

Attachment: Reliability Studies

This document provides a bibliography of 36 recent studies on the impacts of increased deployment of clean energy resources on the reliability of the nation's power grid. This non-exhaustive review includes analyses from a variety of authoritative sources, including grid operators, national labs, academic institutions and government entities. The studies consistently find that current levels of clean energy penetration pose no threat to reliability, that clean energy resources can contribute to the provision of grid reliability services, and that increasing levels of clean energy generation to as high as 80% (and at minimum 25%) would present no threat to reliability. In addition, reports indicate that present day operation of the power system is reliable with wind and solar at times providing as much as 40, 50, even 67% of demand with wind and solar in different parts of the U.S.

Grid operator findings included:

- SPP's 2016 Wind Integration Study, which found that the SPP system could operate reliably with wind generation comprising 60% of its generating capacity;
- CAISO's Using Renewables to Operate Low Carbon Grid study, which found that the ability of renewables to provide a range of grid reliability services was "comparable to, or better than, conventional resources;" and
- PJM's Renewable Integration Study, which found that the PJM system could incorporate 30% variable generation with no loss of reliability.
- NYISO's 2016 Comprehensive Reliability Plan found that New York State Bulk Power Transmission Facilities will meet all applicable Reliability Criteria over the 2017 through 2026 Study Period.
- ERCOT's 2016 Reliability Risks Due to Coal Retirement Report found that coal plant retirement is unlikely to undermine reliability.
- The portion of load served by wind in Texas has reached 48.28%, set on March 23, 2016.¹ In Colorado Wind has met 50% of load for an entire day. And in California, non-hydropower renewable facilities served a record 67.2% of the CAISO's electricity needs.

National lab, governmental, and academic institution findings included:

- NREL's Renewables Future Study reported no concerns on "any reliability metric" with renewable energy resources providing at least 25-50% of electricity, and found that renewable generation levels as high as 80% could be achieved with technologies commercially available today without compromising reliability.
- NREL's Eastern Renewable Generation Integration Study found that integrating up to 30% variable wind and PV generation into the power system is technically feasible at a five-minute interval.

¹ See <http://www.ercot.com/news/releases/show/113533>. See https://www.xcelenergy.com/energy_portfolio/renewable_energy/wind/co_wind_power. See <http://www.sfgate.com/business/article/State-breaks-another-renewable-energy-record-11156443.php>.

- Columbia Center on Global Energy Policy’s Can Coal Make a Comeback Study found that a surge in US natural gas production due to the shale revolution has driven down prices and made coal increasingly uncompetitive in US electricity markets.
- International Energy Agency’s The Power of Transformation: Wind, Sun, and the Economics of Flexible Power Systems Study found that up to 45% of variable renewable energy can be integrated without significantly increasing power system costs in the long run.

Other findings included:

- General Electric’s Minnesota Renewable Energy Integration and Transmission Study found that using wind and solar energy to supply “40% of Minnesota’s annual electric retail sales can be reliably accommodated by the electric power system.” The study also determined that increasing solar to “achieve 50% renewable energy in Minnesota and 25% renewable energy in MISO North / Central (10% above current renewable energy standards in neighboring states),” the power system can be “successfully operated for all hours of the year,” with no unserved load, no reserve violations, and minimal curtailment.
- The Brattle Group’s Integrating Renewable Energy into the Electricity Grid noted the success to date of ERCOT and Xcel Energy Colorado shows that integrating variable renewable energy at penetration levels of 10-20% on average and at times above 50% – i.e., high relative to the current levels in most of the United States – is possible.

Selected Studies on Clean Energy and Grid Reliability

1. American Council on Renewable Energy (ACORE) – Energy Fact Check: The Impact of Renewables on Electricity Markets and Reliability (May 16, 2017), *available at* http://www.acore.org/images/DOE-EFC_2-pager.pdf
2. Advanced Energy Economy Institute – Changing the Power Grid for the Better (May 2017), *available at* <https://cdn2.hubspot.net/hubfs/211732/PDF/Changing-the-power-grid-for-the-better-1.5.pdf>
3. American Wind Energy Association (AWEA) – Renewable Energy Builds a More Reliable and Resilient Electricity Mix (May 2017), *available at* <http://www.ourenergypolicy.org/wp-content/uploads/2017/05/AWEA-Renewable-Energy-Builds-a-More-Reliable-and-Resilient-Electricity-Mix.pdf>
4. The Brattle Group – Integrating Renewable Energy into the Electricity Grid, *available at* <http://info.aee.net/hubfs/EPA/AEEI-Renewables-Grid-Integration-Case-Studies.pdf?t=1440089933677>
5. CAISO – Beyond 33% Renewables: Grid Integration Policy for a Low-Carbon Future, *available at* http://www.cpuc.ca.gov/uploadedFiles/CPUC_Website/Content/Utilities_and_Industries/Energy/Reports_and_White_Papers/Beyond33PercentRenewables_GridIntegrationPolicy_Final.pdf

6. CAISO - Using Renewables to Operate a Low-Carbon Grid, *available at* <https://www.caiso.com/Documents/UsingRenewablesToOperateLow-CarbonGrid.pdf>
7. Columbia Center on Global Energy Policy - Can Coal Make a Comeback? (April 2017), *available at* <http://energypolicy.columbia.edu/sites/default/files/energy/Center%20on%20Global%20Energy%20Policy%20Can%20Coal%20Make%20a%20Comeback%20April%202017.pdf>
8. DOE - Quadrennial Energy Review (Jan 2017), *available at* <https://energy.gov/epsa/quadrennial-energy-review-qer>
9. US Energy Information Administration (EIA) - Short-Term Energy Outlook, *available at* <https://www.eia.gov/outlooks/steo/>
10. International Energy Agency (IEA) - The Power of Transformation: Wind, Sun, and the Economics of Flexible Power Systems, *available at* https://www.iea.org/publications/freepublications/publication/The_power_of_Transformation.pdf
11. Journal of Applied Meteorology and Climatology - Supplying Baseload Power and Reducing Transmission Requirements by Interconnecting Wind Farms (Feb. 2007), *available at* <http://journals.ametsoc.org/doi/pdf/10.1175/2007JAMC1538.1>
12. Nature Climate Change - Potential for concentrating solar power to provide baseload and dispatchable power (Jun. 2014), *available at* <http://www.nature.com/nclimate/journal/v4/n8/full/nclimate2276.html>
13. NERC - 2016 Long-Term Reliability Assessment, *available at* <http://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/2016%20Long-Term%20Reliability%20Assessment.pdf>
14. NREL – 20% Wind Energy by 2030 (2008), *available at* <http://www.nrel.gov/docs/fy08osti/41869.pdf>
15. NREL – Demonstration of Essential Reliability Services by a 300 MW Solar PV Power Plant, *available at* <http://www.nrel.gov/docs/fy17osti/67799.pdf>
16. NREL – Grid Integration and the Carrying Capacity of the US Grid to Incorporate Variable Renewable Energy, *available at* <http://www.nrel.gov/docs/fy15osti/62607.pdf>
17. NREL – Renewable Electricity Futures: Operational Analysis of the Western Interconnection at Very High Renewable Penetrations, *available at* <http://www.nrel.gov/docs/fy15osti/64467.pdf>

18. NREL – Renewable Electricity Futures Study, *available at*
http://www.nrel.gov/analysis/re_futures/
19. NREL – The Role of Advancements in Solar PV Efficiency, *available at*
<http://www.nrel.gov/docs/fy16osti/65872.pdf>
20. NREL – Eastern Renewable Generation Integration Study, *available at*
<http://www.nrel.gov/docs/fy16osti/64472.pdf>
21. PJM’s Evolving Resource Mix and System Reliability (March 2017), *available at*
<http://www.pjm.com/~media/library/reports-notice/special-reports/20170330-pjms-evolving-resource-mix-and-system-reliability.ashx>
22. PJM Renewable Integration Study (March 2014), *available at*
<https://www.pjm.com/~media/committees-groups/subcommittees/irs/postings/pris-executive-summary.ashx>
23. NYISO 2016 Comprehensive Reliability Plan (April 2017), *available at*
http://www.nyiso.com/public/webdocs/markets_operations/services/planning/Planning_Studies/Reliability_Planning_Studies/Reliability_Assessment_Documents/2016CRP_Report_Final_Apr11_2017.pdf
24. Scott Institute for Energy Innovation – Managing Variable Energy Resources to Increase Renewable Electricity’s Contribution to the Grid, *available at*
<http://www.cmu.edu/epp/policy-briefs/briefs/Managing-variable-energy-resources.pdf>
25. SEIA – Solar and Renewables Benefit the Grid and the US Economy SPP – 2016 Wind Integration Study (Jan. 2016), *available at*
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26. SPP – 2016 Wind Integration Study (Jan. 2016), *available at*
[https://www.spp.org/documents/34200/2016%20wind%20integration%20study%20\(wis\)%20final.pdf](https://www.spp.org/documents/34200/2016%20wind%20integration%20study%20(wis)%20final.pdf)
27. Union of Concerned Scientists – Renewables and Reliability Fact Sheet: Grid Management Solutions to Support CA’s Clean Energy Future, *available at*
<http://www.ucsusa.org/sites/default/files/attach/2015/03/california-renewables-and-reliability.pdf>
28. DOE- Meta-analysis of high penetration renewable energy scenarios, *available at*
<http://www.sciencedirect.com/science/article/pii/S1364032113006291?via%3Dihub>
29. GE - Minnesota Renewable Energy Integration and Transmission Study, *available at*
<http://mn.gov/commerce-stat/pdfs/mrits-report-2014.pdf>

30. NREL - Low Carbon Grid Study, *available at* <http://www.nrel.gov/docs/fy16osti/64884.pdf>
31. Nebraska Statewide Wind Integration Study, *available at* <http://www.nrel.gov/docs/fy10osti/47519.pdf>
32. NREL - Eastern Frequency Response Study, *available at* http://www.rynek-ciepla.cire.pl/pliki/2/eastern_frequency_response_study.pdf
33. NREL - Western Wind and Solar Integration Study Phase 3 – Frequency Response and Transient Stability, *available at* <http://www.nrel.gov/docs/fy15osti/62906-ES.pdf>
34. NREL – Relevant Studies for NERC’s Analysis of EPA’s CPP, *available at* <http://www.nrel.gov/docs/fy15osti/63979.pdf>
35. ERCOT - 2016 Reliability Risks Due to Coal Retirement Report, *available at* <http://www.texascleanenergy.org/Reliability%20Risks%20Due%20to%20Coal%20Retirement%20at%20ERCOT%20FINAL%20REPORT%206%20Dec%202016.pdf>
36. Energy Innovation - Secretary Perry, We Have Some Questions Too, *available at* <http://energyinnovation.org/2017/05/19/trending-topics-secretary-perry-questions/>