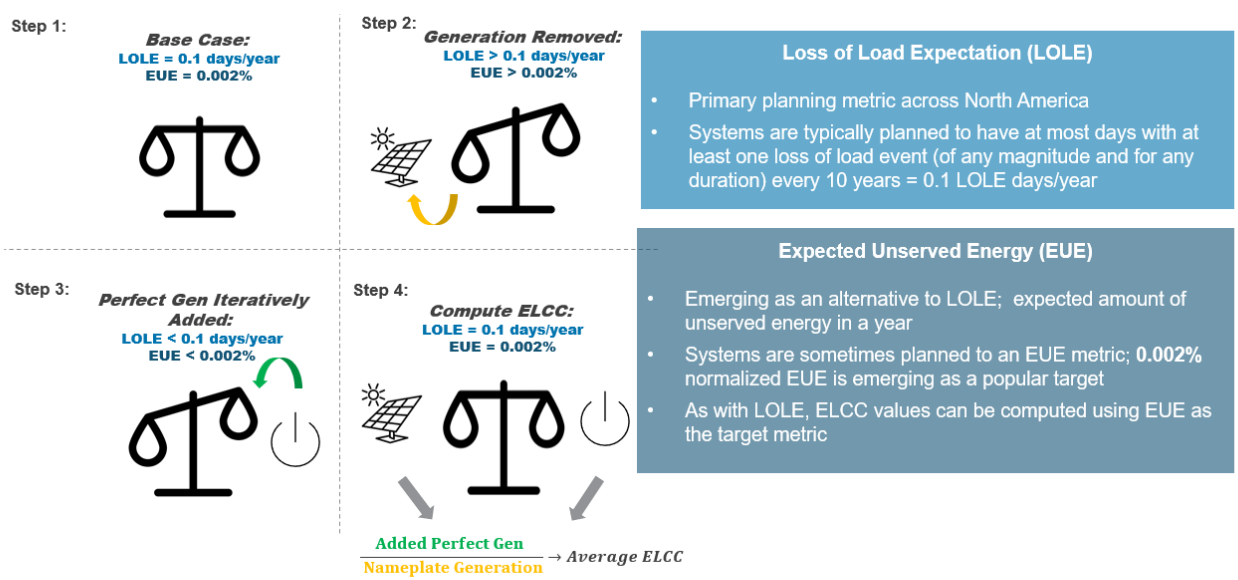
Appendix A – Effective Load Carrying Calculations

Effective Load Carrying Capability (ELCC) emerged as a quantitative method to measure how much of a resource's nameplate capacity can be counted toward meeting reliability needs. ELCCs offer a powerful mechanism for "apples-to-apples" to compare the reliability contribution of different resources.

An ELCC is calculated by first ensuring that a system meets a reliability standard (e.g., LOLE or EUE). Then, the resource in question is removed from the system, which results in degraded reliability. Perfect capacity (i.e., always-available capacity) is added back incrementally until the system returns to the target reliability level. This process is represented in Figure A-1**.** The ELCC is the ratio of this added perfect capacity to the original nameplate capacity of the resource being evaluated.

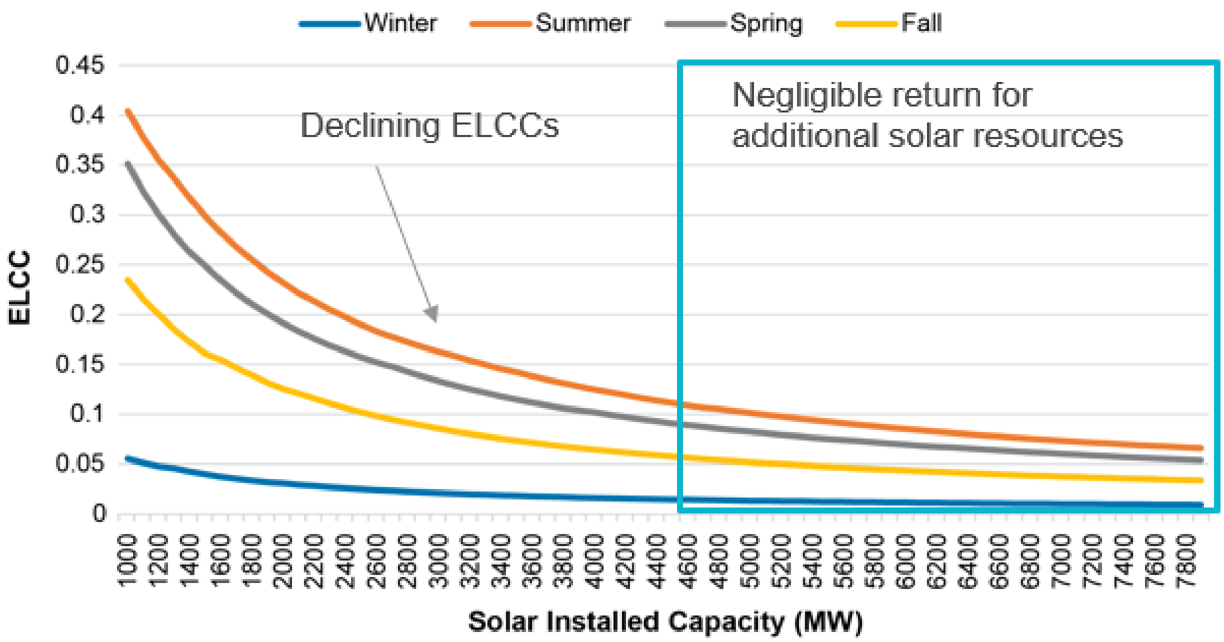
Most systems were designed to meet a **"1-day-in-10 years"**[304] reliability standard, meaning that the likelihood of any load shedding event – regardless of size or duration – should not exceed one day in ten years. In addition to **Loss of Load Expectation (LOLE)**, planners also used complementary metrics such as **Expected Unserved Energy (EUE)** to assess the amount of energy that could go unserved across an entire year.

Figure A-1: ELCC Computation Procedure



304 North American Electric Reliability Corporation, *Methods to Model and Calculate Capacity Contributions of Variable Generation for Resource Adequacy Planning* (IVGTF Task 1 – 2), June 2014, https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/IVGTF1-2.pdf.

Figure A-2: Illustrative example of Seasonal ELCC Values on Synthetic Utility



Importantly, as the penetration of a resource increases, its ELCC tends to decline, due to diminishing marginal contributions to reliability. This is particularly true for solar (See Figure A-2) storage, and wind resources. For example, adding a second solar plant to a system already saturated with solar offers less reliability value than the first since the next solar resource cannot contribute to times of grid stress, which are now after the sun has set. This ELCC degradation has important implications for planning and capacity accreditation in modern power systems.

Disclaimers and acknowledgements