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Clean Energy Keeps the Lights On

Authors

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"Our models found no technical difficulties accommodating much higher levels of variable wind and solar energy, while fully preserving reliability."

— Brattle Group (2013), for the Texas Clean Energy Coalition

Studies sponsored by utilities, government, and nongovernmental organizations and executed by highly-regarded technical experts over the last four years have concluded that: renewable penetrations beyond current state renewable portfolio standards (RPS) can be accommodated with current electric system flexibility; proven technologies and practices can dramatically reduce the cost of operating high penetration variable renewable energy (VRE) portfolios; and the studies that examined very high renewable penetrations found that these same technologies and practices can improve system flexibility and enable the electric system to operate reliably with renewable penetrations well above 50 percent.[1] Each of the studies surveyed in this document recommends investment in additional distribution and transmission system infrastructure as well as changes in electric system operations, markets, and planning to achieve reliability with high penetrations of VRE at least cost, but none of the studies suggest insurmountable reliability problems.

Studies supported by technical experts from PJM, General Electric (GE) Energy Solutions, Energy and Environmental Economics (E3), the Brattle Group, KEMA, the International Energy Agency (IEA), Imperial College London, Massachusetts Institute of Technology (MIT), and the National Renewable Energy Laboratory (NREL) have concluded that electric systems can be operated reliably with levels of VRE of 50 percent or more. PJM, for example, asserts that with adequate transmission additions and some additional regulation reserves, the PJM system will have no reliability issues with VRE penetrations of 30 percent. E3's study commissioned by several California utilities says that no reliability issues arise in California in meeting the current 33-percent RPS if expected transmission and generation investments are made, and that VRE levels of 40 and 50 percent can be accommodated, but the evolution of system operations will be required to minimize the cost of curtailment.[2] The Brattle Group's study for the Texas Clean Energy Coalition indicates that reliability will be maintained

1 The studies summarized at the end of this document were sponsored by diverse organizations ranging from public and investor-owned utilities, Electric Reliability Council of Texas (ERCOT), PJM, the U.S. Department of Energy (U.S. DOE), and International Energy Agency (IEA); and the consultants conducting the studies include the Brattle Group, GE Energy Solutions, KEMA, and Energy and Environmental Economics (E3). The technical experts supporting the studies include many who reside at research institutions like Lawrence Berkeley National Laboratory (LBNL), National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory (PNNL), Massachusetts Institute of Technology (MIT), and Imperial College London.

2 The RPS in California excludes net metered distributed generation (DG), so a 33-percent RPS in California actually includes VRE in excess of 33 percent if one accounts for net metered DG. For an independent review of the assumptions in the E3 study see: Arivizu, D., Borenstein, S., Tierney, S., & Wright, S. (2014). *Report of the Independent Advisory Panel regarding the five California utilities' study of the integration of renewable energy into California's electric system.* Retrieved from https://ethree.com/documents/Advisory_Panel_Report_on_the_CA_RPS_Study_FINAL_1-2014.pdf.

in Texas with increases in wind and solar if some additional ancillary services are secured. NREL examined very high renewable resource penetrations in the United States and found that penetrations up to 80 percent are feasible, but significant infrastructure additions and changes in operating practices are required. Each of these studies and the others cited later agree that transmission investments are often necessary to deliver renewable energy to markets and that the cost of high penetration VRE portfolios can be significantly reduced by improving electric grid resources and operation.[3] Each of the studies indicates that the lights can be kept on with VRE penetrations that exceed current state RPS requirements.

When VRE penetration grows in a highly concentrated fashion in one location, reliability challenges can appear. The high adoption rate of distributed solar photovoltaics (PV) in southern California presents one example of a local reliability challenge. High local adoption of solar PV suppresses demand during the afternoon and then accelerates demand as dusk approaches, and for some days of the year this produces a load shape that presents several operational challenges. However, even in this circumstance, proven technologies and feasible changes in operating practices can be used to meet the challenge.[4]

Some current challenges are sometimes misrepresented as evidence that higher penetrations of VRE will necessarily compromise reliability. One example is the energy transformation underway in Germany, called the "Energiewende." Because Germany has undertaken serval major challenges simultaneously, it is both a laboratory for change and is ripe for misunderstanding and misinterpretation. Electricity demand in Germany has been essentially flat since 2008, owing to a combination of aggressive efficiency programs and the continued effects of the financial crisis. During that period a number of large new fossil-fired generators initiated prior to the crisis came online, and a large quantity of new renewable generation was commissioned pursuant to Germany's feed-in-tariff legislation. As a result, Germany is awash in surplus capacity, which has led to a collapse in wholesale energy prices and considerable financial pressure on some power plant owners. Many have been quick to assert that there is a threat to resource adequacy that is a direct consequence of the variability and low marginal cost of production of the new renewable resources on the system. There is simply no basis in fact to support that conclusion, and furthermore the German system operators have been quite public and consistent in asserting that there is no fundamental reason the Central European grid cannot reliably incorporate the current and expected level of renewable production.[5] There are certainly system operation challenges that Germany needs to come to grips with, but reversing course on the deployment of renewables is not one of them, and current government policy is consistent with that conclusion.

The evidence is clear: clean energy portfolios with renewable energy penetrations well above existing state RPS requirements can keep the lights on. The tools to manage a diverse and robust array of resources are available now and improving with use, with better models and more capable computing and communications systems. The question is not whether a low-carbon, high-VRE future is technically feasible. The question is, will utilities, system operators, and regulators work together to ensure the necessary investments and changes in operations, markets, and planning are made to achieve a low-carbon future at least cost?

3 A few of the commonly cited system improvements include: building a more robust network that facilitates intra-hour and inter-day regional exchanges, taking better advantage of current demand-side resource capabilities, incorporating advanced demand response capabilities that take advantage of the two-way information flow of the emerging grid, and investing in existing and new storage technologies.

4 Hogan, M. & Paulos, B. (2014). *Dealing with the duck.* Montpelier, VT: Regulatory Assistance Project.

Lazar, J. (2014). *Teaching the "duck" to fly.* Montpelier, VT: Regulatory Assistance Project.

5 *European grid declaration on electricity network development and nature conservation in Europe.* (2011). Brussels, Belgium: Renewables Grid Initiative.

Summaries of Recent Technical Studies

Some utilities assert that electric service cannot be reliable if the share of energy needs met by renewable energy and demand-side resources increase. For example, in a recent speech, FirstEnergy CEO Tony Alexander warned that, "energy efficiency, renewable power, distributed generation, microgrids, rooftop solar and demand reduction are examples of what 'sounds good' but really are 'untested policies' that will threaten grid reliability and raise electricity prices."[6] In contrast, recent scholarly reports amply demonstrate that renewable energy penetrations in excess of state-mandated RPSs will not compromise reliability, and that demand-side resources like demand response and storage can play an important role in keeping the cost of electricity down. Some recent studies affirming the reliability of increasing amounts of renewable resources are summarized and linked below.

Roadmap 2050: A Practical Guide to a Prosperous Low-Carbon Europe, 2010

Prepared for the European Climate Foundation by McKinsey and Company, KEMA, the Energy Futures Laboratory at Imperial College of London, and Oxford Economics

Available at: http://www.roadmap2050.eu/attachments/files/Volume1_fullreport_PressPack.pdf

"By deploying technologies already commercial today, or in late development stage, Europe could reduce greenhouse gases [sic] emissions by 80% by 2050 compared to 1990 and still provide the same level of reliability as the existing energy system."

Roadmap 2050 seeks to establish technically feasible pathways to 80-percent carbon reduction in Europe by 2050. Initial analysis found that the power sector must be 95-percent to 100-percent decarbonized by 2050 for the economy-wide goal to be met, so technical analysis was undertaken to evaluate the feasibility of decarbonizing the power sector. Several pathways were examined, including very high renewable energy futures. The study finds that full decarbonization is technically feasible with technologies that exist today or that are in the very late stage of development. All scenarios include energy efficiency improvement of about two percent per year, and the renewable portion of the portfolios ranges from 40 percent to 100 percent of all electric generation.[7] The study highlights the importance of implementing energy efficiency, making steady improvements in low-carbon technology performance, improving grid and integrated market operation, and using markets to induce the necessary investment.

Eastern Wind Integration and Transmission Study, 2011

Prepared by EnerNex Corporation for NREL

Available at: http://www.nrel.gov/docs/fy11osti/47078.pdf

"The direct incremental cost associated with high renewable generation is comparable to published cost estimates of other clean energy scenarios. Improvement in the cost and performance of renewable technologies is the most impactful lever for reducing this incremental cost."

The U.S. Department of Energy (U.S. DOE) commissioned the *Eastern Wind Integration and Transmission Study* in 2007 to investigate a number of questions relating to the operational consequences of 20-percent to 30-percent wind penetration in the Eastern Interconnection by 2024. One scenario was constructed to serve as a reference case, and that scenario included six percent of all

6 Kuckro, R. (2014, April 9). FirstEnergy CEO decries mandates driven by 'social agenda.' *Environment & Energy Publishing*. Retrieved from www.eenews.net.

7 European Climate Foundation. (2010). *Roadmap 2050: A practical guide to a prosperous low-carbon Europe*. Retrieved from http://www.roadmap2050.eu/attachments/files/Volume1_fullreport_PressPack.pdf.

energy being served by wind generation. Three 20-percent scenarios considered the consequences of different mixes of offshore and onshore wind development, and a 30-percent scenario looked at the consequences of high onshore and offshore development. The 20-percent and 30-percent scenarios included penetrations of different levels around sub-regions of the Eastern Interconnection, but the total levels of wind generation studied range from a low of about 220,000 MW to a high of about 420,000 MW. Study findings include:

- New transmission will be required for all wind development scenarios, including the reference case;
- High penetrations of wind generation are technically feasible if adequate transmission is constructed; and
- Interconnection-wide costs are manageable with large regional operating pools and significant market, tariff, and operational changes.

Although the study finds there will be some costs associated with integrating large amounts of wind generation, the cost is modest: "With large balancing areas and fully-developed regional markets, the cost of integration for all scenarios is about $5 (US$ 2009) per megawatt-hour (MWh) of wind, or about $0.005 per kilowatt-hour (kWh) of electricity used by customers."[8]

Renewable Electricity Futures Study, 2012

Prepared for and by NREL, edited by individuals from NREL, U.S. DOE, MIT, and Ed DeMeo Consulting

Available at: http://www.nrel.gov/analysis/re_futures/

"Renewable electricity generation from technologies that are commercially available today, in combination with a more flexible electric system, is more than adequate to supply 80% of total U.S. electricity generation in 2050 while meeting electricity demand on an hourly basis in every region of the country."

The purpose of this study, which was funded by the U.S. DOE, Office of Energy Efficiency and Renewable Energy, was to conduct an initial investigation of the feasibility of renewable energy meeting the electricity needs of the continental United States over the next several decades. The team included members from NREL and MIT, and subject matter experts from U.S. DOE national laboratories, including NREL, Idaho National Laboratory, Lawrence Berkeley National Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, and Sandia National Laboratories, as well as Black & Veatch and other utility, industry, university, public sector, and nonprofit participants.

Renewable Electricity Futures Study analyzes renewable energy resources as well as the technical issues related to the operability of the U.S. electricity grid. The study concludes that a future based on 80-percent renewable energy is possible; that all regions of the United States could contribute substantially; and that further work to develop this pathway is warranted.[9] Furthermore, the study concludes that the incremental cost associated with high renewable generation is comparable to published cost estimates of other clean energy scenarios (for efficient natural gas, clean coal, energy efficiency, and nuclear technologies). Moreover, no insurmountable long-term constraints to renewable energy manufacturing capacity, materials supply, or labor availability were identified.

In order for the high usage of renewable generation to take place, the electricity system would need to be transformed. This would involve every element of the grid, from system planning through operation. Adequate planning and operating reserves would need to be ensured along with the increased flexibility of the electric system. Multistate transmission infrastructure would need to be expanded. Furthermore, key to the success of this endeavor would be the development and adoption of technology advances, new operating procedures, evolved business models, and new market rules.

Western Wind and Solar Integration Study, Phase 1: 2010; Phase 2: 2013

Prepared by GE Energy Consulting for NREL

Phase 1: http://www.nrel.gov/docs/fy10osti/47781.pdf
Phase 2: http://www.nrel.gov/docs/fy13osti/58798.pdf

"The technical analysis performed in this study shows that it is feasible for the WestConnect region to accommodate 30% wind and 5% solar energy penetration. This requires key changes to current practice, including substantial balancing area cooperation, sub-hourly scheduling, and access to underutilized transmission capacity."

8 EnerNex Corporation. (2011). *Eastern wind integration and transmission study.* Retrieved from http://www.nrel.gov/docs/fy11osti/47078.pdf.

9 National Renewable Energy Laboratory. (2012). *Renewable electricity futures study.* Retrieved from http://www.nrel.gov/analysis/re_futures/.

The Western Wind and Solar Integration Study examines the electric system effects of 35 percent wind and solar penetration in the WestConnect footprint of the Western Interconnection. The study was led by NREL and overseen by a technical review team to ensure reasonable technical analysis. The technical review team included representatives of utilities in the WestConnect footprint. Phase 1 of the study examined the operational feasibility of 35 percent of the WestConnect annual energy demand served by wind and solar resources in 2017 from a resource adequacy perspective.[10] A number of changes in operational practices of the utilities and balancing area operators in the WestConnect are identified, including: least-cost economic dispatch across the WestConnect footprint; entities gain the ability to schedule transmission on an intra-hour basis; all available transmission is available for use on a non-firm basis; and the 38 Western Interconnection balancing areas virtually consolidate to operate as if they were five distinct entities.[11] Phase 2 of the study addresses stakeholder concerns that coal plant cycling would impose significant costs on consumers. However, Phase 2 found that increased costs from coal plant cycling were very small and represented only a very small fraction of the variable cost savings associated with the 35-percent scenarios. Phase 3 of the study is underway to examine whether high renewable penetration scenarios have frequency response or transient stability issues, and the result of Phase 3 is expected in the fall of 2014. In sum, the studies performed to date indicate that operators in the WestConnect footprint could keep the lights on with 35-percent renewable energy penetration if the operational practices in the footprint evolve in a number of respects. Studies coming later this year will test this proposition by examining two more specific aspects of system reliability.

Exploring Natural Gas and Renewables in the Electric Reliability Council of Texas, Part II: Future Generation Scenarios for Texas, 2013

Prepared by the Brattle Group for the Texas Clean Energy Coalition

Available at: http://www.texascleanenergy.org/TCEC_Report%20Final%20Clean%2012%203%2013.pdf

"Our models found no technical difficulties accommodating much higher levels of variable wind and solar energy, while fully preserving reliability."

The Brattle Group was asked to explore six scenario futures for Texas for the period ending in 2032. The total generation capacity in ERCOT in 2012 was 83,650 MW and the generation capacity required in 2032 for the Reference Case was found to be 96,903 MW. For each alternative scenario, the Brattle Group ran a generation expansion model to build the least-cost portfolio and then examined the reliability implications of each portfolio with a system optimization model. Natural gas and renewable generation accounted for all generation expansion under all six scenarios. Texas already has the largest wind portfolio in the country, with 12,000 MW operating, and the scenario results produced 2032 wind capacity levels ranging from about 4,000 MW in the scenario least favorable for renewable development up to 46,000 MW in the scenario with conditions most favorable for renewable development. Solar development ranged from about 6,000 MW up to about 13,000 MW. The size of the gas generation fleet in 2032 ranged from about 50,000 MW to about 65,000 MW. Coal generation ranged from maintaining current levels of generation (18,694 MW) to different levels of decline, with the greatest decline happening in a stronger federal carbon rule scenario, where 2032 coal generation fell to 3,495 MW. The reliability assessment of the portfolios indicates that generation portfolios with the highest levels of renewable generation would require an increase in certain ancillary services, but no insurmountable reliability challenges were revealed in any scenario.[12]

10 GE Energy Consulting. (2010). *Western wind and solar integration study, phase 1*. Retrieved from http://www.nrel.gov/docs/fy10osti/47781.pdf.

11 For a more complete description of these operational changes, see GE Energy Consulting, 2010, ES-1.

12 Brattle Group. (2013). *Exploring natural gas and renewables in the Electric Reliability Council of Texas, part II: future generation scenarios for Texas.* Retrieved from http://www.texascleanenergy.org/TCEC_Report%20Final%20Clean%2012%203%2013.pdf.

Investigating a Higher Renewables Portfolio Standard for California, 2014

Prepared by Energy and Environmental Economics (E3) for the Los Angeles Department of Water and Power, Sacramento Municipal Utility District, Pacific Gas and Electric, Southern California Edison, and San Diego Gas and Electric

Available at: https://www.ethree.com/documents/E3_Final_RPS_Report_2014_01_06_with_appendices.pdf

"The most important challenge is over-generation during daylight hours."

California's current RPS is set at 33 percent of energy being delivered by qualified renewable energy facilities by 2020, but extensions of the standard to 40 percent and 51 percent by a future year beyond 2020 are under consideration. The study builds portfolios to ensure resource adequacy and to meet the operational challenges that arise with high-penetration variable energy. The study finds that all scenarios meet a "day in ten years" loss of load expectation criteria with minimal or no incremental fossil resource additions.[13] The study also finds that the flexibility of the existing fleet is adequate to meet the ramping challenges, even on the most severe days observed in any of the scenarios.[14] The challenge presented in the study is not a reliability challenge, but rather the challenge of curtailing generation to avoid over-generation. The required curtailment ranges from the negligible amount of 0.2 percent of total renewable energy over-generation in the 33-percent case to the significant amount of 8.9 percent over-generation in one of the 50-percent cases.[15] Curtailment mitigation options such as diversifying the sources of supply on a regional basis, accessing conventional demand response resources, accessing advanced demand response resources, and taking advantage of storage are offered to reduce the need for curtailment. No mitigation options are required to ensure reliability, because all portfolios meet the resource adequacy and operational reliability requirements.

PJM Renewable Integration Study, 2014

Prepared by General Electric Energy Consulting for PJM

Available at: http://pjm.com/~/media/committees-groups/task-forces/irtf/postings/pris-executive-summary.ashx

"The study findings indicate that the PJM system, with adequate transmission expansion and additional regulating reserves, will not have any significant issues operating with up to 30% of its energy provided by wind and solar generation."

The *PJM Renewable Integration Study* (PJM Study) investigates the operational, planning, and energy market effects of having renewable energy provide up to 30 percent of energy to the PJM region.[16] The PJM Study was commissioned by PJM and undertaken by a team led by GE Energy Consulting and consisting of AWS Truepower, EnerNex, Exeter Associates, Intertek Asset Integrity Management, and PowerGEM. In 2011, renewable energy generation accounted for two percent of the energy produced in the PJM balancing area. Current state renewable energy requirements will result in this percentage growing to 14 percent of annual electric energy in 2026, and the study evaluates scenarios that reach as high as 30 percent renewable energy penetration. The operational and planning aspects of the study indicate that keeping the lights on with much greater renewable energy penetration in 2026 is plausible. The study also examines whether electricity service would be reliable on an hourly basis as well as on a sub-hourly and real-time basis. The study selected operational conditions such as situations in which renewable energy variation and energy demand levels combined to produce a potentially challenging situation. The study results indicate that more regulation reserves were used, more ramping capability was accessed, and additional transmission was required to interconnect higher levels of renewable energy penetration; however, the study found no instances of loss of load. To state it plainly, the study found that with 30 percent of annual energy provided by renewable energy resources, the lights would stay on even under the most challenging operational situations.[17]

13 For the 33-percent RPS, about 600 MW of incremental fossil is needed to supplement the fossil fleet of about 40,000 MW in 2030, and no incremental resources are required for any of the 40-percent and 50-percent cases. See pp. 56 and 84 of Energy and Environmental Economics. (2014). *Investigating a higher renewables portfolio standard for California.* Retrieved from https://www.ethree.com/documents/E3_Final_RPS_Report_2014_01_06_with_appendices.pdf.

14 Energy and Environmental Economics, 2014. See p. 113.

15 Energy and Environmental Economics, 2014. See p. 107.

16 GE Energy Consulting. (2014). *PJM renewable integration study: executive summary.* Retrievable from http://pjm.com/~/media/committees-groups/task-forces/irtf/postings/pris-executive-summary.ashx

17 GE Energy Consulting, 2014.

Wind, Sun, and the Economics of Flexible Power Systems, 2014

Prepared for and by the IEA

Available at: http://www.iea.org/Textbase/npsum/GIVAR2014sum.pdf

"An assessment of case study regions with the revised IEA Flexibility Assessment Tool (FAST2) showed that annual VRE (Variable Renewable Energy) shares of 25% to 40% can be achieved from a technical perspective, assuming current levels of system flexibility."

The study examines the cost and reliability consequences of relatively high wind and solar penetration through seven scenarios spanning 15 countries from Europe, North America, South America, India, and Asia. The findings indicate that wind and solar penetration in the five-percent to ten-percent range poses no significant cost or reliability consequences with current levels of system flexibility. Penetrations in the 25-percent to 40-percent range yield reliable service, even assuming current levels of system flexibility. However, the cost of integrating renewables in this higher range benefits from system-friendly VRE deployment, from improved system and market operation, and from investment in additional flexible resources. Transforming electric system operations to provide these system-friendly changes can reduce the system cost impact of 45-percent VRE penetration by two-thirds.[18]

18 International Energy Agency. (2014). *Wind, sun, and the economics of flexible power systems.* Retrieved from http://www.iea.org/Textbase/npsum/GIVAR2014sum.pdf.

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