NREL
NATIONAL RENEWABLE ENERGY LABORATORY





Assessing Capacity Value of Wind Power

Bethany A. Frew

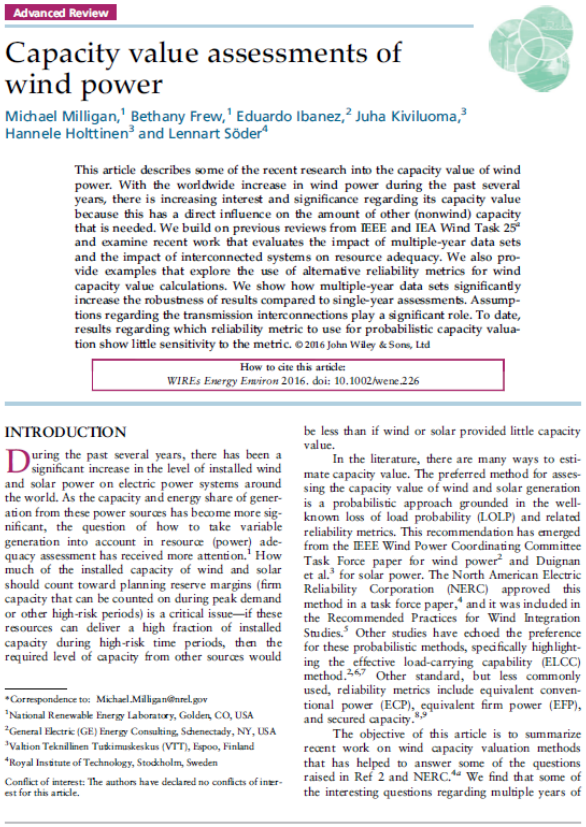
15th International Workshop on Large-Scale Integration of Wind Power into Power Systems

Vienna, Austria
November 17, 2016

NREL/PR-6A20-67501

Full team and paper

- **Hannele Holttinen** and **Juha Kiviluoma** (VTT, Finland)
- **Michael Milligan** and **Bethany Frew** (NREL, USA)
- **Lennart Söder** (KTH Royal Institute of Technology, Sweden)



Advanced Review

Capacity value assessments of wind power

Michael Milligan,[1] Bethany Frew,[1] Eduardo Ibanez,[2] Juha Kiviluoma,[3] Hannele Holttinen[3] and Lennart Söder[4]

This article describes some of the recent research into the capacity value of wind power. With the worldwide increase in wind power during the past several years, there is increasing interest and significance regarding its capacity value because this has a direct influence on the amount of other (nonwind) capacity that is needed. We build on previous reviews from IEEE and IEA Wind Task 25[a] and examine recent work that evaluates the impact of multiple-year data sets and the impact of interconnected systems on resource adequacy. We also provide examples that explore the use of alternative reliability metrics for wind capacity value calculations. We show how multiple-year data sets significantly increase the robustness of results compared to single-year assessments. Assumptions regarding the transmission interconnections play a significant role. To date, results regarding which reliability metric to use for probabilistic capacity valuation show little sensitivity to the metric. © 2016 John Wiley & Sons, Ltd

How to cite this article:
WIREs Energy Environ 2016. doi: 10.1002/wene.226

INTRODUCTION

During the past several years, there has been a significant increase in the level of installed wind and solar power on electric power systems around the world. As the capacity and energy share of generation from these power sources has become more significant, the question of how to take variable generation into account in resource (power) adequacy assessment has received more attention.[1] How much of the installed capacity of wind and solar should count toward planning reserve margins (firm capacity that can be counted on during peak demand or other high-risk periods) is a critical issue—if these resources can deliver a high fraction of installed capacity during high-risk time periods, then the required level of capacity from other sources would be less than if wind or solar provided little capacity value.

In the literature, there are many ways to estimate capacity value. The preferred method for assessing the capacity value of wind and solar generation is a probabilistic approach grounded in the well-known loss of load probability (LOLP) and related reliability metrics. This recommendation has emerged from the IEEE Wind Power Coordinating Committee Task Force paper for wind power[2] and Duignan et al.[3] for solar power. The North American Electric Reliability Corporation (NERC) approved this method in a task force paper,[4] and it was included in the Recommended Practices for Wind Integration Studies.[5] Other studies have echoed the preference for these probabilistic methods, specifically highlighting the effective load-carrying capability (ELCC) method.[2,6,7] Other standard, but less commonly used, reliability metrics include equivalent conventional power (ECP), equivalent firm power (EFP), and secured capacity.[8,9]

The objective of this article is to summarize recent work on wind capacity valuation methods that has helped to answer some of the questions raised in Ref 2 and NERC.[4,a] We find that some of the interesting questions regarding multiple years of

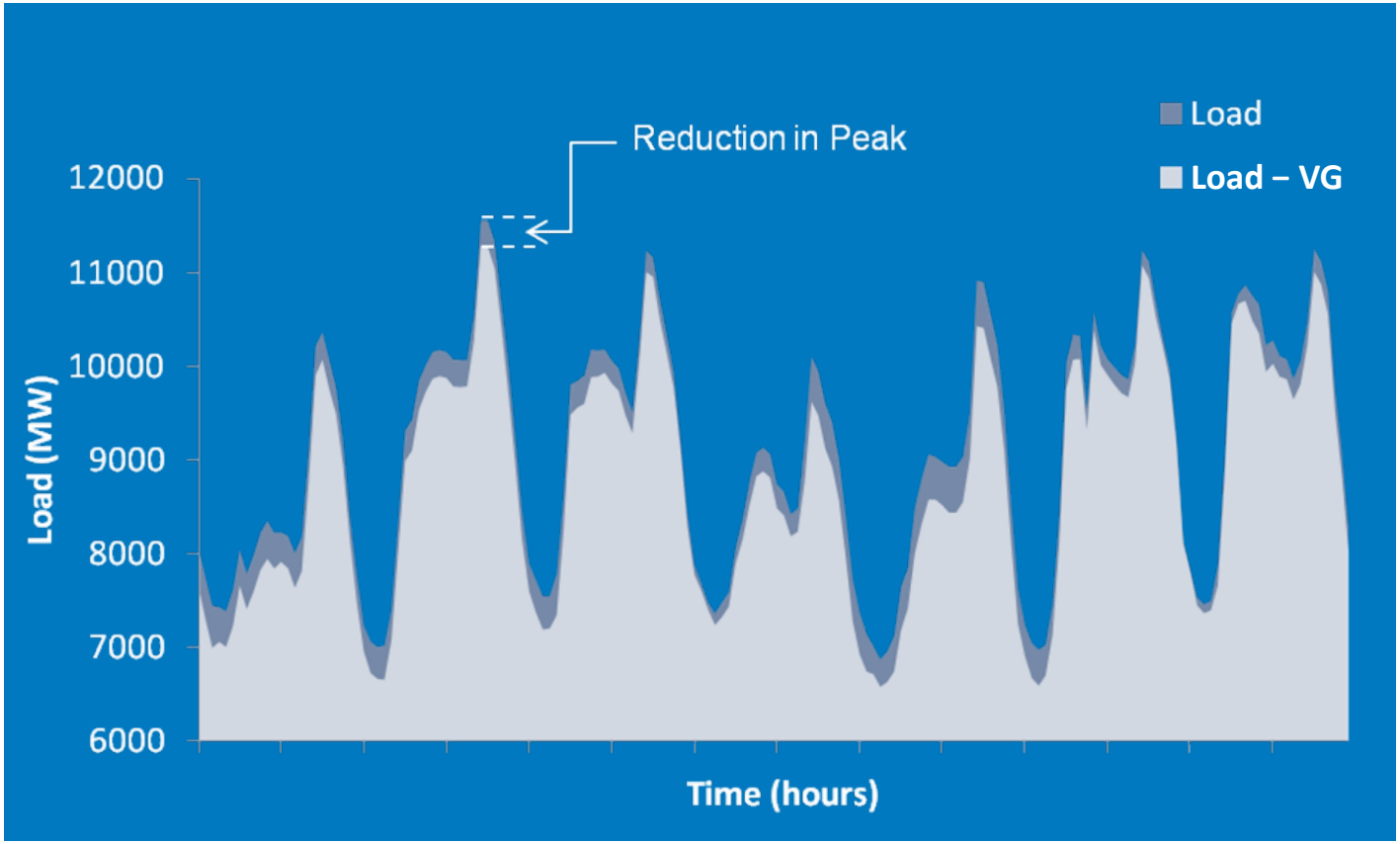
*Correspondence to: Michael.Milligan@nrel.gov
[1]National Renewable Energy Laboratory, Golden, CO, USA
[2]General Electric (GE) Energy Consulting, Schenectady, NY, USA
[3]Valtion Teknillinen Tutkimuskeskus (VTT), Espoo, Finland
[4]Royal Institute of Technology, Stockholm, Sweden

Conflict of interest: The authors have declared no conflicts of interest for this article.

NREL funding by U.S. Department of Energy Wind Program

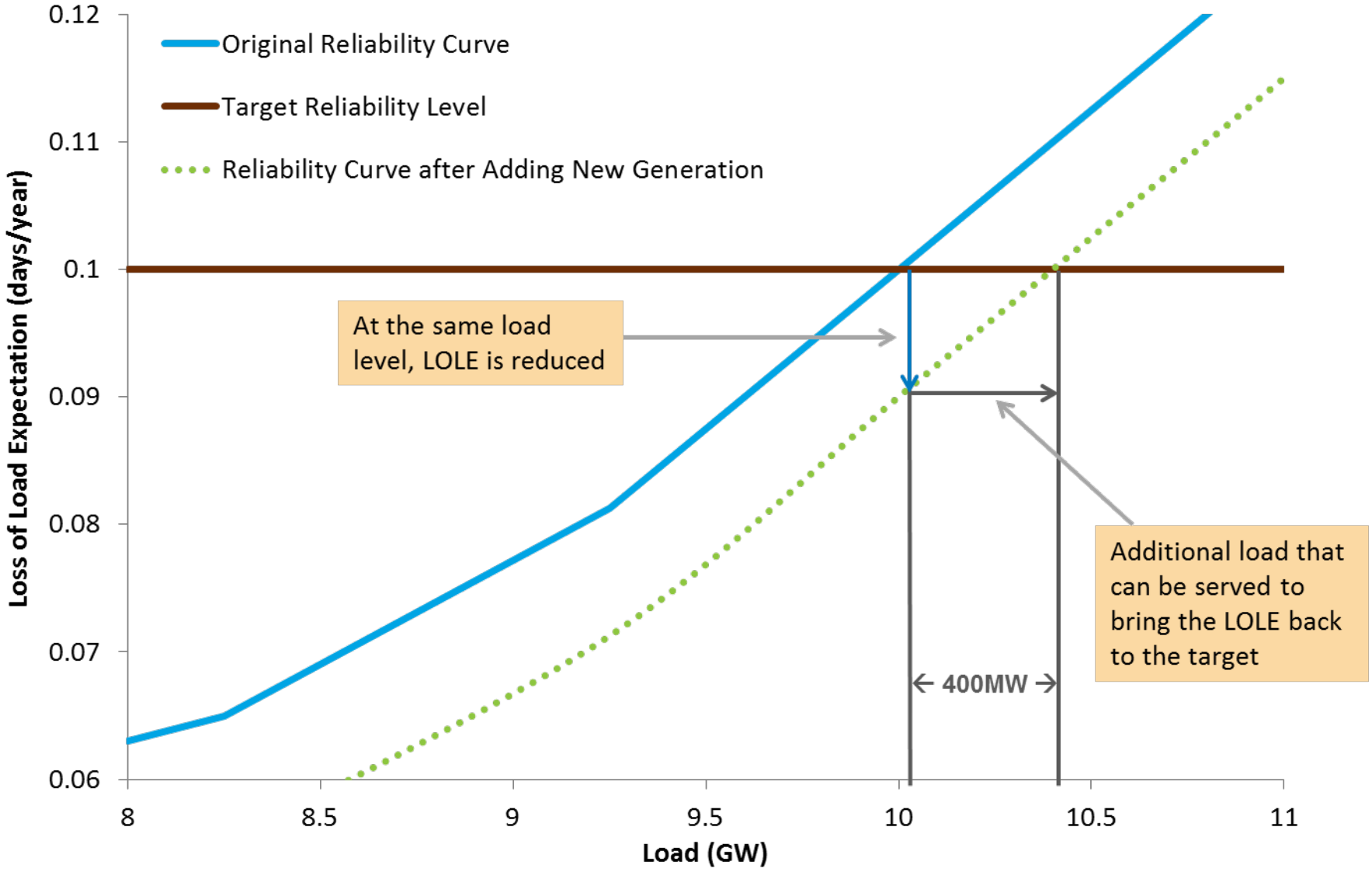
http://onlinelibrary.wiley.com/doi/10.1002/wene.226/pdf

CV: contribution to system resource adequacy

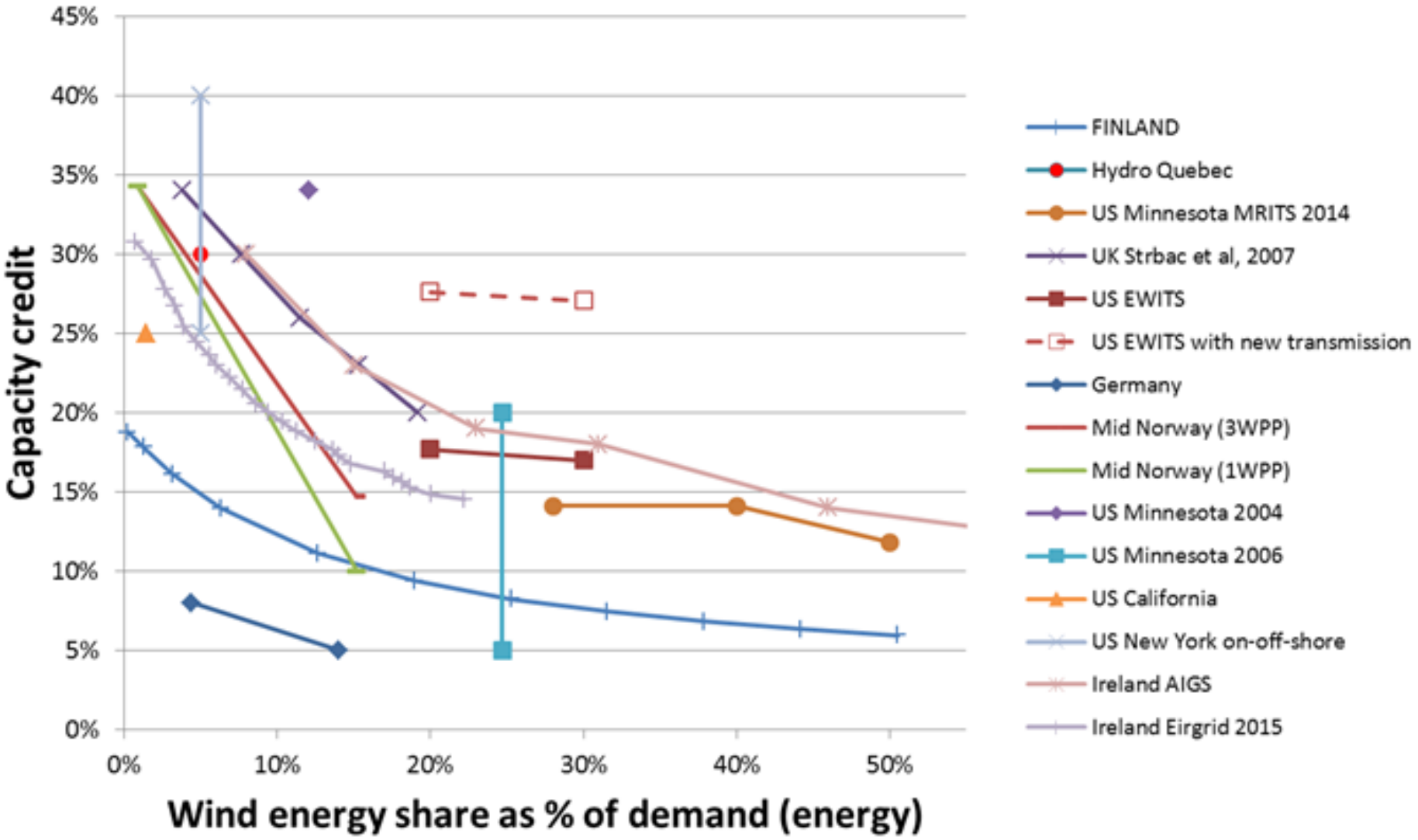


- We care about Effective Load Carrying Capability (ELCC) in highest Loss of Load Probability (LOLP) hours

ELCC


Original Reliability Curve
Target Reliability Level
Reliability Curve after Adding New Generation
At the same load level, LOLE is reduced
Additional load that can be served to bring the LOLE back to the target
400MW
Loss of Load Expectation (days/year)
0.12
0.11
0.1
0.09
0.08
0.07
0.06
8
8.5
9
9.5
10
10.5
11
Load (GW)

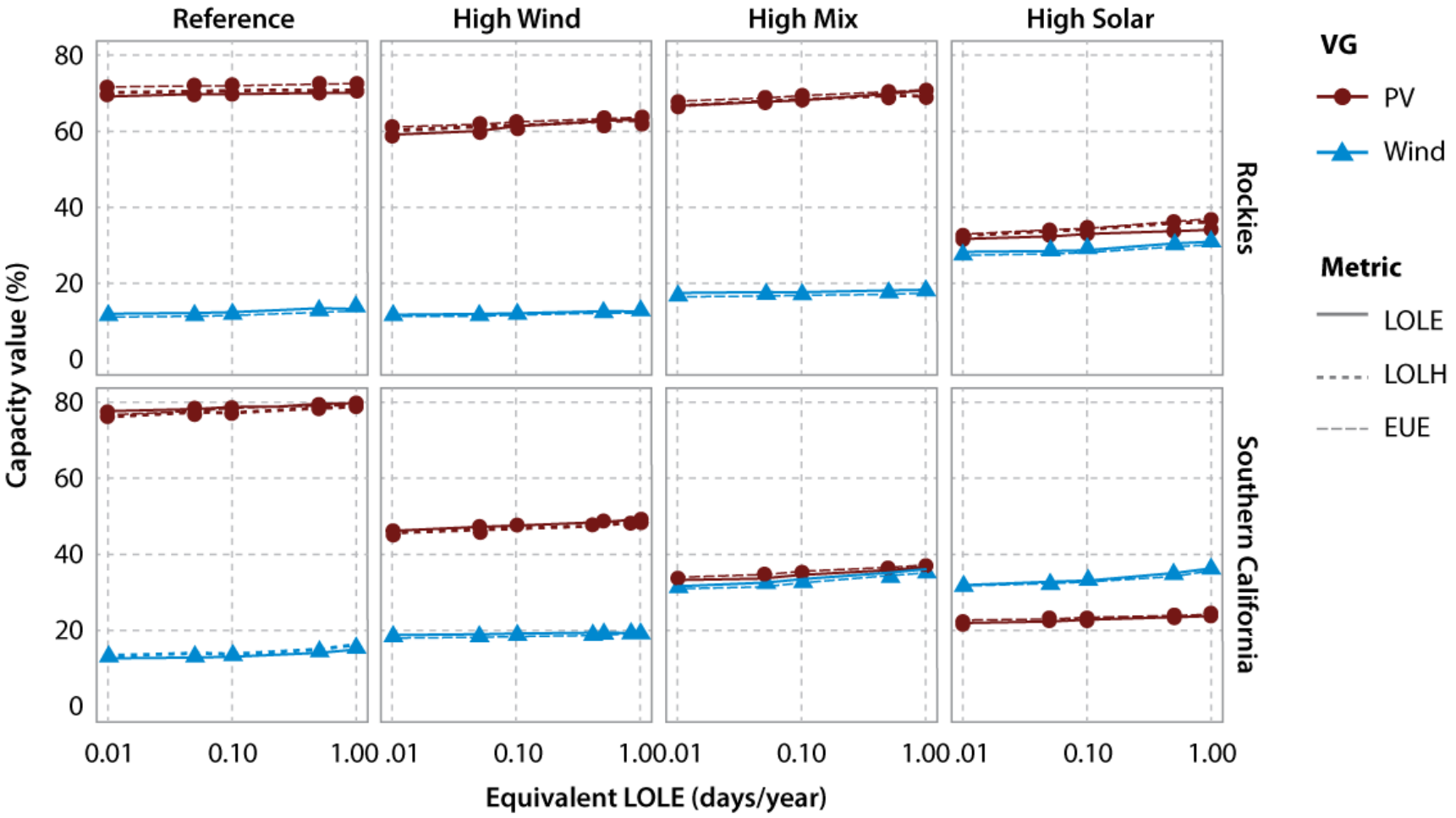
Declining CV with wind penetration level



Key topics in wind capacity valuation

- **Choice of CV metric/method**
  - Probabilistic-based reliability metrics
  - Simplified CV methods
- **Impact of multiple-year data sets**
- **Impact of transmission assumptions**

CV insensitive to probabilistic-based reliability metrics



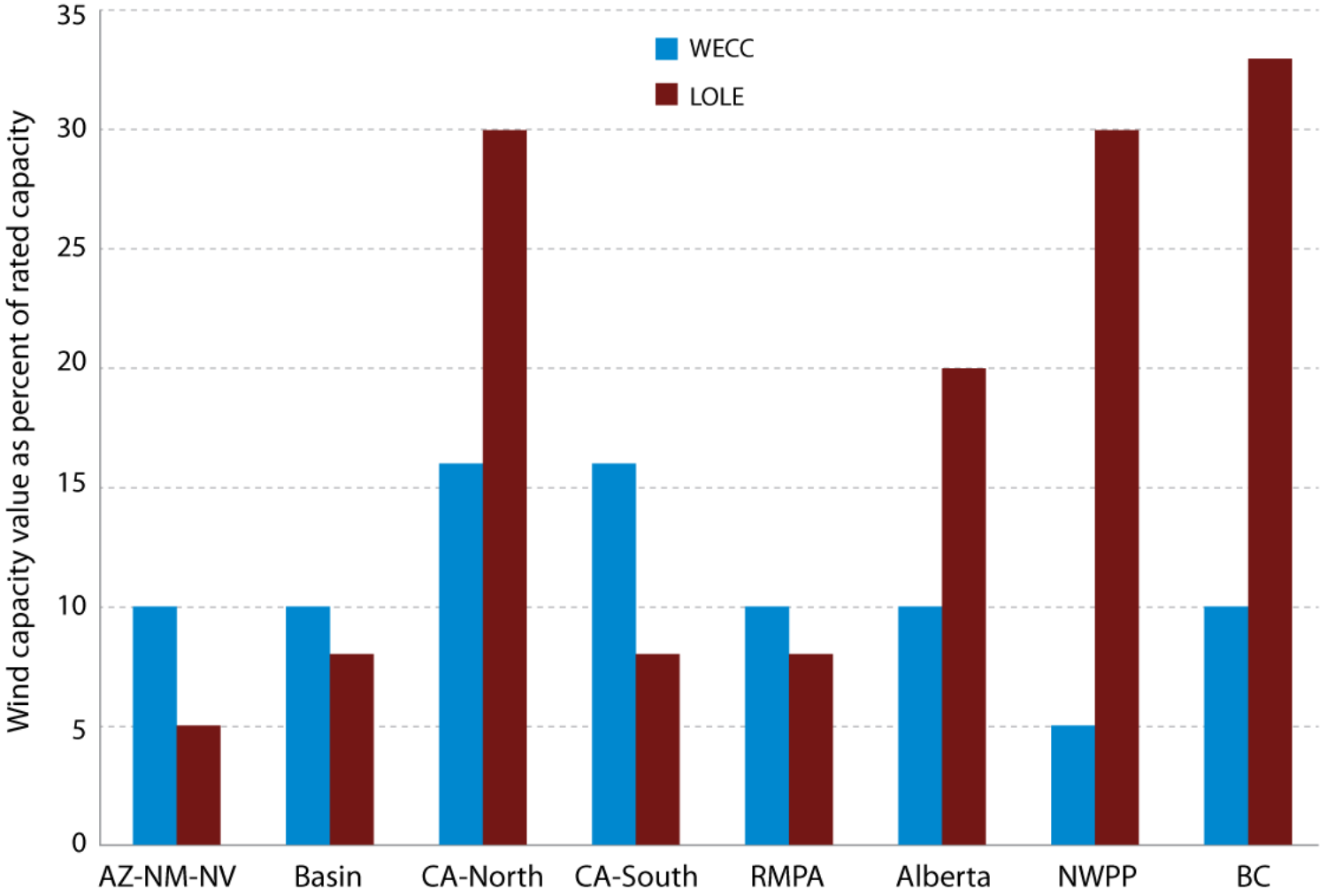
CV of wind and solar relatively robust against underlying reliability metric if LOLE, LOLH, or EUE are used

Simplifications for calculating CV

- **ELCC estimations**
  - Approximate the relationship between capacity additions and LOLP
  - e.g., Z-method (Dragoon and Dvortsov 2006), Garver's method (Garver 1966), and Garver's method extended to multistate generators (D'Annunzio and Santoso 2008)

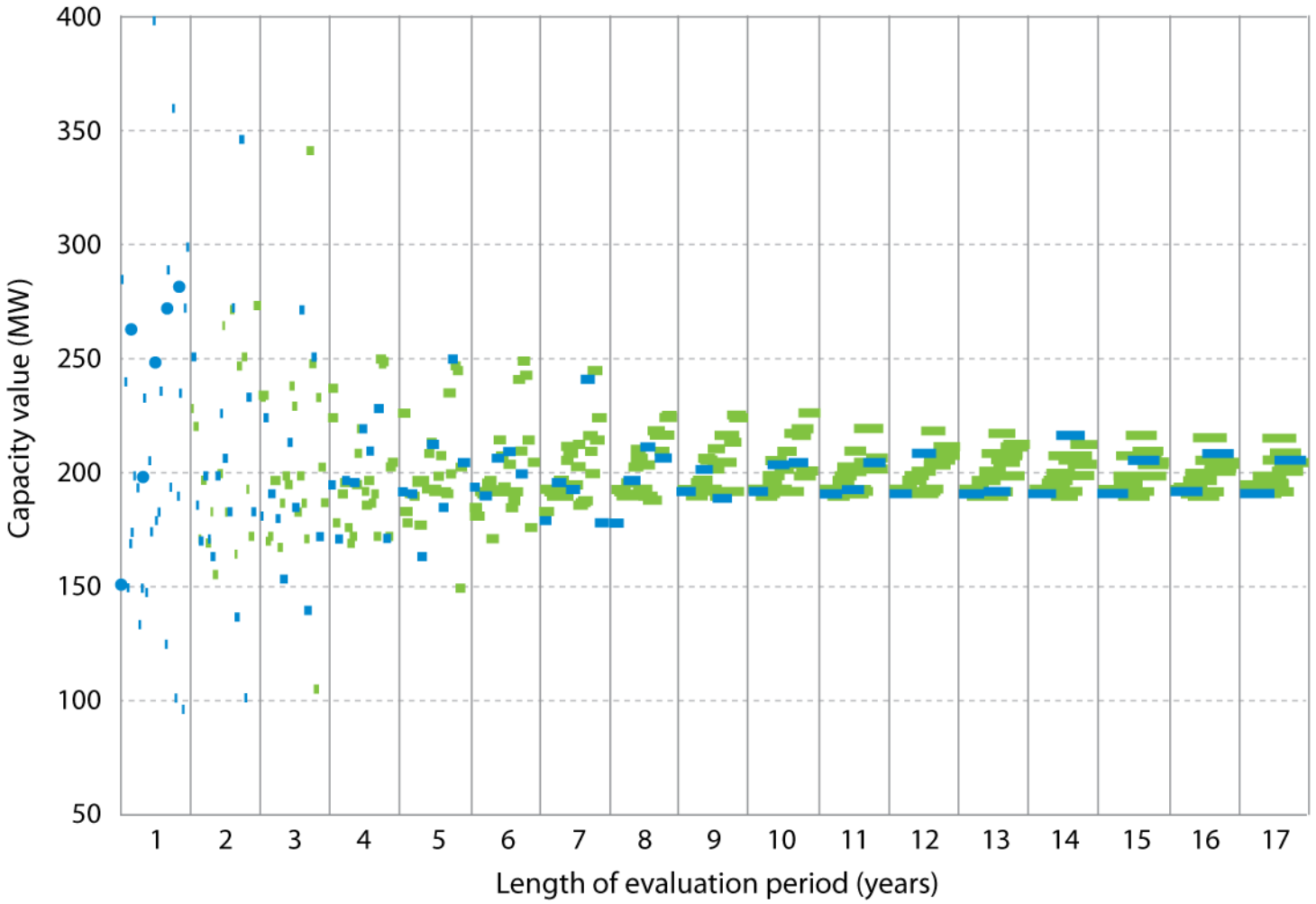
- **Capacity factor proxy**
  - Applied to "high risk" hours (e.g., Milligan and Parsons 1999 for wind, Madaeni et al. 2013 for solar)
  - Ad-hoc rule of thumbs

Rule of thumb CV methods are inconsistently inaccurate



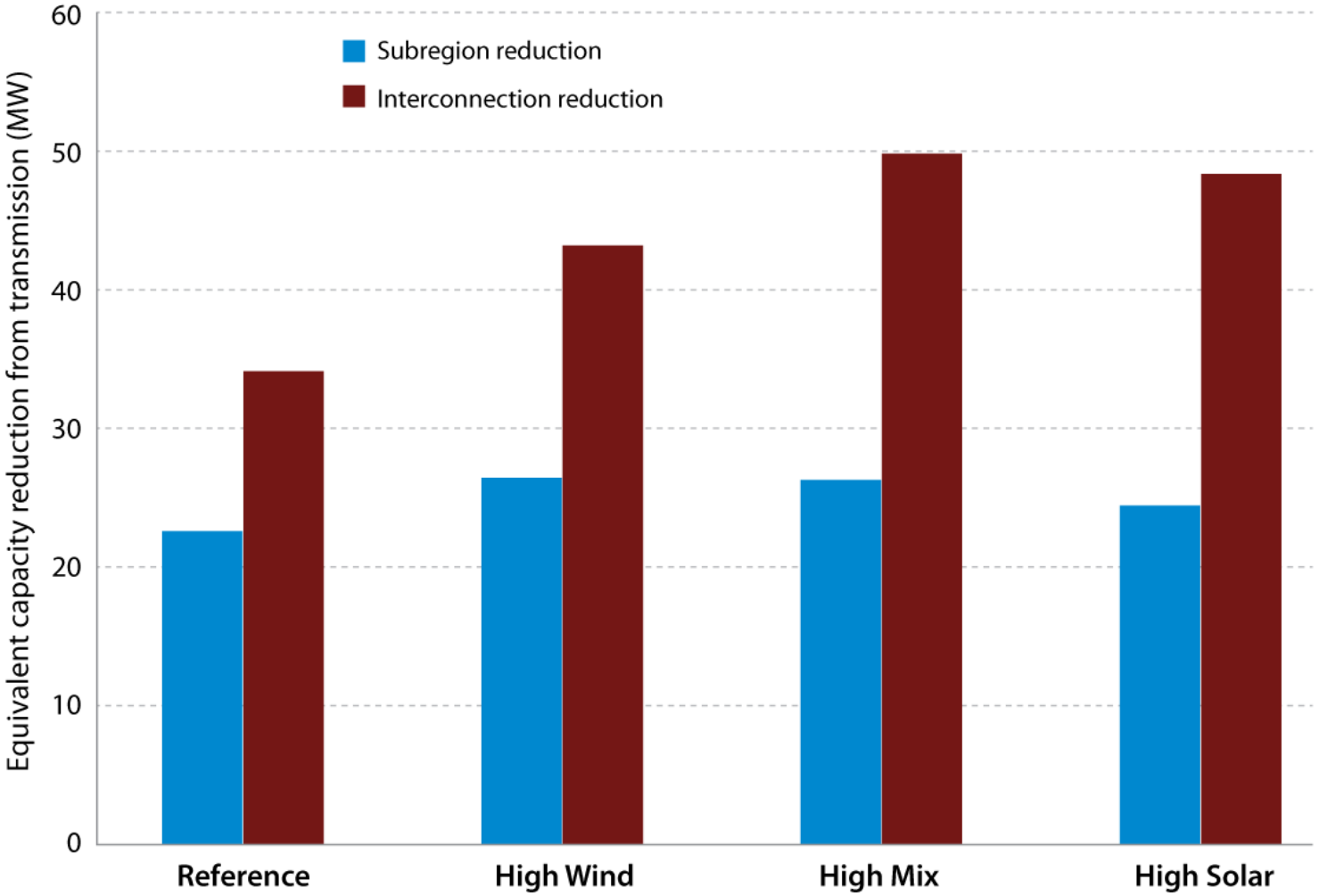
Western Electricity Coordinating Council (WECC) rules of thumb versus full reliability model

Achieve more robust CV results with multiple-year data sets



Studies suggest 8-9 years to converge on long-term value, which is key for planning decisions

Transmission assumptions impact resource adequacy level



Greater reduction in required ELCC for reliability target is achieved with increasing degrees of interconnection

Summary and future research needs

- **LOLP-based CV methods** are most accurate, and results are relatively insensitive to choice of LOLE, LOLH, and EUE
- **CV rule of thumb methods** are often inconsistent and unreliable
- **Multiple-year data sets** significantly increase the robustness of results compared to single-year assessments
- **Transmission** interconnection assumptions have significant impact on resource adequacy and associated contribution needed by wind
- **Future research needs**: continued improvements in multi-area methods, simplified methods, flexibility valuation, and capacity market structures

References and select additional sources

D'Annunzio, C.; Santoso, S. (2008). "Noniterative Method to Approximate the Effective Load Carrying Capability of a Wind Plant." *IEEE Transactions on Energy Conversion*, Vol. 23, No. 2, pp. 544-550, June 2008.

Zachary, S.; Dent, C.J.; Brayshaw, D.J. (2011) "Challenges in quantifying wind generation's contribution to securing peak demand."*2011 IEEE Power and Energy Society General Meeting*, San Diego, CA, 2011, pp. 1-8.

Dragoon, K. and Dvortsov, V. (2006). Z-method for power system resource adequacy applications. *Power Systems, IEEE Transactions on*, *21*(2), pp.982-988.

Duignan, R.; Dent, C. J.; Mills, A.; Samaan, N.; Milligan, M.; Keane, A.; O'Malley, M. (2012). "Capacity Value of Solar Power." Proceedings of the 2012 IEEE Power and Energy Society General Meeting; July 22–26 2012, San Diego, California. Piscataway, NJ: Institute of Electrical and Electronics Engineers, 6 pp. NREL/CP-5500-54832. Golden, CO: National Renewable Energy Laboratory. http://dx.doi.org/10.1109/PESGM.2012.6345429

Ueckerdt, F.; Brecha, R.; Luderer, G.; Sullivan, P.; Schmid, E.; Bauer, N.; Böttger, D.; Pietzcker, R. (2015). "Representing power sector variability and the integration of variable renewables in long-term energy-economy models using residual load duration curves." *Energy*, 90, Part 2, 1799-1814.

Garver, L. L. (1966). "Effective load carrying capability of generating units." *IEEE Trans. Power Appl. Syst*., vol. PAS-85, no. 8, pp. 910-919.

Hasche, B.; Keane, A.; O'Malley, M. (2011). "Capacity Value of Wind Power, Calculation, and Data Requirements: The Irish Power System Case." *IEEE Transactions on Power Systems*, Vol. 26, No. 1, Feb.; pp. 420–430.

Huang, D.; Billinton, R. (2009). "Effects of Wind Power on Bulk System Adequacy Evaluation Using the Well-Being Analysis Framework." *IEEE Transactions on Power Systems*, Vol, 24, No. 3, Aug. 2009.

Ibanez, E.; Milligan, M. (September 2012). "A Probabilistic Approach to Quantifying the Contribution of Variable Generation and Transmission to System Reliability." NREL/CP-5500- 56219. Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov/docs/fy12osti/56219.pdf

Keane, A.; Milligan, M.; Dent, C.J.; Hasche, B.; D'Annunzio, C.; Dragoon, K.; Holttinen, H.; Samaan, N.; Söder, L.; O'Malley, M. (2011). Capacity value of wind power. Power Systems, IEEE Transactions on, 26(2), pp.564-572.

Madaeni, S.H.; Sioshansi, R.; Denholm, P. (2013). Comparing capacity value estimation techniques for photovoltaic solar power. *IEEE Journal of Photovoltaics*, *3*(1), pp.407-415.

Milligan, M. and B. Parsons (1999), "A Comparison and Case Study of Capacity Credit Algorithms for Wind Power Plants." *Journal of Wind Engineering*. Multi-Science Publishing Co. LTD. Brentwood, Essex, United Kingdom. Vol 23, No. 3, 1999.

Milligan, M. (2001). "A Sliding Window Technique for Calculating System LOLP Contributions of Wind Power Plants." NREL/CP-500-30363. Golden, CO: National Renewable Energy Laboratory. Available at http://www.nrel.gov/docs/fy01osti/30363.pdf

Munoz, F. D.; Mills, A.D. (2015). "Endogenous Assessment of the Capacity Value of Solar PV in Generation Investment Planning Studies." *IEEE Transactions on Sustainable Energy*, Vol. 6, No. 4, Oct.; pp. 1574-1585.

bethany.frew@nrel.gov

www.nrel.gov

NREL
NATIONAL RENEWABLE ENERGY LABORATORY