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December 14, 2015

Via Electronic Mail
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Public Utility Commission of Oregon
PO Box 1088
Salem OR 97308-1088

Re: UM 1719 - Investigation to Explore Issues Related to a Renewable Generator's Contribution to Capacity – Portland General Electric Company's Direct Testimony

Attention Filing Center:

Enclosed for filing in Docket Number UM 1719 are Portland General Electric Company's Direct Testimony of Franco Albi, Robert Macfarlane and Arne Olson.

If you have any questions or require further information, please call Robert Macfarlane at (503) 464-8954.

Please direct all formal correspondence and requests to the following email address: pge.opuc.filings@pgn.com.

Sincerely,

Rob Macfarlane
for

Karla Wenzel
Manager, Pricing & Tariffs

Enclosure

UM 1719 / PGE / 100
Albi – Macfarlane

BEFORE THE PUBLIC UTILITY COMMISSION

OF THE STATE OF OREGON

UM 1719

Investigation to Explore Issues Related to a Renewable Generator's Contribution to Capacity

PORTLAND GENERAL ELECTRIC COMPANY

Direct Testimony of

Franco Albi
Robert Macfarlane

December 14, 2015

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I. Introduction and Summary

Q. Please state your names and positions with Portland General Electric ("PGE").

A. My name is Franco Albi. I am the Manager of Integrated Resource Planning for PGE.

My name is Robert Macfarlane. I am a senior analyst in Pricing and Tariffs for PGE.

Our qualifications are included at the end of this testimony.

Q. What is the purpose of your testimony?

A. Our testimony responds to OPUC Order No. 15-077 ("Investigation to Explore Issues Related to Renewable Generator's Contribution to Capacity"). Our testimony includes the following:

- Summary of PGE's response to issues raised in Staff's Report;
- Discussion of issues related to methodologies, input data, results, and applications;
- Discussion of PGE's capacity contribution methodologies in the 2013 IRP, 2016 IRP, and future considerations;
- Summary of PGE's response to the minimum required topics; and
- Conclusion and recommendations.

In addition, our testimony incorporates expert witness testimony provided by Arne Olson of Energy and Environmental Economics (E3) in PGE Exhibit 200. Mr. Olson's testimony addresses the following questions:

1. Why are assessments of capacity contribution important for system planning?
2. What are the most commonly-used methodologies for determining capacity adequacy?
3. What techniques are used to assess the capacity contribution of variable generation resources and what are their advantages and disadvantages?

4. What methodology did PGE select to assess capacity contribution for the 2016 Integrated Resource Plan (IRP)?
5. What are the strengths and limitations of PGE's approach?

Q. Please discuss the Staff Report included in Commission Order No. 15-077.

A. The Staff Report provided a definition of renewable resource contribution to capacity, a discussion of issues related to determining capacity contribution and a statement that ". . . no single method has clearly been accepted as either an adopted standard or a de facto standard."[1] Staff also summarized methods used in IRPs by Oregon investor-owned utilities (IOUs) in 2013 and 2015.

Staff summarized some of the potential stakeholder impacts identified in comments from the 2013 IRP proceedings. These included qualifying facilities (QFs), planning reserve capacity, regulation reserve capacity, costs to comply with the Oregon Renewable Portfolio Standard, the resource value of solar, and fairness to customers and independent power producers (IPPs) for capacity payments.

Finally, Staff identified potential issues for investigation in this docket, including fairness of treatment, variations in approaches, and frequency of updates. These issues are discussed in Section II of this testimony.

Q. Does PGE have any initial comments on the Staff Report?

A. Yes. PGE would like to discuss Staff's description of a renewable resource's capacity contribution in order to clarify terminology used in PGE's testimony and to note that many terms discussed in this docket are subject to differing interpretations by each party.

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[1] Order No. 15-077, Appendix A at 2.

The Staff Report for Order No. 15-077, states "[a] renewable generator's contribution to capacity (CTP) is a measure of the most likely amount of capacity (megawatts) the resource can deliver at the exact time of the utility's annual peak load."[2]

PGE uses "CTP" as an abbreviation for "Contribution to Peak" and in PGE's understanding, the definition provided by Staff is one specific version of various definitions of CTP. PGE considers CTP to be one subset of definitions of "contribution to capacity".

CTP is an assessment of the contribution to some specified peak hours or alignment with some definition of peak load. While this may be considered a proxy for contribution to capacity, it is a limiting definition. Contribution to capacity also has broader meanings, including effective load carrying capacity (ELCC) and equivalent firm or conventional capacity.

In determining whether or not the appropriate methodology is being used, it is first useful to determine the question that is being assessed. In some cases, the question may indeed be to determine the CTP, while in others, the question may be to determine the ELCC.

Many of the other issues raised in the report will be discussed in the following sections of this testimony or in PGE Exhibit 200.

Q. Are there minimum required issues to address in this testimony?

A. Yes. On August 25, 2015, the Administrative Law Judge issued a Memorandum requesting parties to address a set of minimum issues in their testimony. PGE addresses the issues throughout this testimony and in PGE Exhibit 200. Additionally, Section VI Minimum Topics of this testimony provides a summary of PGE's responses to the minimum issues.

Q. Please summarize PGE's recommendations to the Commission in this docket.

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[2] Order No. 15-077, Appendix A at 2.

A. PGE recommends no changes to existing procedures and policies as a result of the issues raised in this docket. Existing policies and procedures are sufficient, have adequate mechanisms to raise and address questions, and are functioning well in service to all stakeholders.

A requirement for a standardized methodology will not benefit customers, utilities, developers, or IPPs. It will not improve results and may be problematic or impractical for a given system, a given application, or a given set of resource data. Additionally, it could unnecessarily result in lengthy regulatory proceedings to adopt updates to the methodology. Such proceedings may inhibit or delay planning and procurement processes.

In this testimony, PGE recommends questions for utilities and stakeholders to consider, within the existing regulatory framework, in order to improve upon all aspects for capacity contribution values while maintaining the flexibility to adapt to rapidly changing systems, technologies, and modeling tools.

II. Staff Issues

Q. What is the first item in the list of Staff Identified Issues?

A. The first item is:

"At present, each utility is left to make its own determination of CTP. This could be seen as unfair treatment of independent renewable power produces (IPPs) under a standard PURPA QF contract among the three utilities – some parties will gain and some lose simply based on the CTP calculations method chosen. The relative risks and benefits of a standardized method of calculations should be explored."[3]

Q. Does the current process of each utility determining renewable resource contribution to capacity provide for unfair treatment of IPPs?

A. No. The fact that each utility separately determines renewable capacity contribution values is not an unfair process for IPPs. First, an IPP selects the utility to receive its output. Second, as discussed in PGE Exhibit 200, in addition to depending on the profile of the resource, the estimated capacity contribution that an individual project (including IPP projects) brings is utility-specific because it depends on the load and resource characteristics of the system to which the project is delivered. Third, the current values are determined in IRP processes that allow extensive public involvement. Public meetings, workshops, comment periods, and discovery provide opportunity for stakeholder input, review and engagement in both IRP planning and the Commission's IRP acknowledgment process. Finally, in avoided cost proceedings, the capacity contribution value is just one of several items each utility calculates independently, often with independent methodologies. For example, each utility proposes its own resource needs affecting the sufficiency/deficiency

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[3] Order No. 15-077, Appendix A at 5.

period delineation, renewable integration costs, market energy price forecasts, gas price forecasts, cost of capital, resource costs, long-term transmission costs, and a variety of other factors that affect prices paid to IPPs.

Q. Would standardizing the methodologies provide for standardized capacity contribution values?

A. No. For many methodologies, the calculations are specific to the load and resources of each utility and would likely result in different contribution values.

Q. What are the potential benefits of requiring a standardized methodology?

A. One perceived benefit is a simplification of the regulator review process due to a reduction of the number of methods used. However, as discussed below, this potential benefit may not be achievable and is outweighed by the disadvantages.

Q. Are there any potential risks to requiring a standardized methodology?

A. Yes. Requiring the use of a standardized methodology does not improve results. There are a number of potential risks including the following:

- The required methodology may not be appropriate for all systems and applications, potentially creating less robust or less applicable results than other methodologies. For example, a requirement to use a time-window methodology with specified hours may not align with an individual utility's peak needs, resulting in less meaningful capacity contribution values.
- A standardized methodology may not align with each utility's capacity needs assessment methodology, potentially creating inconsistencies between the assessment of capacity needs and the attribution of capacity values to renewable resources.

- For some methodologies, the complexity of the calculations may cause them to be impractical to use in every application, resulting in the need to generalize the methodology or to use an alternate methodology. Additional discussion of this is included in Section III of this testimony and in PGE Exhibit 200.
- A standardized methodology may create a false sense of accuracy in the results by nature of it being required. Due diligence on the appropriateness of a methodology is reduced when the methodology is standardized.
- The regulatory process to approve an update to a required methodology applied to all utilities may be cumbersome and time consuming. This could potentially result in substantial disconnects between the methodology and rapidly evolving utility systems, as well as delays in the ability to adopt advanced models or methodologies that may emerge.
- If a required methodology is not appropriate for a system or application, utilities may need to perform additional calculations with more appropriate methodologies to plan for system reliability.

Q. What was Staff's second issue?

A. The second issue raised by Staff was that "[t]he various approaches currently used by Oregon utilities to determine CTP have not been compared to each other and analyzed for accuracy and precision. The methodologies should be compared to those methods utilized by utilities outside of Oregon to compare accuracy and precision."[4]

Q. Please discuss this issue.

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[4] Order No. 15-077, Appendix A at 5.

A. Utilities may use different methodologies for a variety of reasons, including the capacity contribution question that is being studied (for example, "contribution to peak" vs. "effective load carrying capacity"), the nature of their systems, and the data available.

As discussed in PGE Exhibit 200, methodology is only one factor in determining the reasonableness of results. The data used and data processing are significant factors in determining the usefulness of results. Methodology, by itself, does not guarantee a level of accuracy or quality.

Further, PGE notes that forward looking renewable resource capacity contribution values are estimates and often reflect a specific modeling snapshot of technology, load, and system characteristics. The estimates are likely to differ with different technology parameters and system profiles. For some technologies, the behavior of the resource can vary significantly year-over-year.

For these reasons, comparing methodologies between utilities is not a straightforward process and may not be useful in assessing accuracy. Focusing on "compar[ing] accuracy" and precision" may result in a false sense of correctness. The appropriateness of calculations and the reasonableness of the results depend on the utility, the technology, and the capacity question.

With the objective to obtain appropriate and reasonable results, parties may consider the following questions when examining capacity contribution values:

1. What is the appropriate capacity contribution question for the specific application?
2. Does the methodology selected address the question? (And when relevant, does the methodology align with the utility's capacity assessment methodology?)

3. Are the input data, and the method to process the data, appropriate?
4. Are the results being applied appropriately to specific applications?

Q. Did Staff identify any additional issues?

A. Staff raised the issue of how frequently capacity contribution values should be updated.

Q. Why might the results of capacity contributions calculations need to be updated?

A. There are several reasons that results of capacity contribution calculations may need to be updated. As discussed in PGE Exhibit 200, many contribution values represent estimates for specific resources given a specific modeling of a system and load. Some of the reasons that may create the need to update contribution values include changes to the following:

1. Load forecasts and shapes;
2. Resource portfolios, including the acquisition of new resources;
3. Available input data to model the renewable resource in question;
4. Reliability requirements;
5. Capacity needs assessment modeling;
6. Other related parameters

Q. When should capacity contribution values be updated?

A. The timing of updates will vary by utility and resource. Each utility needs to assess its circumstances to determine when it is necessary to update capacity contribution values. For example, as discussed in PGE Exhibit 200, the marginal capacity contribution for a resource type declines as a utility adds additional resources of the same type to a system. The rate of decline can vary substantially between resource types and depending on the saturation level of the utility. This may mean that the acquisition of 100 MW of one resource for a particular utility could trigger the need to update the marginal capacity contribution value while the acquisition of 100 MW of a different resource may not.

III. Capacity Contribution Methodology

Q. What are the main types of capacity contribution methodologies?

A. The two main varieties of capacity contributions are heuristic methodologies and ELCC methodologies. Within each type, there are a number of variations to the methodologies. Heuristics and ELCC methodologies are described in PGE Exhibit 200, including a discussion of benefits and risks.

Q. Are there factors that might make one methodology more appropriate than another for specific applications or utilities?

A. Yes. One consideration is the nature of the specific capacity contribution question. For example, different methodologies may be better suited to addressing the contribution for a specific peaking period, while others may be better suited to estimating contributions to reducing potential loss of load events. Another consideration is the composition of resources that a utility has, such as whether or not a system has large amounts of storage. The data available is also an important factor. For example, using a complex statistical model may bring little value if a data set is very limited. These and other factors are discussed in PGE Exhibit 200.

Q. PGE Exhibit 200 discusses PGE's planned use of an ELCC methodology in the 2016 IRP. Does PGE recommend that all utilities be required to use ELCC methodologies to calculate capacity contributions for renewable energy resources?

A. No. ELCC calculations may not be necessary or appropriate for all utilities and all applications. Depending on a utility's portfolio of resources, capacity assessment methodology, input data availability and the capacity contribution question, another methodology, such as a heuristic, may be more appropriate. Each utility needs to determine and support the appropriateness of its selected methodology given associated risks, resources, and planning procedures. Additionally, utilities that use ELCC methodologies may also need to use simpler methods or apply additional adjustment factors for some applications.

Q. Please discuss why simpler methods may be needed for some applications.

A. ELCC-type calculations are for a specific forecast of system conditions and a specific set of resources. As discussed in PGE Exhibit 200, they are computationally, time, and data intensive. It may not be practical or useful to produce ELCC studies for all permutations of system conditions and potential resources. For example, in an IRP process, portfolio construction may involve a number of years, each representing different system conditions and a number of different combinations of candidate resources across those years. Calculating ELCC values for each instance would be impractical. Generalizations may be needed to interpolate between, or extrapolate from, ELCC calculations.

Q. Please discuss what is meant by "apply additional adjustment factors".

A. If, for example, a utility calculates a generic ELCC value for solar in Region A, based on a set of plant characteristics, the utility may also develop an equation to adjust the capacity contribution value attributed to individual projects based on their specific parameters, such as panel orientation, tracking systems, or photovoltaic technology.

Q. Why might this be useful?

A. Given the impracticality of producing project specific ELCC calculations for all potential permutations of projects and system conditions, using an equation to adjust capacity value based on project characteristics may be a practical way to develop project specific values. This can be important when comparing two projects in the same region with different plant characteristics in a request for proposal (RFP) process or when determining capacity pricing in avoided cost calculations.

Q. Are there benefits to requiring other methodologies to be benchmarked against an ELCC?

A. In some instances, such as the use of generalizations to interpolate between or extrapolate from calculated ELCC values, an ELCC calculation could be used to check that the interpolation or extrapolation method is reasonable; however, due to the complexity of ELCC calculations, it likely would not be practical to check all generalizations.

Q. Are there any drawbacks to requiring other methodologies to be benchmarked against an ELCC?

A. Yes. Such a requirement would disallow other reasonable ways of supporting methodologies without using an ELCC calculation and would not guarantee that the benchmark produces a useful assessment of the methodology in question.

Depending on the nature of the question (contribution to peak vs. effective load carrying capacity) and the nature of the system (such as one with considerable storage), an ELCC calculation may not provide a useful assessment of capacity contribution, in which case it would also not serve as a useful benchmark for the methodology in question.

Additionally, given the complexity of ELCC calculations and the importance of data preparation, it may not be practical or useful to require ELCC calculations as a benchmark for all situations. For example, in some instances, the time and resources needed to conduct a meaningful ELCC calculation may be prohibitive.

Q. In the current regulatory framework, what mechanisms are available for stakeholders to address concerns about capacity contribution methodologies?

A. Stakeholders have the opportunity to participate in utilities' IRPs through public meetings, technical workshops, discovery, and comments. For some applications such as avoided cost pricing, stakeholders also have the opportunity to file comments or testimony, in addition to discovery.

Q. Are these mechanisms functioning to address stakeholder concerns?

A. Yes. For example, stakeholder concerns raised during PGE's 2013 IRP process contributed to the prioritization of reviewing capacity contribution methodologies in PGE's 2016 IRP process. The study conducted to update the methodologies for the 2016 IRP is discussed in PGE Exhibit 200 and in this testimony.

IV. Input Data, Results, and Applications

Q. What updates to capacity contribution inputs may be needed?

A. Utilities may need to update inputs to reflect changes to their profiles of resources, needs, or requirements, such as to incorporate updated load forecasts or recently acquired resources.

Updates may also be needed to incorporate additional historic or synthetic generation data for resources, or to incorporate refreshed correlations among load and resource data sets.

Q. When should data be updated?

A. As discuss previously, the timing of updates will vary by utility and resource type. Each utility needs to assess the changes to its system and determine whether or not the input data to a capacity contribution calculation needs to be updated. For example, a utility may update inputs during an IRP cycle and then determine that significant changes in the load forecast require the load inputs and correlations to be updated prior to producing calculations for an RFP cycle.

Q. Why is it important to update inputs?

A. The usefulness of results is highly dependent on the quality of data available, as discussed in PGE Exhibit 200. Incorporating updates to inputs increases the likelihood the results reasonably reflect the resource capacity contributions. This allows for better valuations for customers, shareholders, and IPPs.

Q. Are there additional data issues to consider?

A. Yes. Additional issues are discussed in PGE Exhibit 200. These include the sample size, annual variability, synthetic data, and data preparation.

Given the importance of data to the quality of results, it is necessary to understand the nature of the variability of the resources that are modeled and the quality and limitations of the data available, as well as to apply care to the preparation of data, including the correlations among data sets.

Q. Are the results of renewable resource capacity contribution assessments dependent on the characteristics of the utility receiving output from the resource?

A. Yes. For most methodologies, the results are dependent on the characteristics of the utility. Utilities have different system profiles, including loads, resources, and existing renewables. This means that the same project would have different capacity values depending on the balancing authority to which it is delivered, regardless of whether or not the same methodology is used to calculate the capacity contribution. This is discussed in PGE Exhibit 200.

Q. Is this reasonable even though a project's generation is the same regardless of the utility that receives it?

A. Yes. As discussed in PGE Exhibit 200, the capacity contribution of a resource depends on both the load profiles and the characteristics of the other resources in the portfolio to which it is added. Just as a specific project may incur different integration charges depending on the system that provides its integration services, the capacity value of a project is dependent on the system that it is delivered to. The output of a project is only one component in determining capacity contribution. Accounting for the profile of the receiving system must be considered.

Q. Would it be reasonable to require all utilities to use a regionally calculated capacity contribution value for each resource type?

A. No. The Pacific Northwest does not have a single, centrally-cleared market for capacity. Each utility is responsible for procuring capacity sufficient for its own load-service obligations. It would not be reasonable to apply regional capacity contribution values to a group of utilities that are independently responsible for their capacity adequacy as each utility has a different profile of needs and resources. The alignment of generation from a renewable resource with the hours of need of an individual utility will differ from the alignment with the hours of need of the region. For example, the Pacific Northwest includes both winter peaking and summer peaking utilities. The capacity contribution of solar resources would obviously be much lower for a winter-peaking utility than for a summer-peaking utility. The estimated capacity contribution should be calculated based on an individual utility's characteristics, not that of the Pacific Northwest region as a whole.

Q. Please describe some possible uses for the results of capacity contribution calculations.

A. Examples of applications include, but are not limited to, IRP capacity needs assessments, IRP portfolio construction, RFP evaluation processes, RPS compliance implementation plans, avoided cost pricing, Value of Solar, Voluntary Renewable Energy Tariff, and Community Solar programs.

Q. What are some of the considerations that need to be addressed when applying results to different applications?

A. For each application, the capacity contribution calculation needs to be framed by appropriate contextual parameters. For example, an IRP may produce a single annual capacity contribution for Resource A. While this may be suitable for long-term capacity planning questions related to Resource A, it may not be appropriate for capacity price calculations such as in avoided cost pricing. For price calculations, it may be necessary to incorporate additional factors such as seasonal and diurnal shaping of capacity need in order to calculate meaningful prices.

Q. Does this testimony establish a specific process for applying a capacity contribution to an avoided cost price calculation?

A. No. This docket is not the place to determine the specific steps for applying a capacity contribution value to avoided cost pricing for QFs or for any other specific application. The application of results from a capacity contribution methodology should be examined individually, with consideration for appropriate adjustments based on the specific application.

Q. Has PGE established procedures for applying the capacity contribution methodology to other applications?

A. No. The study for the 2016 IRP was completed in the fall of 2015 and PGE has not established procedures to meaningfully apply the methodology to other applications. As the new methodology is a substantial change from the 2013 IRP, PGE anticipates additional factors may need to be addressed as procedures are developed for other applications. As each application is addressed, a variety of questions will be examined, including the following:

- Does the question of capacity contribution for the application align sufficiently with the 2016 IRP methodology?
- Are there any material updates to resources or requirements that need to be incorporated?
- Are there any substantial modeling changes that need to be incorporated?

- Is a generalized methodology needed to interpolate or extrapolate from the calculated values from the 2016 IRP study?
- Are adjustments needed to account for project specific attributes?
- Is information needed in addition to an annual capacity contribution value?
- What steps are needed to apply the results appropriately to the specific application?
- Are there other relevant considerations that need to be addressed?

V. PGE Capacity Contribution Calculations

A. 2013 IRP

Q. How did PGE assess capacity need in the 2013 IRP?

A. In the 2013 IRP, PGE assessed separate winter and summer seasonal capacity needs based on forecast one-in-two seasonal peak loads plus additional reserves. The reserves were composed of a six percent contingency reserves and approximately six percent operating reserves (spinning and non-spinning reserves). PGE indicated that it would likely consider alternative capacity assessments for the next IRP cycle.[5]

Q. How did PGE estimate renewable capacity contributions in its 2013 IRP capacity needs assessment?

A. In the 2013 IRP, PGE estimated the capacity contribution of the Biglow Canyon Wind Farm (Biglow) based on Biglow's generation during peak load hours in 2011 and 2012.[6] When estimating seasonal capacity needs, PGE applied Biglow's capacity contribution to all other wind resources. The capacity contribution for solar resources was estimated based on an examination of forecasted alignment of solar generation with peak load that used a similar method to Biglow's analysis.[7]

B. 2016 IRP

Q. Does PGE plan to provide an updated capacity contribution methodology in the 2016 IRP process?

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[5] PGE's 2013 Integrated Resource Plan at 49.

[6] PGE's 2013 Integrated Resource Plan at 174.

[7] "Stakeholder Presentation," Slides 57-68. Public Meeting, August 29, 2013. Available at https://portlandgeneral.com/our_company/energy_strategy/resource_planning/docs/august2013_stakeholder.pdf

A. Yes. PGE retained Energy and Environmental Economics, Inc. (E3) to conduct a planning reserve margin and capacity contribution study using E3's Renewable Energy Capacity Planning (RECAP) model. The study used a comprehensive reliability based methodology for assessing capacity needed to achieve a resource adequacy target and the capacity contributions of existing resources. It also produced marginal capacity contribution estimates for potential renewable resources using consistent methodology and system modeling. PGE Exhibit 200 describes this study in greater detail.

Q. Is this study an improvement to the 2013 IRP?

A. Yes. The study has a number of improvements. First, the study allows PGE to assess the capacity needed to achieve a resource adequacy target based on a comprehensive loss of load study of PGE's expected system in 2021. Second, the study allows PGE to apply a single model and data set to three steps in the IRP process (the capacity needs assessment, the capacity contribution calculations, and portfolio risk assessments), improving the usefulness of the results. Third, an improved and expanded set of input data was used that included more extensive wind and load data. Fourth, the method incorporates portfolio effects, allowing PGE to assess the capacity contributions from candidate portfolios of different wind and solar resources, improving the portfolio evaluation process.

Q. Did this study examine all capacity needs and all capacity attributes of resources?

A. No. As discussed in PGE Exhibit 200, the study assessed resource adequacy and contributions based on hourly values of needs and resource abilities. It did not examine the need for additional capacity to manage sub-hourly following, regulating margin, or frequency response, nor the ability for resources to provide those services. It also did not examine ramping needs, ramping abilities, or unit commitment characteristics.

Q. Does PGE intend to use the methodology or results in applications other than the 2016 IRP?

A. PGE will evaluate on a case-by-case basis whether the capacity contribution methodology is appropriate for other applications such as the RFP process and avoided cost pricing. As discussed previously, in addition to updating inputs as appropriate, care needs to be taken to properly apply the results to different applications. Given the significant changes to the capacity assessment methodology since the 2013 IRP, it will be important for PGE to examine each application individually and monitor for any unforeseen issues as the methodology is utilized in more applications. Additionally, PGE will continue to evaluate the calculations and consider improvements, as discussed in the following subsection.

Q. Are there applications for which PGE intends not to use this methodology?

A. There may be some applications currently using other methodologies that are not be suited to using the same methodology as the IRP, or that may be required to use a specific calculation method. Each application will be addressed on a case-by-case basis.

With respect to the 2016 IRP cycle, it is not practical to conduct a detailed ELCC study for each resource and each combination of resources and load profiles that PGE might consider. As a result, PGE will need to generalize the results of the ELCC studies to apply to combinations other than those studied. This is discussed in PGE Exhibit 200.

C. Future Considerations

Q. Does PGE anticipate any updates to its capacity contribution calculations?

A. As appropriate, PGE will continue to review and improve its capacity calculation methodologies and inputs. Some possible next steps include:

1. Develop the ability to model the capacity need and contribution calculations within PGE. PGE anticipates that bringing the work in-house, rather than reliance on external consultants, will allow for a larger number of modeling runs (with varying locations and technologies) and a faster process for updating input data.
2. Improve and expand input data. PGE plans to continue to work to improve and expand the data used in the calculations. This includes examining the load, wind, and hydro data sets, improving treatments of weather and temperature correlations, adding data to model new resources, and periodically reviewing the modeling of existing resource parameters.
3. Determine the practicality of producing more granular results and the materiality of differing levels of granularity. PGE intends to examine the time and resources necessary to perform calculations at varying levels of granularity for changes to resource type, location, and system attributes. In addition to assessing the modeling time needed, the amount and quality of data will also need to be assessed. These will be considered against the materiality of the results to assess the appropriate level of detail.
4. Explore modeling and methodology options. PGE intends to continue to examine different options for assessing capacity needs and contributions including evaluating expected unserved energy, using a time-sequential model, evaluating different variations of ELCC calculations, and investigating issues related to using ELCC calculations for systems with substantial storage or demand response resources. Evaluations of options will need to consider increases in complexity and time in comparison to benefits of improved results.

VI. Minimum Topics

Q. What are the minimum required issues to address in this testimony?

A. On August 25, 2015, the Administrative Law Judge issued a Memorandum requesting that " . . . all parties address, at minimum, the following matters:

1. The preferred methodology to calculate a renewable generator's contribution to capacity; and
2. The pros and cons of:
    a. Using an Effective Load Carrying Capability (ELCC) calculation;
    b. Requiring an alternative or approximation method to be benchmarked against an ELCC calculation; and
    c. Requiring the utilities to use the same calculation method."

Q. Please summarize PGE's response to the first issue regarding a preferred methodology to calculate a renewable generator's contribution to capacity

A. The preferred methodology for calculating renewable resource capacity contribution values depends on several factors, including the nature of the capacity question and the specific system of the utility. PGE is unaware of a single methodology that is preferred for all questions and all systems regarding capacity contributions. When calculating a capacity contribution value, a utility needs to determine the appropriate methodology based on the best available information at the time of the assessment. It is reasonable that one utility may conclude that a particular methodology is preferred for its assessment while another utility concludes that same methodology is not appropriate for its assessment. As discussed in this testimony and in PGE Exhibit 200, there are potential risks to defining a single "preferred" methodology for all utilities and applications.

Q. Please summarize PGE's response to Item 2a regarding the pros and cons of using ELCC calculations.

A. Some of the advantages of using ELCC calculations include the following:

- The calculations can provide rigorous reliability-based assessments of capacity contributions for many systems.
- ELCC methodologies have the ability to capture complex correlations between resources and load.
- The calculations can capture interactive effects between different renewable resources.

Key challenges and risks for ELCC methodologies include the following:

- ELCC methodologies are not necessarily suited for assessing all systems or applications.
- ELCC calculations require extensive data, data processing, and computation time.
- ELCC models are often complex to validate and explain.
- Rigor, in and of itself, should not be equated to accuracy, but at times complexity can mask issues created by inadequate or poor quality data, leading to false confidence in results.

Additional discussions about the benefits and risks of ELCC calculations are included in PGE Exhibit 200 and in this testimony.

Q. Please summarize PGE's response to Item 2b regarding the pros and cons of requiring methodologies to be benchmarked against an ELCC calculation.

A. Requiring an ELCC calculation as a benchmark for other methodologies would bring few benefits and may be problematic or impractical for a given system or set of data, including adding significant requirements of time and resources without necessarily providing a meaningful benchmark. It unnecessarily disallows other means of supporting methodologies. The benefits and challenges of requiring other methodologies to be benchmarked against an ELCC calculation are discussed in Section III of this testimony and in PGE Exhibit 200.

Q. Please summarize PGE's response to Item 2c regarding the pros and cons of requiring utilities to use the same calculation method.

A. Requiring utilities to use the same methodology is not of service to customers, utilities, developers, or IPPs and does not improve results. The potential benefit of regulatory simplicity is outweighed by the disadvantages. As previously stated in Section II in response to Staff's issue regarding standardized methodologies, the disadvantages include the following:

- The required methodology may not be appropriate for all systems and applications, potentially creating less robust or applicable results than other methodologies. For example, a requirement to use a time-window methodology with specified peak hours may not align with an individual utility's peak hour needs, resulting in less meaningful capacity contribution values.
- A standardized methodology may not align with each utility's capacity needs assessment methodology, potentially creating inconsistencies between the assessment of capacity needs and the attribution of capacity values.
- For some methodologies, the complexity of the calculations may cause them to be impractical to use in every application, resulting in the need to generalize the methodology or to use an alternative methodology. Additional discussion of this is included in Section III of this testimony and in PGE Exhibit 200.

- A standardized methodology may create a false sense of accuracy in the results by nature of it being required. Due diligence on the appropriateness of a methodology is reduced when the methodology is standardized.
- The regulatory process to approve an update to a required methodology applied to all utilities may be cumbersome and time consuming. This could potentially result in substantial disconnects between the methodology and rapidly evolving utility systems, as well as delays in the ability to adopt advanced models or methodologies that may emerge.
- If a required methodology is not appropriate for a system or application, utilities may need to perform additional calculations with more appropriate methodologies to plan for system reliability.

Issues related to requiring a standardized methodology are also discussed in PGE Exhibit 200.

VII. Additional Considerations

Q. Are there any final considerations that PGE would like to discuss?

A. Yes. PGE acknowledges that parties have concerns about the range of methodologies and values utilities use. For the reasons discussed above, a solution of mandating a standard methodology is not a prudent response to those concerns as this may be unreasonable for some systems and may have the potential to decrease the reasonableness of results. PGE also reiterates that even with the same methodology, different utilities may calculate different capacity contribution values for the same resource because of differences in the utilities' resource portfolios and load profiles.

Capacity contribution methodologies <u>estimate</u> capacity contributions and typically do so by examining historic data to forecast future performance. Actual contributions will differ, and as discussed previously, for some technologies, the variation can be substantial.

Additionally, determining an appropriate methodology is only one component of many needed to estimate capacity contributions. Data quality, data processing, and the proper application of results are also significant factors.

PGE notes that the existing regulatory mechanisms for stakeholders to provide input and review into utility capacity contribution methodologies are being utilized and are functional, as seen in the methodology changes between PGE's 2013 IRP and the study conducted for PGE's 2016 IRP. PGE encourages parties to participate robustly in the existing stakeholder process to review the reasonableness of renewable capacity contribution values in a contextually appropriate manner.

PGE recommends the following questions be considered for each application when examining the reasonableness of capacity contribution values:

1. What is the appropriate question of capacity contribution for the specific application?
2. Does the methodology selected address the question? (And when relevant, does the methodology align with the utility's capacity assessment methodology?)
3. Are the input data and the method to process the data appropriate?
4. Are the results being applied appropriately to specific applications?

Finally, the materiality of improvements to results needs to be weighed against the costs of increased complexity of modeling and validation. Minor refinements that require substantial increases to complexity may not be necessary.

Q. Does PGE recommend a preferred methodology?

A. No. As discussed earlier, the preferred methodology for calculating renewable resource capacity contribution values depends on several factors, including the nature of the capacity question and the specific system of the utility. PGE is unaware of a single methodology that is preferred for all questions regarding capacity contributions and all systems. When calculating a capacity contribution value, a utility needs to determine the appropriate methodology based on the best available information at the time of the assessment.

VIII. Recommended Actions

Q. What actions does PGE recommend to the Commission in this docket?

A. PGE recommends no changes to existing procedures and policies as a result of the issues raised in this docket. Existing policies and procedures are sufficient, have adequate mechanisms to raise and address questions, and are functioning well in service to all stakeholders.

Requiring a standardized methodology will not benefit customers, utilities, developers, or IPPs. It will not improve results and may be problematic or impractical for a given system, a given application, or a given set of resource data. Additionally, it may unnecessarily result in lengthy regulatory proceedings to adopt updates to the methodology. Such proceedings may inhibit planning and procurement processes.

IX. Qualifications

Q. Mr. Albi, please describe your qualifications.

A. I have 15 years of experience working in the energy industry. I earned Bachelor and Master of Science degrees in Civil Engineering from Portland State University, and a Master of Business Administration from Marylhurst University. I am a registered Professional Engineer in Oregon and California. Prior to my current role as Manager of Integrated Resource Planning, which I have held since November 2014, I worked as a Project Manager in Generation Projects and an Engineer in Power Supply Engineering Services and System Planning and Engineering.

I led various projects throughout my career, including:

- Project Manager for development, procurement, construction and commissioning of the Tucannon River Wind Farm, a 267 MW generating facility in Eastern Washington.
- Project Manager for the research, development, testing, and procurement of the Dry Sorbent Injection system; and development, procurement, construction and commissioning of the Mercury Control system implemented as part of the Boardman Air Quality Controls Project.
- Project Engineer for the permitting, procurement and construction of the Chappel Creek – Jonah Field 35 mile 230kV transmission line (PacifiCorp).

Q. Mr. Macfarlane, please describe your qualifications.

A. I received a Bachelor of Arts business degree from Portland State University with a focus in finance. Since joining PGE in 2008, I have worked as an analyst in the Rates and Regulatory Affairs Department. My duties at PGE have included pricing, revenue requirement, Public Utility Regulatory Policies Act avoided costs, and regulatory issues. From 2004 to 2008, I was a consultant with Bates Private Capital in Lake Oswego, OR, where I developed, prepared, and reviewed financial analyses used in securities litigation.

Q. Does this conclude your testimony?

A. Yes.

UM 1716 / PGE / 200
Olson

BEFORE THE PUBLIC UTILITY COMMISSION

OF THE STATE OF OREGON

UM 1719

Investigation to Explore Issues Related to a Renewable Generator's Contribution to Capacity

PORTLAND GENERAL ELECTRIC COMPANY

Direct Testimony and Exhibits of

Arne Olson

December 14, 2015

Table of Contents

I. Introduction

Q. Please state your names and position.

A. My name is Arne Olson. I am a partner at the consulting firm Energy and Environmental Economics, Inc. My qualifications are included at the end of this testimony.

Q. Please describe the scope and focus of your testimony.

A. I was retained by PGE to provide a technical overview of capacity contribution metrics in use in other jurisdictions and to describe the method PGE has elected to use in its 2016 Integrated Resource Plan (IRP). My testimony addresses the following questions:

- Why are assessments of capacity contribution important for system planning?
- What are the most commonly-used methodologies for determining capacity adequacy?
- What techniques are used to assess the capacity contribution of variable generation resources and what are their advantages and disadvantages?
- What methodology did PGE select to assess capacity contribution for its 2016 IRP?
- What are the strengths and limitations of PGE's approach?

Q. Please summarize the main conclusions of your testimony.

A. My main conclusions are as follows:

1. *There is no industry standard* for establishing Planning Reserve Margin (PRM), capacity adequacy, or a variable resource's capacity contribution.
2. Because of the variable and uncertain nature of weather-dependent resources such as wind and solar, *different methodologies must be used to estimate the capacity contribution of variable resources relative to conventional resources*. These methodologies fall into two broad categories: heuristic time-window methods and

reliability-based methods estimating a resource's Effective Load Carrying Capability (ELCC).

3. ELCC methods are more detailed and analytically robust than heuristic methods, and are more appropriate at higher penetration levels of variable resources. PGE elected to use an ELCC methodology to estimate the marginal capacity contribution of variable resources in its 2016 IRP, and I believe *PGE's method is reasonable for this purpose*.
4. While the approach is robust for a given set of load and resource conditions, ELCC values are not fixed but rather change as the loads and resources in a portfolio change. Moreover, ELCC may not be appropriate for all applications in which renewable capacity contributions are needed. As a result, *the appropriate capacity contribution methodology should be determined on a case-by-case basis*.

II. Overview of Capacity Adequacy Considerations in Systems with Variable Resources

Q. What is "capacity", and why is it important for electric power systems?

A. Capacity is the ability to generate electric energy at any given point in time. Utilities need adequate generation capacity to meet continuously-varying electric loads reliably over a broad range of conditions. In particular, system planners are concerned about having adequate capacity during peak load conditions to ensure reliable electric service during the hours when customers need it most.

Q. What is the consequence of inadequate capacity?

A. The consequence of inadequate capacity is loss of load. That is, the utility does not have enough capacity to meet all the demands for electric energy, and some customer loads must be involuntary curtailed. This is very disruptive for customers, causing inconvenience and financial loss. Loss of electric power can be life-threatening for customers with special medical needs or if the outage occurs during extreme hot or cold weather. Because of the severe consequences of outages, utilities plan their systems to ensure that loss-of-load events are exceedingly rare.

Q. How do utilities ensure that they have adequate capacity to meet anticipated electric loads?

A. Because electric loads are variable and uncertain, and because electric generators are not always available to produce when needed—whether due to forced outages or resource intermittency—utilities need to procure capacity above forecast load to ensure adequate resources are available during high load conditions. This quantity of resources needed above the forecast peak load is typically referred to as a PRM. The PRM metric is a proxy for system reliability and can be useful for informing resource procurement. Utilities utilize a variety of methods to estimate the PRM necessary to ensure adequate capacity on their systems.

Q. The North American Electric Reliability Council (NERC) develops standards for reliable electricity system operations. Is there a NERC standard, or any other industry-wide standard, for determining capacity adequacy?

A. No, there is no industry standard for PRM or capacity adequacy. NERC develops *operating standards*, aimed at preventing operational problems that might lead to widespread outages such as the outage experienced in the Northeastern United States in August of 2003. These outages can occur even when there is adequate capacity available to meet all electric demands. Capacity adequacy standards are determined by each individual utility. These *planning standards* are independent of NERC's operating standards.

Q. What are some commonly used methods for determining capacity adequacy?

A. Practices are widely varied across the industry. Some examples include:

- Assuming a 15% PRM as a benchmark value based on its common use across the industry.
- Utilizing simple arithmetic formulas such as: 1-in-2 (average year) peak load + X% for forced outages + Y% for weather conditions that may be more extreme than in the average year.
- Setting PRM based on an outage of the largest single generator or transmission line on a utility's system.

- Conducting detailed reliability or "loss-of-load" studies to estimate the probability loads will exceed available resources for a given portfolio, and estimate the capacity needed to ensure this probability remains below a given threshold.

Q. How do loss-of-load studies determine capacity adequacy?

A. First, a statistically-robust distribution of load conditions is developed based on historical information about weather variability. Second, a distribution of resource availability is estimated based on the size and characteristics of the resource portfolio in a test year. Third, these two statistical distributions are combined to find the joint probability that loads exceed available resources for each hour of the test year. These studies generate reliability metrics such as:

- ***<u>Loss-of-Load Probability (LOLP)</u>***: the probability that load will exceed generation in a given hour;
- ***<u>Loss-of-Load Expectation (LOLE)</u>***: the total number of hours during which load will exceed generation within a given time period (e.g., a calendar year), calculated as the sum of all hourly LOLP values during the time period; and
- ***<u>Expected Unserved Energy (EUE)</u>***: the total expected number of megawatt-hours (MWh) of load that cannot be served by the available resources during a given time period, calculated as the sum of all hourly LOLP values multiplied by the MW of shortfall during each hour.

Many utilities use a reliability standard of "1-day-in-10-years" for capacity adequacy. This is generally interpreted to mean that the utility plans for no more than one loss-of-load event per decade. Within this general framework, practices are varied; the definition of a loss of load event may vary by utility, and there are a variety of models and methodologies used for estimating the frequency of such events.

Q. Within these methods, is it important to measure the capacity contribution of individual resources toward system-wide resource adequacy?

A. Reliability is a function of the performance of the entire resource portfolio, and interactions among the resources within a portfolio make it challenging to isolate the effect of a single resource. When determining the reliability of a fixed portfolio of resources, isolating the contribution of an individual resource is unimportant; what matters is the performance of the aggregated portfolio. Nevertheless, it is sometimes necessary to determine the contribution of an individual resource toward the performance of the portfolio, for example in the case where the resources are owned by different parties. A variety of methods exist for doing this.

Q. How do utilities measure the expected capacity contribution of conventional resources toward a system-wide PRM?

A. Practices are varied. Utilities frequently use the installed or "nameplate" capacity (ICAP) as a conventional resource's capacity contribution. Alternatively, unforced capacity (UCAP), i.e. the installed capacity discounted by the expected forced outage rate, can also be used. In some cases, monthly or seasonal multipliers are applied to conventional units to account for temperature effects on the rated capacity of the unit (available capacity declines as temperatures increase).

Q. Can renewable resources be assessed using the same methods?

A. The answer depends on the resource type. Dispatchable or baseload resources such as geothermal or biomass-fueled plants have similar operational characteristics to conventional thermal resources and can be assessed using the same techniques. Variable or weather-dependent resources such as wind, solar, or hydroelectric generators may not be able to generate at their nameplate capacity when needed due to lack of wind, sunshine or water, so alternative techniques are required to assess their capacity contribution. As more variable generation is added to the system, understanding the ability of these generators to contribute to capacity adequacy becomes increasingly important.

Q. What are the main challenges associated with assessing the capacity contribution of weather-dependent resources?

A. There are several:

1. **<u>Variability and uncertainty.</u>** Weather conditions vary continuously on multiple timescales and cannot be predicted with certainty. As a result, the output of weather-dependent resources is also both variable and uncertain. For example, Figure 1 shows the capacity factor of the Biglow Canyon wind farm by hour on seven consecutive days. The chart highlights the unpredictable nature of the resource: output varies widely from hour to hour and exhibits no recognizable daily pattern. Variability in output occurs within the operating day on an hourly and sub-hourly basis, from day to day, within the year on a seasonal basis, and across years. Determination of the expected capacity contribution of weather-dependent resources must take into account their variable nature and also address the uncertainty associated with forecasting future weather conditions.

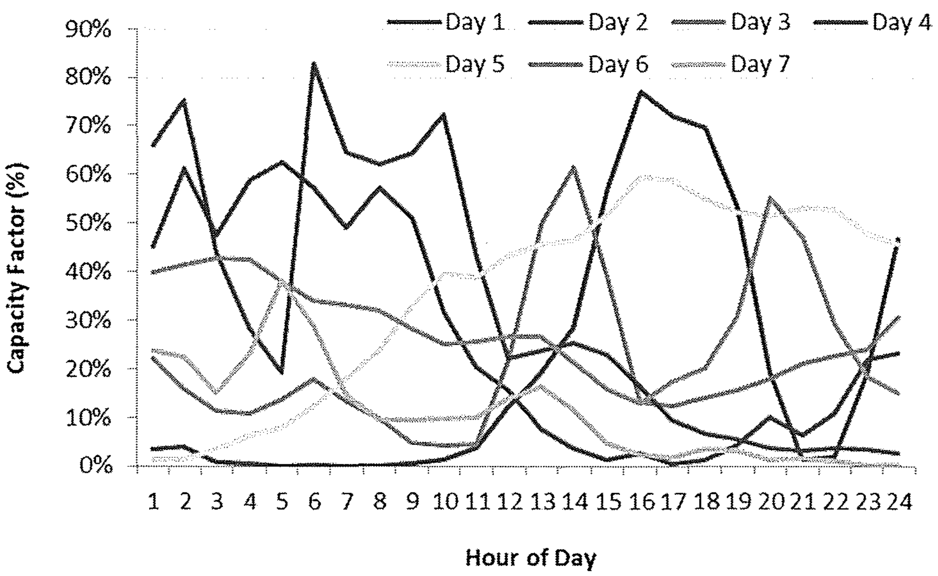

Figure 1. Example of a week of Biglow Canyon output by day and hour of day

2. **<u>Correlations with load.</u>** Production from weather-dependent resources may exhibit meaningful correlations with electric load. For example, solar photovoltaic (PV) production is higher during hours with abundant sunshine; solar PV production may therefore be positively correlated with peak load conditions during summertime hours. Wind production is negatively correlated with load in many regions; Figure 2 shows an example of negative correlation between the load level in Northern California and the output of a Bay Area wind site during summer afternoons. Capturing these correlations depends on the specific estimation methodology, but they may have a meaningful effect on wind and solar capacity contribution.

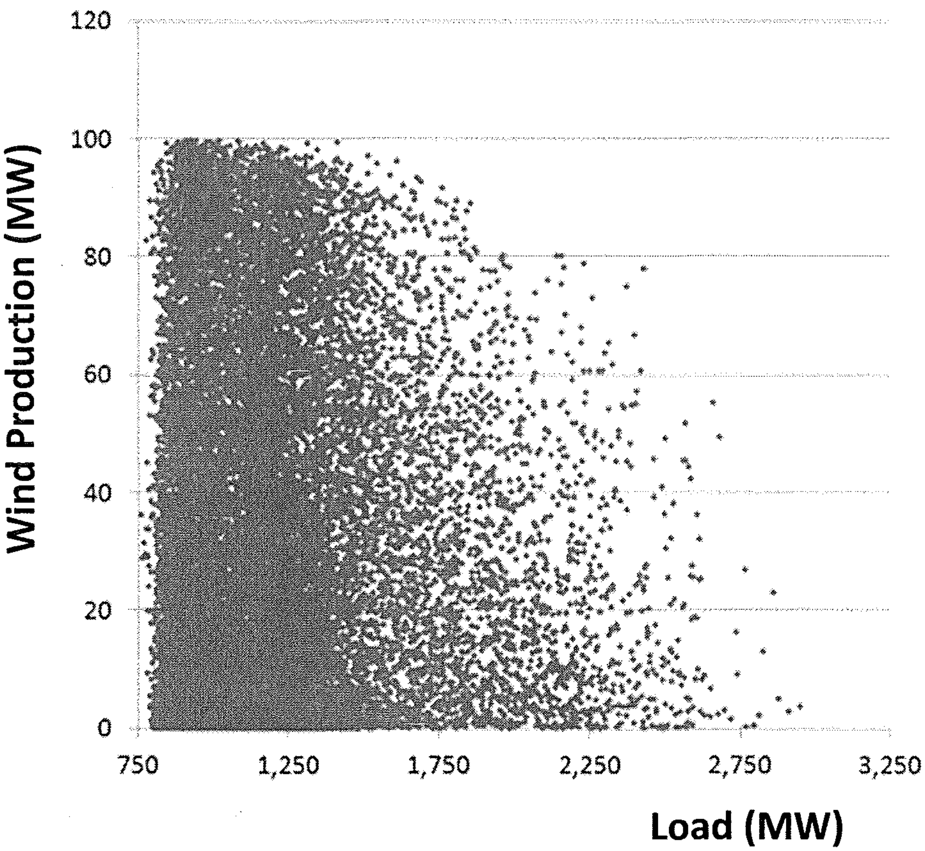

Figure 2. Production of a northern California wind farm is negatively correlated with load on summer afternoons

3. **Data requirements.** Because production from weather-dependent resources may vary from season to season and from year to year, a significant quantity of data is required in order to develop accurate capacity contribution estimates. These include site-specific hourly production and electric system load data for several years. Past studies have indicated that as many as 8 years of production data may be required to develop robust estimates of wind capacity contribution,[1] although in practice there are few sites for which such a long production history is available. Data from a large number of years, in and of itself, does not guarantee accurate results.

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[1] Milligan, M., 2011. Capacity Value of Wind Plants and Overview of U.S. Experience. National Renewable Energy Laboratory, NREL/PR-5000-52856, http://www.nrel.gov/docs/fy11osti/52856.pdf.

4. **System-dependence.** The capacity contribution of variable resources is system-dependent. It depends on the relationship between the production profile of a specific resource and the loads it is intended to serve, due to the correlation issue described above. Resources with higher production during the summertime will have a higher capacity contribution on a summer-peaking system or a system with very large summer capacity de-rates (e.g., heat-related de-rates of thermal resources, or hydro de-rates due to lack of water availability), than on a winter-peaking system or on a system with more stable output ratings throughout the year.

   Capacity contribution of a specific resource also depends on the other variable resources in the portfolio. In many cases, a more diverse portfolio of wind and solar resources will have a higher capacity contribution than a portfolio that is composed of a single resource type. Similarly, a portfolio that is geographically diverse can have a higher capacity contribution that one where development is concentrated in a small geographic area, because production will be less diverse.

5. **Changes over time.** The capacity contribution of variable resources changes over time. Changes in the load profile or in the generation portfolio mix can significantly alter the assessed capacity contribution of a variable resource. The capacity contribution is therefore a snapshot of the additional reliability provided by a marginal resource when added to a particular system, but cannot necessarily be extrapolated to future system conditions.

Q. What is the *marginal* capacity contribution, and how does it differ from other capacity contribution metrics?

A. When evaluating candidate resources to be added to the portfolio, it is important to understand how each candidate resource may affect the reliability of the portfolio. The *marginal capacity contribution* is the change in the overall reliability of the system after the addition of a given resource. This is distinct from methods designed to estimate the contribution of existing resources to a static portfolio. The marginal capacity contribution is appropriate to use in planning or procurement when considering new resources that might be added to the portfolio.

The marginal capacity contribution is especially important to consider when variable resources such as wind or solar achieve higher penetrations. For these resources, the marginal capacity contribution typically declines as more of the resource is added to a portfolio. This is easiest to understand for solar resources. Figure 3 below demonstrates this phenomenon for solar PV on an example day in the California market. Before any solar PV is added, the peak hour on this day occurs at Hour Ending (HE) 15. The first 6 gigawatt (GW) increment of solar reduces the *net* peak load (load minus renewable energy production) by 3 GW, or about 50% of the solar resources' nameplate capacity. After that increment is added, the net peak load hour shifts to HE 16. Adding a second 6 GW increment of PV reduces the net peak load on this day by about 1.5 GW, or 25% of nameplate, and shifts the net peak load hour to HE 17. This value is lower due to the reduced coincidence of PV output with net load. The next 6 GW increment achieves only about 300 MW of net peak load reduction, or 5% of nameplate. By this time the net peak load hour is at HE 18, when solar PV production is very low.

This simplistic example shows the effect of saturation of the system with solar PV on an example day for explicatory purposes. Most methods for estimating the capacity contribution of solar PV would consider multiple days with different load and solar PV conditions; however, these metrics will need to consider these saturation effects as PV resources become a meaningful proportion of the portfolio.

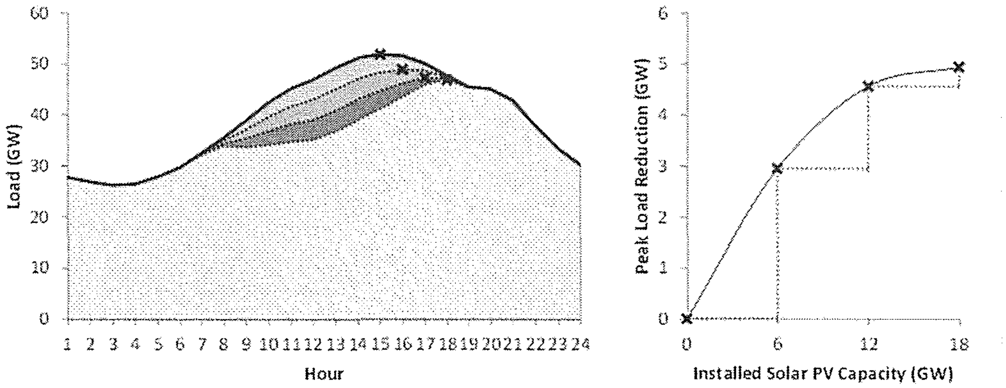

Figure 3. Example of declining capacity contribution of solar PV as a function of penetration in the California market

Q. Is the distinction between average and marginal capacity contribution important for conventional resources?

A. No, the capacity contribution of conventional resources is based on their ability to produce energy during hours with non-zero LOLP. This ability does not change as more resources are added, so the distinction between average and marginal capacity contribution is not important.

Q. Is the capacity contribution of a given variable resource the same for all utilities?

A. No, the same resource can have very a different capacity contribution for each utility, because the coincidence of resource output with high net load conditions is different for each utility due to its unique load profile and resource portfolio.

Q. Is the capacity contribution of a given variable resource fixed over time?

A. No, the capacity contribution of a given variable resource will change if the portfolio loads or resources change. We have already seen that the marginal capacity contribution of a given resource type declines as more of it is added to a system, in particular for solar resources. Conversely, if load conditions evolve over time such that peak load is more coincident with a variable resource's highest output, that resource's capacity contribution will increase.

III. Overview of Methodologies Used to Quantify the Capacity Contribution of Variable Resources

Q. What methodologies are used to assess the capacity contribution of variable resources?

A. There is no industry standard methodology to assess the capacity contribution of variable resources, and a variety of methodologies are in use. Approaches can be placed into two broad categories, heuristics and reliability-based:

- ***<u>Heuristics, e.g., time-window approach</u>*:** heuristic methods generally involve estimation of the resource's likely output over a pre-defined critical system period, usually periods of peak load when ensuring capacity adequacy is most challenging. The relevant time window over which to measure output depends on system-specific conditions. For example, ISO-New England uses a time window of 2 – 6 pm during June – September. Winter-peaking systems might select a time window that spans late afternoon and early evening during December – February. The capacity contribution of the resource's output may be defined as the expected or mean output during the critical periods. Alternatively, an "exceedance" approach defines a percentile at which the output is deemed to be sufficiently reliable. For example, California uses a 70% exceedance value, which means that the capacity contribution is defined as the value production is expected to exceed during 70% of the hours.
- ***<u>Reliability-based, e.g. ELCC approach</u>*:** within LOLP studies, a commonly used metric for an individual resource's capacity contribution is ELCC. ELCC was first introduced as a method of estimating the effect of a change in a conventional unit's capacity or forced outage rate, but has also been useful for assessing the capacity contribution of variable resources. A common definition of ELCC is the additional

load that can be served by an incremental resource while maintaining the same level of system reliability. ELCC can also be defined in terms of avoided capacity needed from a benchmark generator, in many cases defined as a "perfect" generating unit (one with no forced outages or temperature de-rates).

The table below provides a brief survey of methodologies used in a range of jurisdictions.

Table 1: Methodologies used to assess capacity contribution of renewables in other jurisdictions

	Approach	Discussion
Arizona Public Service	ELCC	Average capacity value over several years of LOLE simulations
BC Hydro	ELCC	
BPA	Time window	Wind is assigned zero value based on 85 percent and 95 percent exceedance
California PUC	Time-window	70 percent exceedance during Dec-Mar, 4pm-9pm and Apr-Oct, 1pm-6pm; 3 years of data required
ERCOT	ELCC	
Idaho Power	Time-window	Summer, 3pm-7pm
ISO New England	Time-window	Average of median net output from 2 pm to 6 pm for June to September in previous five years
Midwest ISO	ELCC	
New York ISO	Time-window	Average capacity factor during Jun-Aug, 2pm-6pm and Dec-Feb, 4pm-8pm from previous year
Ontario IESO	Time-window	Capacity factor over the top 5 contiguous daily peak demand hours; median value for 18-Month Outlook; probabilistic assessment for Comprehensive/Interim Reviews of Resource Adequacy
PJM	Time-window	Average capacity factor during Jun-Aug, 4pm-6pm based on last three years; 13 percent used for new wind plants with no data available
PNM	Time-window	Peak hour
PSCO/Xcel	ELCC	Based on 10-year ELCC study
Quebec Balancing Authority Area	Other	Monte Carlo analysis supplemented by analysis of fourteen critical extreme cold weather events

Sources: Milligan and Porter 2008,[2] NERC 2011,[3] Rogers and Porter 2012[4]

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[2] Milligan, M., Porter, K., 2008. Determining the Capacity Value of Wind: an Updated Survey of Methods and Implementation. National Renewable Energy Laboratory, NREL/CP-500-43433, http://www.nrel.gov/docs/fy08osti/43433.pdf.

[3] NERC, 2011. Methods to Model and Calculate Capacity Contributions of Variable Generation for Resource Adequacy Planning. http://www.nerc.com/files/ivgtf1-2.pdf.

Q. Are there advantages and disadvantages of each methodology used to assess capacity contribution of variable energy resources?

A. Yes. The table below summarizes the main advantages and disadvantages of the heuristic and ELCC approaches to evaluating the capacity contribution of variable resources. The principal advantage of heuristic methods is that they are easy to understand and to calculate. They generally consist of simple statistics averaged over a large number of hours. When renewable penetration is low, heuristic methods may serve as reasonable approximations for a more detailed analysis.

The principal disadvantage of heuristics is a lack of analytical depth. Heuristic methods are based on designation of hours that may not correspond to the most critical hours, as they generally do not explicitly consider factors such the expected availability of other resources or the correlations between load and variable resource output within the time window. Therefore, they may fail to identify the critical hours when serving load is most challenging, i.e., when LOLP is highest. Conversely, a time window heuristic often includes hours during which LOLP is insignificant; this can be problematic if variable resource production is different during these hours than during the most critical hours.

ELCC methodologies, by contrast, incorporate information on load conditions and generator availability across a wind range of conditions. They also capture the correlations among load and variable resource production in order to identify the critical set of hours, those in which a system has non-negligible loss of load probability. Further, the hours with highest LOLP have a larger weight in determining the ELCC. In that sense, the calculations

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[4] Rogers, J., Porter, K., 2012. Summary of Time Period-Based and Other Approximation Methods for Determining the Capacity Value of Wind and Solar in the United States. National Renewable Energy Laboratory, NREL/SR-5500-54338, http://www.nrel.gov/docs/fy12osti/54338.pdf.

are more robust than heuristics, which do not necessarily isolate the most critical system hours. ELCC methods are also better able to capture the interactive effects between different variable resources as penetrations increase. ELCC methods therefore are more rigorous. Although they are more cumbersome and costly to implement, analytically rigorous methods may be beneficial at higher renewable penetration levels.

While more rigorous than heuristic methods, conventional ELCC methodologies may not be appropriate for all systems. For example, in systems dominated by hydroelectric resources with storage and shaping capability, the output of variable resources during the critical system hours may not be a good indicator of their expected capacity contribution. Similarly, as the penetration of variable energy resources increases on a system, integration solutions such as demand response or energy storage may be needed to shape load and renewable output. ELCC approaches may need to be adapted to account for the presence of these energy-limited resources.

Table 2: Advantages and disadvantages of heuristic and ELCC methodologies for determining renewable energy capacity contribution

	Heuristics	ELCC
Advantages	• Easy and quick to calculate • Lower data requirements • Easy to explain and understand	• More detailed and robust • Assesses a large set of system conditions • Calculations can capture complex correlations between resources and load and declining value with increased penetration
Disadvantages	• May miss critical system conditions, e.g. peak load period may not be highest-risk period due maintenance, seasonal outage probabilities, hydro conditions, etc. • May not capture correlations between resources and load or declining value with increased penetration	• Calculations are complex • Time-intensive to gather and validate data inputs • Difficult to explain and understand • Require significant quantities of high-resolution, high-quality data

IV. Capacity Contribution Approach Used for PGE's 2016 IRP

Q. What methodology did PGE elect to use to assess capacity contribution for use in the 2016 IRP?

A. PGE retained E3 to review its resource adequacy planning techniques in light of increased penetration of wind energy and impending loss of existing hydro and thermal assets in its resource portfolio. E3 recommended, and PGE adopted, a reliability-based framework for estimating PGE's PRM and determining the capacity contribution of renewables. E3 performed studies to estimate the Target PRM, i.e., the PRM required for PGE's resource portfolio to meet a 1-day-in-10-year loss-of-load standard in a 2021 test year. E3 then estimated the marginal contribution of additional renewable resources toward PGE's capacity needs using an ELCC methodology with consistent data, analytical framework, and modeling techniques as were used to estimate the required PRM. All studies were performed using E3's Renewable Energy Capacity (RECAP) planning model, which uses common industry techniques for estimating loss-of-load probability and related metrics.

Q. PGE elected to use a methodology to assess capacity contribution of renewables that is consistent with the methodology used to determine PRM for its resource portfolio. Why is this important?

A. Consistent methods should be used to ensure the target level of system reliability is maintained. Discrepancies introduced by the use of inconsistent methods could result in either underestimating or overestimating the capacity required for resource adequacy. For example, if the Target PRM is determined using a LOLP approach, it would be inconsistent to utilize a time-window approach to estimate the marginal capacity contribution of wind and solar resources, since the hours included in the time-window would necessarily be different from the hours in which the reliability model finds non-negligible LOLP. Conversely, if the PRM is determined using a heuristic, a consistent heuristic should be used to estimate the marginal capacity contribution of wind and solar.

Q. Please describe the RECAP model.

A. RECAP is a loss-of-load-probability model developed by E3 to calculate system reliability as a function of detailed inputs on load level and variable resource availability. RECAP compares probability distribution functions for supply and demand by month, hour, and day type (weekend, weekday) and determines the probability that load will exceed supply in each time slice. Relevant correlation between variables is enforced using conditional probability distributions. A detailed description of the model is available in PGE Exhibit 201.

Q. Has the RECAP model been used before for other planning studies and processes?

A. Yes, RECAP was first developed through work with the California Independent System Operator (CAISO) to evaluate the need for system capacity in scenarios with 33 percent renewable portfolio standard (RPS). E3 continues to use RECAP to support the CAISO's modeling of capacity and flexibility needs to accommodate high penetrations of variable renewable generation. E3 has also used RECAP to evaluate the capacity contribution of variable and dispatch-limited resources such as wind, solar and demand response on behalf of the California Public Utilities Commission (CPUC) and the Sacramento Municipal Utilities District (SMUD). Outside of California, E3 has utilized RECAP to estimate Target PRM and renewable ELCCs for systems in Florida, Texas and throughout the Western Interconnection.

Q. What metrics are used in RECAP to characterize system performance and resource capacity contribution with respect to reliability?

A. RECAP calculates conventional reliability metrics including:

- Loss of Load Probability (LOLP);
- Loss of Load Expectation (LOLE);
- Target Planning Reserve Margin (Target PRM); and
- Expected Load Carrying Capability (ELCC)

Q. What are the main advantages of using the RECAP methodology to assess capacity contribution relative to a simple load-resource balance analysis?

A. The traditional load-resource balance calculations are focused on resource availability in a single hour of the year: the peak load hour. RECAP considers a broad range of stochastic variables such as load level, wind and solar output, hydro availability, and generator outages—and the correlations among them—to arrive at robust probabilities of loss of load and estimates of resource capacity contribution. RECAP provides detailed information to analyze the balance between loads and the total portfolio of resources over a large set of conditions. For the purposes of Integrated Resource Planning studies, using the RECAP methodology makes it possible to calculate the marginal capacity contribution of adding new resources to the existing portfolio, taking into account any changes in marginal ELCC value as the penetration level of the resource is varied.

Q. Please describe the data that was used in RECAP to model PGE's load, wind resources, and solar resources.

A. The study for PGE utilized the following data:

- *Load:* the study used weather-based hourly load time series capturing 33 years of weather conditions (1980-2012). Historical load data from 2007-2012 were used to train a neural-network model and simulate load shapes for prior years based on each year's respective weather conditions. PGE load data for 2008-2014 were also incorporated into the load time series. The load shape was scaled to match PGE's 2021 monthly and seasonal 1-in-2 peaks and total energy.
- *Wind:* the study utilized synthetic hourly wind shapes for 2004-2006 for each wind site as well as historical output data from 2008-2014 for Biglow Canyon.
- *Solar:* the study used 2006 synthetic solar shapes.

Q. Please describe the LOLP results from PGE's study.

A. Figure 4 shows a "heat map" of LOLP for the 2021 PGE modeled system. The columns represent each month of the year, and the rows represent hours of the day. The values in each cell are the LOLE for the PGE system during that time slice in a test year of 2021. Red shading indicates hours with high LOLP, while green shading indicates hours in which LOLP is negligible.

The analysis shows non-zero LOLP during many hours of the 2021 test year due to a significant resource shortfall. Hours with non-zero LOLP occur during all seasons but are highest during summer afternoons and winter evenings. PGE's load tends to be higher in the winter, but summer peaks are become increasingly frequent. PGE's resource availability is lower during the summer than during the winter, and as a result, there are significant periods with high LOLP during both the summer and winter peaks.

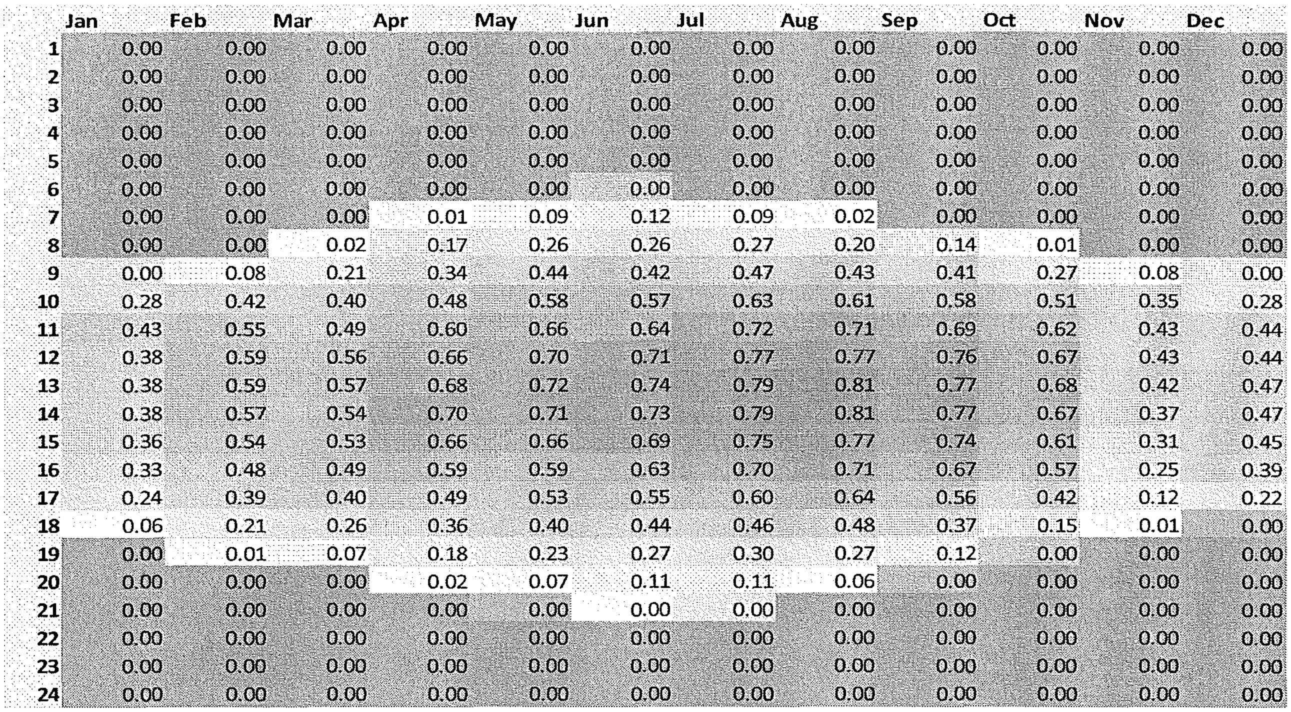
Summing the LOLP across all hours of the test year yields a LOLE of 332 hours. Of these, 161 hours occur during the summer season (June – September), 160 hours occur during the winter season (November – February), and the remainder of the hours occur during the shoulder seasons.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.007	0.005	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.004	0.024
2	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.006
3	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.005
4	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.006
5	0.004	0.005	0.003	0.002	0.000	0.000	0.000	0.000	0.000	0.001	0.005	0.016
6	0.095	0.085	0.049	0.020	0.000	0.000	0.001	0.006	0.011	0.015	0.132	0.221
7	0.616	0.466	0.327	0.046	0.001	0.001	0.009	0.029	0.045	0.087	0.517	1.326
8	2.288	1.212	0.576	0.088	0.005	0.005	0.054	0.157	0.148	0.168	1.149	2.971
9	3.735	2.105	0.782	0.053	0.011	0.024	0.212	0.673	0.208	0.142	2.083	4.669
10	3.277	1.663	0.625	0.039	0.025	0.079	0.782	1.599	0.354	0.102	1.872	4.506
11	2.724	1.237	0.450	0.028	0.050	0.188	1.846	3.001	0.586	0.079	1.517	4.063
12	2.160	0.958	0.292	0.021	0.083	0.384	2.982	4.435	0.866	0.068	1.262	3.450
13	1.920	0.687	0.146	0.015	0.137	0.658	4.363	5.794	1.358	0.060	1.052	2.787
14	1.553	0.443	0.091	0.012	0.179	1.004	5.653	7.225	1.931	0.068	0.865	2.143
15	1.247	0.309	0.064	0.009	0.233	1.222	6.626	8.347	2.430	0.071	0.756	1.658
16	1.142	0.299	0.053	0.008	0.269	1.476	7.254	8.844	2.858	0.077	0.884	2.156
17	1.710	0.462	0.084	0.008	0.295	1.521	7.295	8.897	3.037	0.140	1.446	3.991
18	3.803	1.020	0.173	0.012	0.274	1.250	6.316	8.263	2.835	0.279	3.072	6.586
19	5.858	1.962	0.417	0.014	0.196	0.761	4.706	7.171	2.365	0.441	4.662	8.323
20	5.693	2.176	0.618	0.026	0.126	0.410	3.234	5.619	2.064	0.348	4.120	7.589
21	4.231	1.469	0.416	0.023	0.074	0.209	2.058	4.266	1.555	0.144	2.979	5.584
22	2.457	0.778	0.133	0.008	0.023	0.072	0.229	1.012	0.135	0.021	1.572	3.261
23	0.882	0.253	0.019	0.001	0.001	0.005	0.021	0.194	0.008	0.003	0.553	1.052
24	0.119	0.030	0.001	0.000	0.000	0.000	0.001	0.012	0.000	0.000	0.084	0.179

Figure 4. Loss-of-Load Probability "heat map" for the PGE system shows relatively equal probability of lost load during summer and winter months (numbers represent Loss-of-Load Expectation, measured in hours, for each time-slice)

Q. What renewable resource production patterns have the highest capacity contributions for the PGE system?

A. The key characteristic determining a resource's capacity contribution is the coincidence, or lack thereof, of periods of high resource output with periods of high load. Because of these LOLP patterns, renewable resources that are expected to produce at a high level during either the summer peak hours or the winter peak hours can be expected to have a high marginal ELCC relative to resources producing at lower levels during those hours. For example, Figure 5 shows the average capacity factor for a generic solar PV site by month-hour time slice. Expected plant output is high in the summer and coincident with the periods of high LOLP on summer afternoons. However, the same site has relatively low output during the periods of high LOLP in the winter. Solar resources therefore do little to improve reliability during winter evenings but can have a significant effect during summer afternoons when LOLP is high. These relationships are captured and appropriately weighted within the RECAP framework to arrive at a robust assessment of expected capacity contribution.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.01	0.09	0.12	0.09	0.02	0.00	0.00	0.00	0.00
8	0.00	0.00	0.02	0.17	0.26	0.26	0.27	0.20	0.14	0.01	0.00	0.00
9	0.00	0.08	0.21	0.34	0.44	0.42	0.47	0.43	0.41	0.27	0.08	0.00
10	0.28	0.42	0.40	0.48	0.58	0.57	0.63	0.61	0.58	0.51	0.35	0.28
11	0.43	0.55	0.49	0.60	0.66	0.64	0.72	0.71	0.69	0.62	0.43	0.44
12	0.38	0.59	0.56	0.66	0.70	0.71	0.77	0.77	0.76	0.67	0.43	0.44
13	0.38	0.59	0.57	0.68	0.72	0.74	0.79	0.81	0.77	0.68	0.42	0.47
14	0.38	0.57	0.54	0.70	0.71	0.73	0.79	0.81	0.77	0.67	0.37	0.47
15	0.36	0.54	0.53	0.66	0.66	0.69	0.75	0.77	0.74	0.61	0.31	0.45
16	0.33	0.48	0.49	0.59	0.59	0.63	0.70	0.71	0.67	0.57	0.25	0.39
17	0.24	0.39	0.40	0.49	0.53	0.55	0.60	0.64	0.56	0.42	0.12	0.22
18	0.06	0.21	0.26	0.36	0.40	0.44	0.46	0.48	0.37	0.15	0.01	0.00
19	0.00	0.01	0.07	0.18	0.23	0.27	0.30	0.27	0.12	0.00	0.00	0.00
20	0.00	0.00	0.00	0.02	0.07	0.11	0.11	0.06	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 5. Average capacity factor of a solar site as a fraction of nameplate capacity by month-hour time slice.

Q. Does the ELCC value indicate how much capacity PGE can rely on from a given resource at all times?

A. No, the metric is a statistical *expectation* and does not guarantee that level of output will materialize. During some critical hours, production from the resource will be *less* than indicated by the ELCC metric. By the same token, there will be some hours in which *more* than the expected level of output will be available. ELCC captures the reliability implications of both conditions through their contribution to system-wide LOLP.

Importantly, a resource's capacity contribution expectation will also change as PGE's load shape and total resource portfolio evolve over time. In the example above, if system conditions were to change so that summer LOLP were to decrease, either through summer load reductions or the addition of resources with high summer output such as solar PV, the assessed capacity contribution of the sample solar site would decrease due to the lower coincidence with system LOLP, which would now be concentrated in the winter. Conversely, if resources with high winter output were to be added to the system, the capacity contribution of the sample site would increase because LOLP would be more concentrated during the summer months.

Q. What ELCC value does this methodology assign to PGE's existing renewable resources?

A. Table 3 below shows the nameplate rating and ELCC values for PGE's existing portfolio of resources, consisting mostly of wind resources in the Columbia Gorge area. The table shows ELCC values for the winter and summer seasons as well as the annual value representing all hours of the year. The combined annual ELCC of PGE's existing portfolio of 902 MW of renewable resources is assessed at 127 MW or 14.1% of nameplate based on simulated 2021 system conditions. ELCC values are calculated relative to a conventional unit with nameplate capacity of 100 MW and 5% forced outage rate.

Table 3: Nameplate rating and ELCC of PGE's existing portfolio of renewable resources in 2021

	Winter	Summer	Annual
Nameplate rating MW	902	902	902
Portfolio ELCC (MW)	108	138	127
Portfolio ELCC (% of nameplate MW)	12.0%	15.3%	14.1%

Q. What marginal ELCC value does PGE's methodology assign to renewable resources that are candidates for addition to PGE's portfolio?

A. The marginal ELCC is a function of the size and composition of the portfolio of resources to be added. Table 4 below shows example values for a given portfolio in 2021 that includes 665 MW of Columbia Gorge wind resources and 142 MW of solar PV resources. The wind sites have a marginal ELCC that is lower than the value for the existing portfolio of resources, due to the saturation effects discussed above. Solar PV resources have a higher marginal ELCC given the low solar penetration in PGE's current portfolio and the high LOLP during the summer peak period. The combined portfolio is assessed to have a marginal ELCC of 135 MW, or 17% of nameplate.

Table 4: Nameplate rating and marginal ELCC of a candidate portfolio of renewable resources including a mix of Columbia Gorge wind and solar PV resources

Resource	Nameplate Rating (MW)	Marginal Winter ELCC	Marginal Summer ELCC	Marginal Annual ELCC
Incremental Wind Sites	665 MW	118 MW (18%)	60 MW (9%)	69 MW (11%)
Incremental Solar Sites	142 MW	11 MW (8%)	78 MW (55%)	59 MW (42%)
Total Incremental Portfolio	807 MW	133 MW (16%)	139 MW (17%)	135 MW (17%)

Q. Was a full ELCC study conducted for each potential new resource and combination of new resources under consideration during the 2016 IRP?

A. No, it would be impractical to do so. As mentioned above, the ELCC values are a function of the particular load conditions in a given year as well as the rest of the generation portfolio, and therefore represent only a single snapshot of the complex dynamics of the system. Examining all such combinations of load and resources would not be feasible due to the time, labor and computer processing required. Instead, E3 conducted ELCC studies for combinations of candidate resource types. E3 also provided an interpolation method that enables PGE to quickly derive reasonably accurate estimates of portfolio ELCC values for any combination of these resource types for a range of potential penetration levels. This approach captures the most important dynamics in determining ELCC value: correlations of production and load, saturation effects at higher penetrations, and the effect of portfolio diversity.

V. Limitations and Additional Considerations

Q. What are the principal limitations of the ELCC methodology selected by PGE to assess capacity contribution for use in the 2016 IRP?

A. The principal limitation of applying this methodology is related to the need to gather and process significant amounts of high-quality data. The RECAP approach is multifaceted, has substantial data requirements, and is computationally intensive. More time and resources are required to prepare and validate data and modeling assumptions than for heuristic methodologies. Data inputs must be updated frequently, as substantial changes in load forecast and resource mix may occur from year to year. Communicating the results is also more challenging due to the complexity of the approach.

Q. Are the ELCC values shown in Table 4 valid for all combinations of resources today or at any time in the future?

A. No, the values in Table 4 are specific to a given portfolio. They represent the marginal ELCC values for a given mix of wind and solar resources added to PGE's system in 2021. These marginal ELCC values for new resources are not directly applicable to any existing resources on the PGE system, nor to any other combinations of new resources added to PGE's system, nor to any other utility.

Q. Can PGE's ELCC method be used to isolate the capacity contribution of individual existing resources on PGE's system?

A. Table 3 shows the combined ELCC of PGE's existing portfolio of resources in the modeled 2021 PGE system. These ELCC values are a function of this specific portfolio. Adding or removing resources would change these ELCC values. Moreover, the values are shaped by portfolio effects. For example, wind farms at different locations provide a more diverse supply portfolio than resources located closer together. Similarly, wind and solar resources are often complementary, in the sense that one resource may be producing during hours when the other is not. This results in portfolio effects in which the whole can be greater than the sum of the parts.

This effect can be seen in the numbers presented in Table 4. The annual marginal ELCC is 69 MW for incremental Columbia Gorge wind sites and 59 MW for solar sites. The marginal ELCC for the combined portfolio of wind and solar sites is 135 MW, greater than the simple sum of 128 MW due to diversity benefits.

Because the whole does not equal the sum of the parts, calculating the contribution of a specific resource to the ELCC of a portfolio requires two steps:

1. Calculate the ELCC for the portfolio of resources;
2. Allocate the portfolio ELCC to the individual resources.

Q. Is there a mathematically rigorous way to perform the allocation required in Step 2 above?

A. No, there is not. There are a variety of methods in use, but each requires a somewhat arbitrary assumption about how each resource contributes to the diversity benefits described above.

Q. What are the main considerations relating to the quality and quantity of data inputs to RECAP?

A. The robustness of model results is dependent on the availability and quality of the input data. Broadly, the data considerations can be divided into the following categories:

- ***Sample size.*** To obtain meaningful results, at least one year of time-synchronized hourly load and variable resource output data is required. Longer time durations increase confidence in the robustness of capacity contribution estimates by capturing a broader range of potential conditions.

- ***Correlations with load.*** The precision of the correlation between load and resources is affected by the way in which the data are segmented. To capture correlations between load and resource output, RECAP creates distributions for each month, hour, and weekday or weekend day type. However, there is often correlation even within each month/hour/day type. For example, high load may be correlated with high temperatures, and high temperatures may be correlated with decreased wind output or increased PV output. To account for these correlations, RECAP can create bins (or groupings) based on load level within each month/hour/day type, e.g. How these bins are created depends on data availability. Creating more and smaller bins increases the precision of the correlation assessment, but reduces the number of data points in each bin and therefore lowers the confidence in the estimate.
- ***Inter-annual variability.*** Because large variation in resource output patterns may exist between years, especially for wind, multiple years of data are desired. Figure 6 shows the average capacity factor of PGE's Biglow Canyon wind farm from 5 PM to 9 PM in December for each of the past seven years. The average plant capacity factor in those hours has varied between 12 percent and 30 percent across these years. Accounting for this kind of variability can improve the robustness of the estimates, but data for a large number of years spanning a range of different conditions are often not available.

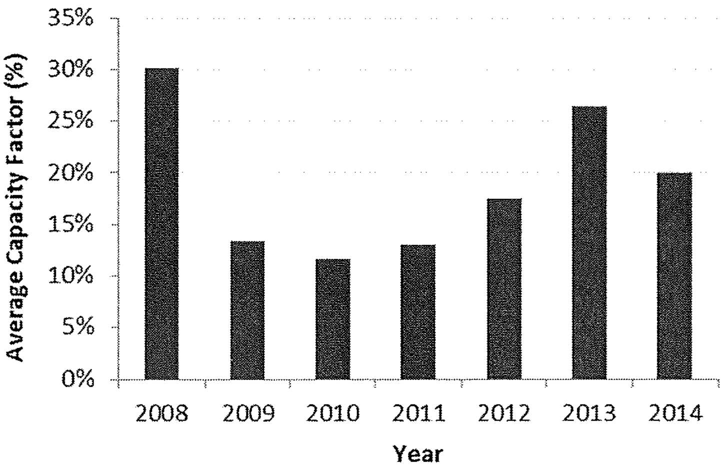


Figure 6. The average capacity factor of Biglow Canyon wind farm during winter peak hours (December, 5PM-9PM) varies substantially depending on the year

- ***Data availability.*** When actual historical output data are not available, synthetic data may be used. For example, the National Renewable Energy Laboratory has published simulated wind capacity factor estimates for each year between 2004 and 2006 (3TIER 2010). However, discrepancies between actual historic production data and NREL's synthetic data for similar sites have been observed. Synthetic data should therefore be used with caution and be verified against actual performance data as the latter become available. Other options include deploying anemometers at candidate sites to measure wind speed or requiring developers to submit expected performance data for contractual purposes. As already discussed, considerable inter-annual variability in resource availability may exist, so continual data collection and re-evaluation of a resource's capacity contribution as data become available are critical to improving precision of results.

Q. Does the methodology PGE selected to assess capacity contribution for use in the 2016 IRP provide information about needs for operational flexibility?

A. No. The approach provides an assessment of hourly capacity need and resource availability. It does not consider system operating and flexibility constraints such as ramping, start-up and shut-down time, minimum up- and down-time, minimum loading, etc.

VI. Conclusions

Q. Given its limitations, is the PGE approach to evaluating the capacity contribution of variable resources reasonable?

A. Yes, I believe PGE's method is reasonable for estimating the marginal capacity contribution of candidate resources during PGE's 2016 IRP. The biggest advantage of PGE's ELCC methodology is in its use of existing data on loads and conventional resources to identify a set of hours with non-zero LOLP, and to assess the likely production of wind and solar generation during these hours. The data needed for this step—multiple years of load shapes and forced outage rates for existing generators—are readily available. Thus, while considering the limitations is important for proper interpretation of the results, the PGE approach provides more detailed and precise information about system capacity needs and a resource's capacity contribution, and is therefore superior to heuristic methodologies. With additional data and continual re-assessment of system conditions, it allows for a robust assessment of system reliability.

The limitations of PGE's methodology stem largely from concerns about data availability and quality, particularly for wind and solar production. However, it should be noted that heuristic methods for evaluation of capacity contribution rely on the same underlying data and would therefore suffer from the same limitations if data were limited, flawed, or altogether unavailable.

Q. Is the PGE approach to evaluating the capacity contribution of variable resources reasonable for other purposes?

A. I have not studied the use of PGE's methodology for any purpose other than for evaluation of marginal capacity contribution of new resources, and therefore I have no opinion about it.

Because of the complexity of the ELCC methodology, adaptations are likely necessary if it is to be applied to other purposes. These adaptations will need to be determined on a case-by-case basis.

Q. Are you aware of any applications for an ELCC methodology would likely not be an appropriate methodology for estimating capacity contribution of variable resources?

A. While I have not studied any other application on PGE's system in detail, PGE's ELCC method developed for its 2016 IPR would likely not be appropriate for determining the capacity contribution of variable energy resources toward reducing peak load on a distribution feeder. Distribution system planning does not typically involve studying the multiple outage conditions of a portfolio of generators. Rather, a single distribution feeder serves all load connected to it and as a consequence, distribution system planning typically involves power flow analysis of the hour with the highest peak load to ensure that the single feeder can meet all demands placed upon it. While distributed solar PV resources can help to reduce that highest peak load—assuming it does not occur after sundown—LOLP studies are generally not used to estimate PV contribution to meeting distribution system peaks due to the nature of the distribution system studies. Rather, heuristics are used to estimate the likely contribution of PV during the peak hour studied.

Q. Should the Commission mandate a "one-size-fits-all" methodology, applied uniformly to all utilities under its jurisdiction in all circumstances?

A. No. While I believe there are significant advantages to the ELCC methodology that PGE has elected to use in its 2016 IRP cycle relative to the heuristic methods commonly used in the industry, I do not recommend that the Commission mandate its use at all times and under all circumstances, for the following reasons:

- ELCC estimation is a significant effort requiring detailed calculations, extensive data, and sophisticated computer models. Whether to embark on such an effort should be evaluated on a case-by-case basis.
- ELCC requires significant quantities of high-quality data in order to support accurate calculations. If these data are not available, the advantages of the ELCC methodology may be blunted.
- The ELCC value of a resource is portfolio-specific and can change over time as the portfolio loads or resources change. Thus, application of the ELCC methodology to an individual resource must be done with a specific aim in mind. PGE intends to use the ELCC values described herein to estimate the capacity contribution of potential resources to its portfolio during the 2016 IRP cycle, and I believe that its methodology for doing so is reasonable. However, the ELCC methodology may need to be adapted if it is to be used for other applications.
- For example, while the methodology can provide robust estimates of the ELCC of PGE's current portfolio of renewable resources, there is no mathematically rigorous way to attribute this portfolio ELCC to individual existing resources. Using ELCC for this purpose would require development of allocation methodologies that are unavoidably arbitrary.
- There may be other factors besides those considered in the ELCC methodology, such as the availability of transmission capacity, that have a bearing on a resource's capacity contribution.
- While the ELCC methodology can provide a statistically robust estimate of the capacity contribution of variable resources, the calculations are only estimates and are not a

guarantee that the resource will be available under any given circumstances. It may be prudent for a utility to consider additional measures to ensure reliable electric service due to the uncertainty inherent in the calculations.

VII. Qualifications

Q. Mr. Olson, please describe your qualifications.

A. I have over 20 years of experience in the energy industry, specializing in the areas of transmission planning, rate and tariff design, integrated resource planning and renewable energy planning –including renewable energy procurement, program design and transmission assessment, and energy policy analysis. I have consulted extensively for renewable energy project developers, utilities, transmission system operators, transmission project developers, and state regulatory commissions regarding renewable energy procurement and related transmission needs. I hold a Master of Science degree in Energy Management and Policy from the University of Pennsylvania and Bachelor of Science degree in Statistics and Mathematical Sciences from the University of Washington. I have previously been retained as an expert and have provided expert testimony in front of the California Energy Commission, the California Public Utilities Commission and the Alberta Utilities Commission.

I have led various projects throughout my career, including:

- Developing renewable energy generation and transmission scenarios spanning the Western Interconnection to meet current and potential future policy goals, on behalf of the Western Electric Industry Leaders' Group, a group of western utility Chief Executive Officers.
- Conducting a landmark study of the feasibility, cost, transmission needs and renewable integration challenges of achieving a 50% renewable grid, on behalf of California's five largest electric utilities.

- Developing a new stochastic production simulation modeling framework for estimating flexible capacity needs for renewable integration under high penetration.
- Developing a stochastic model of power system resource adequacy based on a Loss-of-Load Probability framework, in which the capacity contribution probability of renewable electric generators is explicitly considered.

I have also acted as an advisor to:

- the California Independent System Operator in an assessment of conventional and flexible capacity needs under high renewable penetration.
- the California Public Utilities Commission staff in its administration of California's Renewables Portfolio Standard, including development of computer models that forecast renewable energy procurement based on net value to ratepayers, incorporating estimates of capacity credit for wind and solar generation.
- renewable energy developers in California in development strategy including assessment of net ratepayer value under "Full Capacity Deliverability Status" vs. "Energy-Only" (no capacity value).
- electric utilities throughout North America in developing analytical frameworks and performing calculations to estimate the quantity and value of capacity provided by renewable energy resources.

A copy of my curriculum vitae is attached as PGE Exhibit 202.

Q. Does this conclude your testimony?

A. Yes, it does.

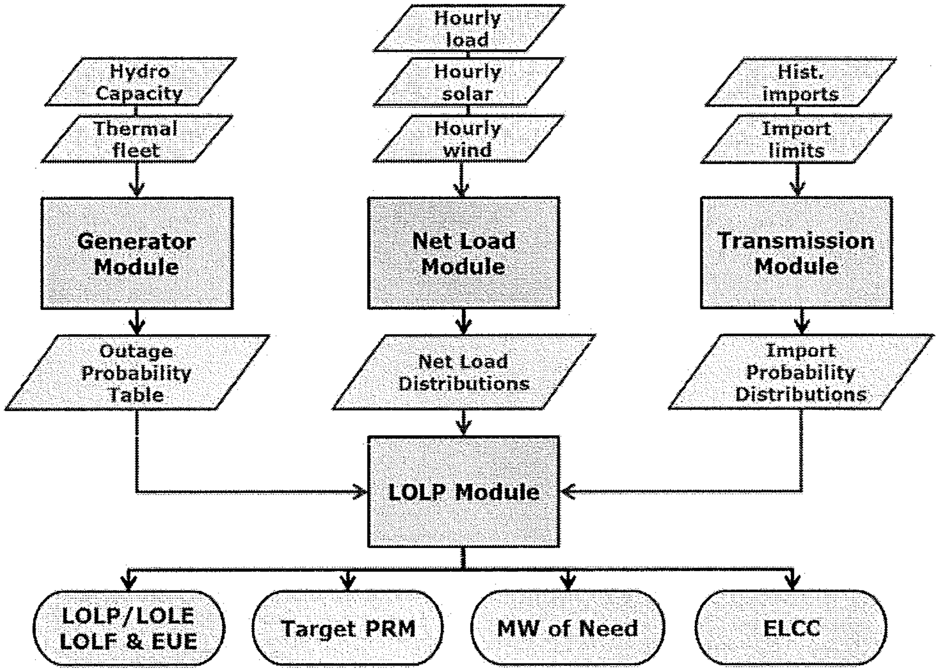
VIII. List of Exhibits

PGE Exhibit	Description
201	RECAP Methodology
202	Curriculum Vitae of Arne Olson

RECAP Methodology

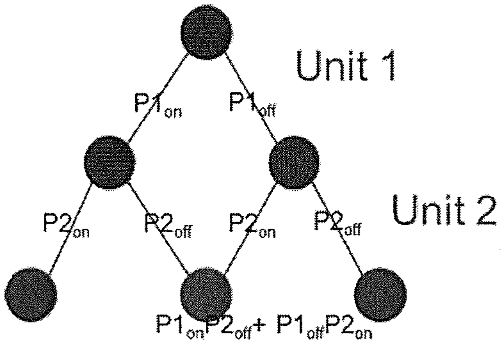
The Renewable Energy Capacity Planning Model (RECAP) works by comparing probability distribution functions (PDFs) for supply and demand by month, hour, and day type (weekend, weekday) in order to find the probability that load will be greater than supply in the pertinent time slice. Relevant correlation between variables is enforced using conditional probability distributions. The model is organized into three modules, shown in Figure 1, the methods of which are summarized below.

Figure 1: RECAP model flowchart



The generator module uses forced outage rates for a fleet of generators to calculate the probability of different total amounts of capacity outage. The output from this module is a capacity outage probability table, a standard output from resource adequacy models.

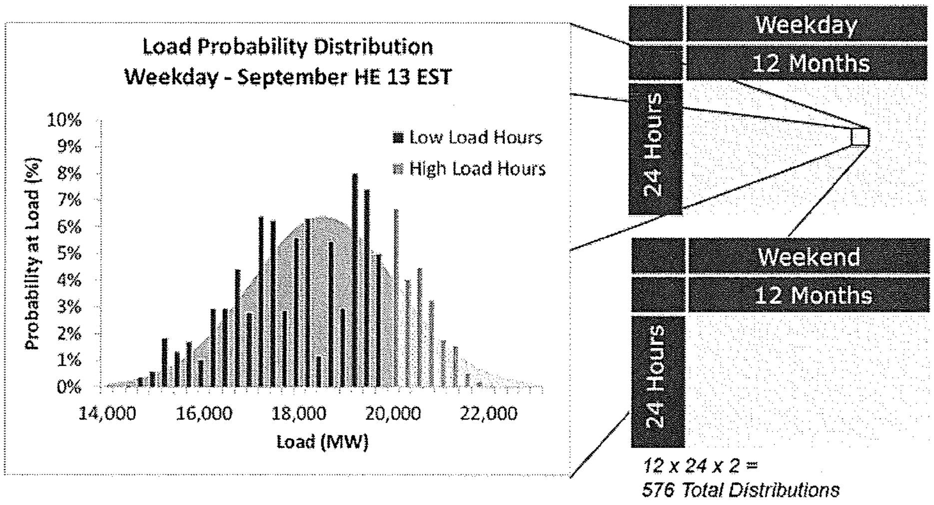
Figure 2: Process to create a capacity outage probability table



The transmission module creates import probability distributions using historical transmission outage distributions. Together with the capacity outage probability table, the import probability distributions give the probability of having different amounts of supply side resources available to a system operator.

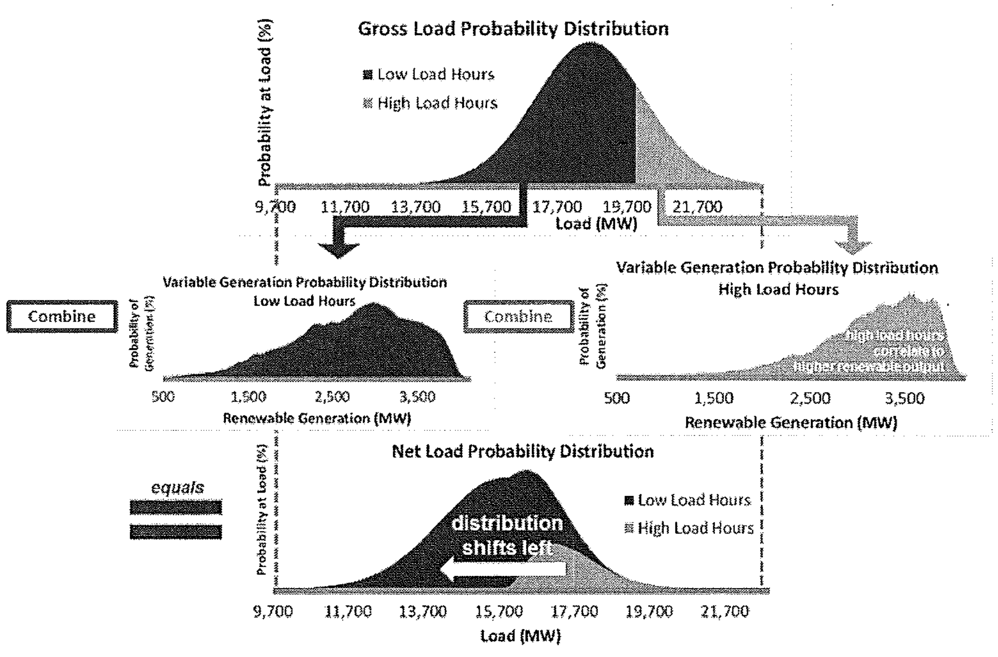
The net load module creates a probability distribution function for net load . The design was driven by the goal of making full statistical use of historical data, recognizing that often such data is not aligned through time. Gross load distributions are specific to a single month-hour-day type combination, as shown in Figure 3.

Figure 3: Gross load distribution



Relevant correlations between load, wind, and solar are enforced, where significant, using conditional probability distributions. Mathematically, the net load distribution function is a convolution of each of the constituent distributions. Within the RECAP Model the convolution is done a fast Fourier transform convolution algorithm. The convolution process is shown in Figure 4. The resulting net load probability distribution function is then fed into the LOLP module.

Figure 4: Net load distributions



The LOLP module combines the outputs from the net load module and generator module to arrive at a probability of lost load for each month/hour/day-type. Multiplying by the appropriate number of month/hour/day-type observations in one year and then summing across the year gives loss of load expectation, measured in hours of lost load per year. Expected Unserved Energy (EUE) is calculated by weighing each loss of load probability with the severity of each deficiency.

The resources are added or subtracted from the simulated power system and the resulting outage metrics are recorded. This result can be used directly to determine an economic target planning reserve margin. Alternatively, the outputs can be used to benchmark to engineering standards or calculate the effective load carrying capability (ELCC) for variable generation resources.

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ENERGY AND ENVIRONMENTAL ECONOMICS, INC. San Francisco, CA
Partner

Since joining E3 in 2002, Mr. Olson has been a lead in the practice areas of Resource Planning; Renewables and Emerging Technology; Transmission Planning and Pricing; and Energy and Climate Policy. He is an expert in evaluating the impacts of aggressive state and federal policies to promote clean and renewable energy production. He led the technical analysis and drafting of the recent report *Investigating a Higher Renewable Portfolio Standard for California*, prepared for the five largest utilities in California. He led a multi-company team that developed the Renewable Energy Flexibility (REFLEX) Model, a new stochastic production simulation model that calculates the need for power system flexibility under high renewable penetration, which was used for the California utility report as well as for separate renewable integration analysis performed on behalf of the California ISO. He has led numerous other resource planning studies on behalf of utilities, government agencies and electricity consumers, including studies of a 33% RPS for the California Public Utilities Commission and multiple studies of the economic benefits of long-line transmission projects. In 2007, he served as advisor, facilitator and drafter to the Idaho Legislature in developing the 2007 Idaho Energy Plan, the state of Idaho's first comprehensive, state-wide energy plan in 25 years. His clients include the California Independent System Operator, California Public Utilities Commission, Colorado Public Utilities Commission, the Western Electric Coordinating Council, the Western Electric Industry Leaders' Group, the Western Interstate Energy Board, the City of Seattle, Pacific Northwest Generating Cooperative, Mid-American, AltaLink, Pacific Gas & Electric Company, Southern California Edison Company, the Sacramento Municipal Utilities District, the Bonneville Power Administration, TransElect, BC Hydro, and Hydro-Quebec TransEnergie.

Resource Planning and Valuation:

- Currently leading a team that is evaluating the need for flexible generation capacity on behalf of Portland General Electric.
- Led a team that assessed electricity-natural gas infrastructure issues on behalf of the Western Interstate Energy Board.
- Led a team that investigated the capacity contribution of new wind, solar and demand response (DR) resources on behalf of the Sacramento Municipal Utilities District.
- Assisted the Colorado Public Utilities Commission in developing long-term scenarios to use across a range of energy infrastructure planning dockets.
- Assisted BC Hydro in evaluating the impact of BC's provincial greenhouse gas reduction policies on future electric load as part of BC Hydro's 2011 Integrated Resource Plan.
- Provided expert testimony in front of the California Public Utilities Commission on rates and revenue requirements associated with several alternative portfolios of demand-side and supply-side resources, on behalf of Pacific Gas and Electric Company, Southern California Edison, and San Diego Gas & Electric.

- Served as lead investigator in assisting the California Public Utilities Commission (CPUC) in its efforts to reform the long-term procurement planning process in order to allow California to meet its aggressive renewable energy and greenhouse gas reduction policy goals.
- Prepared an integrated resource plan (IRP) on behalf of Umatilla Electric Cooperative, a 200-MW electric cooperative based in Hermiston, Oregon. The IRP considered a number of different resource and rate product options, and addressed ways in which demand-side measures such as energy efficiency, distributed generation and demand response can help UEC reduce its wholesale energy and bulk transmission costs.
- Served as lead investigator in developing integrated resource plans for numerous publicly-owned utilities including PNGC Power, Lower Valley Energy, and Platte River Power Authority.
- Provided generation and transmission asset valuation services to a number of utility and independent developer clients.

Renewables and Emerging Technology:

- Currently leading a team that is advising Portland General Electric Company on potential strategies for cost-effective procurement of distributed or utility scale solar generation.
- Currently leading a team that is evaluating flexible capacity needs under high renewable penetration across the Western Interconnection on behalf of the Western Electric Coordinating Council and the Western Interstate Energy Board. The team includes technical contributions from E3, NREL and Energy Exemplar.
- Led the technical analysis and drafting of the influential report *Investigating a Higher Renewable Portfolio Standard for California*. The report evaluated the operational challenges, costs and solutions for integrating a 40% or 50% Renewable Portfolio Standard on behalf of the five largest utilities in California.
- Led the team that developed the Renewable Energy Flexibility (REFLEX) model, commercial software that assesses power system flexibility needs under high renewable penetration.
- Led the team that developed the Renewable Energy Capacity Planning (RECAP) model, commercial software that calculates reliability metrics such as Loss of Load Probability (LOLP), Loss of Load Expectation (LOLE) and Planning Reserve Margin (PRM), along with Effective Load-Carrying Capability (ELCC) of wind and solar resource, demand response programs, and other dispatch-limited resources.
- Currently advising the CPUC on renewable energy resource policy and procurement.
- Currently leading the California Independent System Operator's (CAISO) renewable integration needs studies. The studies are evaluating the need for firming capacity and flexible resources to accommodate the variable and unpredictable nature of wind and solar generation. Results of the studies will be used to determine the need to procure new, flexible resources.
- Led the team that developed renewable and conventional resource cost and performance characteristics for use in the WECC's Regional Transmission Expansion Planning process.
- On behalf of the Wyoming Governor's Office, developed a model of the cost of developing wind resources in Wyoming relative to neighboring states to inform policy debate regarding taxation. The model included detailed representations of state-specific taxes and capacity factors.
- On behalf of the CPUC, investigated a number of strategies for achieving a 33% Renewables Portfolio Standard in California by 2020, and estimated their likely cost and rate impacts using the 33% RPS Calculator, a publicly-available spreadsheet model developed for this project.
- Evaluated market opportunities and provided strategic advice for renewable energy developers in California and the Southwest.

- Investigated for Bonneville Power Administration (BPA) the economics and feasibility of investing in new, long-line transmission facilities connecting load centers in the Pacific Northwest with remote areas that contain large concentrations of high-quality renewable energy resources. The study informed BPA about cost-effective strategies for procuring renewable energy supplies in order to meet current and potential future renewable renewables portfolio standards and greenhouse gas reduction targets.
- Co-authored *Load-Resource Balance in the Western Interconnection: Towards 2020*, a study of west-wide infrastructure needs for achieving aggressive RPS and greenhouse gas reduction goals in 2020 for the Western Electric Industry Leaders (WEIL) Group, comprised of CEOs and executives from a number of utilities through the West, and presented results indicating that developing new transmission infrastructure to integrate remote renewable resources can result in cost savings for consumers under aggressive policy assumptions.

Transmission Planning and Pricing:

- Currently serving as technical support to the Western Electric Coordinating Council's Scenario Planning Steering Group (SPSG). The SPSG is developing scenarios for long-term transmission planning in the Western Interconnection.
- Currently advising several transmission developers seeking approval for projects through the CAISO's Transmission Planning Process.
- Led a team that investigated the use of Production Cost Modeling for the purpose of allocating costs of new transmission facilities on behalf of the Northern Tier Transmission Group, and contributed to NTTG's Order 1000 compliance filing.
- Served as an expert witness in front of the Alberta Utilities Commission in a case regarding the Alberta Electric System Operator's proposed methodology for allocating Available Transmission Capacity among interties during times of congestion.
- Led studies in 2009, 2011 and 2012 to develop generation and transmission capital cost assumptions for use in WECC's Transmission Expansion Planning and Policy Committee (TEPPC) studies.
- Contributed to a study of the benefits of North-South transmission expansion in Alberta on behalf of AltaLink.
- Led a study for WECC to estimate the benefits of developing a centralized Energy Imbalance Market (EIM) across the Western Interconnection. The study estimated benefits due to increased generation dispatch efficiency resulting from reduced market barriers and increased load and resource diversity among western Balancing Authorities. Led several follow-up studies of alternative Western EIM footprints for potential EIM participants.
- Retained by a consortium of southwestern utilities and state agencies including the Wyoming Infrastructure Authority, Xcel Colorado, Public Service Company of New Mexico, and the Salt River Project to perform an economic feasibility study of the proposed High Plains Express (HPX) transmission project, a roadmap for transmission development in the Desert Southwest and Rocky Mountain regions.
- Provided assistance to the Seattle City Council to develop guidelines for the evaluation of large electric distribution and transmission projects by Seattle City Light (SCL). Guidelines specified the types of evaluations SCL should perform and the information the utility should present to the City Council when it seeks approval for large distribution or transmission projects.
- Conducted screening studies of long-distance transmission lines connecting to remote renewable energy zones for multiple western utilities.

- Assisted in the development of a methodology for evaluating the renewable energy benefits of the Sunrise Powerlink transmission project in support of expert testimony on behalf of the California ISO.
- Assisted British Columbia Transmission Corporation and Hydro-Quebec TransEnergie with open access transmission tariff design.
- Represented BC Hydro in RTO West market design process in areas of congestion management, ancillary services, and transmission pricing.

Energy and Climate Policy:

- Developed policy themes and integrated them into the four long-term planning scenarios under consideration by WECC's Scenario Planning Steering Group.
- Led a team that developed a model of deep carbon dioxide emissions reductions scenarios in the western United States and Canada on behalf of the State-Provincial Steering Committee, a body of western state and provincial officials that provides oversight for WECC.
- Led a study of likely changes to power flows and market prices at western electricity trading hubs following California's adoption of a cap-and-trade system for regulating greenhouse gas emissions in 2013.
- Served as advisor, facilitator and drafter to the Interim Committee in developing Idaho's first comprehensive, statewide energy plan in 25 years. The Interim Committee and subcommittees held 18 days of public meetings and received input from dozens of members of the public in developing state-level energy policy recommendations. This process culminated in Mr. Olson drafting the 2007 Idaho Energy Plan, which was approved by the Legislature and adopted as the official state energy plan in March 2007.
- Developed a model that forecasted renewable and conventional generating resources in the WECC region in 2020 as part of an E3 project to advise the California Public Utilities Commission, California Energy Commission and California Air Resources Board about the cost and feasibility of reducing greenhouse gas emissions in the electricity and natural gas sectors.

WASHINGTON OFFICE OF TRADE AND ECONOMIC DEVELOPMENT Olympia, WA
Senior Energy Policy Specialist 1996-2002

- **Electricity Transmission**: Lead responsibility for developing and representing agency policy interests in a variety of regional forums, with a primary focus on pricing and congestion management issues. Lead negotiator on behalf of agency in IndeGO and RTO West negotiations in areas of Congestion Management, Ancillary Services, and Transmission Planning. Participated in numerous subgroups developing issues including congestion zone definition, nature of long-term transmission rights, and RTO role in transmission grid expansion.
- **Western Regional Transmission Association, 1996-2001:** Member, WRTA Board of Directors. Participated in WRTA Tariff, Access and Pricing Committee. Participated in sub-groups examining "seams" issues among multiple independent system operators in the West and developing a proposal for tradable firm transmission rights in the Western interconnection.
- **Wholesale Energy Markets:** Monitored and analyzed trends in electricity, natural gas and petroleum markets. Editor and principal author of Convergence: Natural Gas and Electricity in Washington, a survey of the Northwest's natural gas industry in the wake of the extreme price events of winter 2000-2001, and on the eve of a significant increase in demand due to gas-fired power plants. Authored legislative testimony on the ability of the Northwest's natural gas industry to meet the demand from new, gas-fired power plants.

- **Electricity Restructuring:** Co-authored Washington Electricity System Study, legislatively-mandated study of Washington's electricity system in the context of ongoing trends and potential methods of electric industry restructuring. Authored legislative testimony on the impact of restructuring on retail electricity prices in Washington, electric industry restructuring and Washington's tax system, and the interactions between restructured electricity and natural gas markets.
- **Energy Data:** Managed three-person energy data team that collected and maintained a repository of state energy data. Developed Washington's Energy Indicators, a series of policy benchmarks and key trends for Washington's energy system; second edition published in January 2001.

DECISION ANALYSIS CORPORATION OF VIRGINIA Vienna, VA
Associate 1993-1996

- **Energy Modeling and Analysis:** Developed energy demand forecasting models for Energy Information Administration's National Energy Modeling System. Results are published each year in EIA's Annual Energy Outlook.

Education

University of Pennsylvania Philadelphia, PA
Institut de Francais du Petrole Rueil-Malmaison, France
M.S., International Energy Management & Policy

University of Washington Seattle, WA
B.S., Mathematical Sciences, B.S. Statistics

Citizenship

United States

Expert Witness Testimony

1. *Province of Ontario, Commercial Arbitration, 2015, testified regarding policies related to renewable energy procurement and determination of available transmission capacity.*

2. *California Energy Commission, 2014, testified on behalf of Abengoa and BrightSource Energy regarding the cost and feasibility of distributed generation and energy storage alternatives to a large, concentrating solar power plant project in the context of a power plant siting case.*

3. *California Energy Commission, 2013, testified on behalf of BrightSource Energy regarding the cost and feasibility of distributed generation alternatives to a large, concentrating solar power plant project in the context of a power plant siting case.*

4. *Alberta Electric Utilities Commission, 2012, testified on behalf of Powerex Corporation reviewing industry practices regarding treatment of existing transmission capacity, in the case when new transmission lines are interconnected.*

5. *California Public Utilities Commission, 2011, provided testimony on behalf of Pacific Gas and Electric Company, Southern California Edison Company, and San Diego Gas & Electric Company regarding cost, revenue requirement, average retail rates, and cost of carbon reductions from alternative resource portfolios in the Long-Term Procurement Planning Proceeding.*

6. *California Energy Commission, 2010, testified on behalf of BrightSource Energy regarding the cost and feasibility of distributed generation alternatives to a large, concentrating solar power plant project in the context of a power plant siting case.*

Refereed Papers

1. *C.K. Woo, J. Moore, B. Schneiderman; A. Olson; R. Jones; T. Ho; N. Toyama; J. Wang; and J. Zarnikau, "Merit-order Effects of Day-ahead Wind Generation Forecast in the Hydro-rich Pacific Northwest", The Electricity Journal, forthcoming*

2. *Olson, A., R. Jones, E. Hart and J. Hargreaves, "Renewable Curtailment as a Power System Flexibility Resource," The Electricity Journal, Volume 27, Issue 9, November 2014, pages 49-61*

3. *Hargreaves, J., E. Hart, R. Jones and A. Olson, "REFLEX: An Adapted Production Simulation Methodology for Flexible Capacity Planning," IEEE Transactions on Power Systems, Volume:30, Issue: 3, September 2014, pages 1306 - 1315*

4. *C.K. Woo, T. Hob, J. Zarnikau, A. Olson, R. Jones, M. Chait, I. Horowitz, J. Wang, "Electricity-market price and nuclear power plant shutdown: Evidence from California", Energy Policy,* 2014, vol. 73, issue C, pages 234-244

5. *Woo, C.K., Zarnikau J, Kadish J, Horowitz I, Wang J, Olson A. (2013) "The Impact of Wind Generation on Wholesale Electricity Prices in the Hydro-Rich Pacific Northwest," IEEE Transactions on Power Systems, 28(4), 4245-4253.*

6. *Olson A., R. Jones (2012) "Chasing Grid Parity: Understanding the Dynamic Value of Renewable Energy," Electricity Journal, 25:3, 17-27.*

7. *Woo, C.K., H. Liu, F. Kahrl, N. Schlag, J. Moore and A. Olson (2012) "Assessing the economic value of transmission in Alberta's restructured electricity market," Electricity Journal, 25(3): 68-80.*

8. *DeBenedictis, A., D. Miller, J. Moore, A. Olson, C.K. Woo (2011) "How Big is the Risk Premium in an Electricity Forward Price? Evidence from the Pacific Northwest," Electricity Journal, 24:3, 72-76.*

9. *Woo, C.K., I. Horowitz, A. Olson, A. DeBenedictis, D. Miller and J. Moore (2011) "Cross-Hedging and Forward-Contract Pricing of Electricity in the Pacific Northwest," Managerial and Decision Economics, 32, 265-279.*

10. *Moore, J., C.K. Woo, B. Horii, S. Price and A. Olson (2010) "Estimating the Option Value of a Non-firm Electricity Tariff," Energy, 35, 1609-1614.*

11. *Olson A., R. Orans, D. Allen, J. Moore, and C.K. Woo (2009) "Renewable Portfolio Standards, Greenhouse Gas Reduction, and Long-line Transmission Investments in the WECC," Electricity Journal, 22:9, 38-46.*

12. *Moore, J., C.K. Woo, B. Horii, S. Price, A. Olson (2009) "Estimating the Option Value of a Non-firm Electricity Tariff," Energy, 35, 1609-1614.*

13. *Woo, C.K., I. Horowitz, N. Toyama, A. Olson, A. Lai, and R. Wan (2007) "Fundamental Drivers of Electricity Prices in the Pacific Northwest," Advances in Quantitative Analysis of Finance and Accounting, 5, 299-323.*

14. *Lusztig, C., P. Feldberg, R. Orans, and A. Olson (2006) "A survey of transmission tariffs in North America," Energy-The International Journal 31, 1017-1039.*

15. *Woo, C.K., A. Olson, I. Horowitz and S. Luk (2006) "Bi-directional Causality in California's Electricity and Natural-Gas Markets," Energy Policy, 34, 2060-2070.*

16. *Woo, C.K., I. Horowitz, A. Olson, B. Horii and C. Baskette (2006) "Efficient Frontiers for Electricity Procurement by an LDC with Multiple Purchase Options," OMEGA, 34:1, 70-80.*

17. *Woo, C.K., A. Olson and I. Horowitz (2006) "Market Efficiency, Cross Hedging and Price Forecasts: California's Natural-Gas Markets," Energy, 31, 1290-1304.*

18. *Woo, C.K., A. Olson and R. Orans (2004) "Benchmarking the Price Reasonableness of an Electricity Tolling Agreement," Electricity Journal, 17:5, 65-75.*

19. *Orans, R., A. Olson, C. Opatrny, Market Power Mitigation and Energy Limited Resources, Electricity Journal, March, 2003.*

Selected Public Presentations

1. *"Planning for Variable Generation Integration Needs", invited panelist, Utility Variable-generation Integration Group, Operating Impact And Integration Studies Users Group Meeting, San Diego, California, October 13, 2015*

2. *"The Role of Renewables in a Post-Coal World", invited panelist, Energy Foundation, Beyond Coal to Clean Energy Conference, San Francisco, California, October 9, 2015,*
3. *"Implications of a 50% RPS for California", invited panelist, Argus Carbon Summit, Napa, California, October 6, 2015*
4. *"Western EIM: Status Report and Implications for Public Power", Keynote speaker, Large Public Power Council meeting, Seattle, Washington, September 16, 2015*
5. *"California's 50% RPS Goal: Opportunities for Western Wind Developers", Keynote speaker at a meeting of the Wyoming Infrastructure Authority, Berkeley, California, July 28, 2015*
6. *"Western Interconnection Flexibility Assessment", Western Electric Coordinating Council Board of Directors, Salt Lake City, Utah, June 24, 2015*
7. *"California's New GHG Goals: Implications for the Western Electricity Grid", invited panelist, National Association of State Energy Officials, Western Regional State and Territory Energy Office Meeting, Portland, Oregon, May 14, 2015*
8. *"Replacing Aging Fossil Generation," invited panelist, Northwest Energy Coalition NW Clean & Affordable Energy Conference, Portland, Oregon, November 7, 2014*
9. *"Investing in Power System Flexibility," invited panelist, State/Provincial Steering Committee & Committee on Regional Electric Power Cooperation System Flexibility Forum, San Diego, California, October 20, 2014*
10. *"Opportunities and Challenges for Higher Renewable Penetration in California", invited panelist, Beyond 33%: University of California at Davis Policy Forum Series, Sacramento, California, October 17, 2014*
11. *"Renewable Curtailment as a Power System Flexibility Resource," Boise State University Energy Policy Research Conference, San Francisco, California, September 4, 2014*
12. *"Natural Gas Infrastructure Adequacy: An Electric System Perspective", Pacific Northwest Utilities Conference Committee Board of Directors, Portland, Oregon, August 8, 2014*
13. *"The Future of Renewables in the American West," invited panelist, Geothermal Energy Association Annual Meeting, Reno, Nevada, August 6, 2014*
14. *"Long-Term Natural Gas Infrastructure Needs", invited panelist, U.S. Department of Energy Quadrennial Energy Review, Public Meeting #7, Denver, Colorado, July 28, 2014*
15. *"Meeting the Demands of Renewables Integration—New Needs, New Technologies, Emerging Opportunities", invited panelist, InfoCast 2nd Annual California Energy Summit, San Francisco, California, May 28, 2014*
16. *"Power System Flexibility Needs under High Renewables", EUCI Utility Resource Planning Conference, Chicago, Illinois, May 14, 2014*

17. *"Natural Gas Infrastructure Adequacy: An Electric System Perspective", Western Interstate Energy Board Annual Meeting, Denver, Colorado, April 24, 2014*

18. *"Power System Flexibility Needs under High RPS", invited panelist, joint meeting of the Committee on Regional Electric Power Cooperation, State-Provincial Steering Committee and Western Interconnection Regional Advisory Body, Tempe, Arizona, March 26, 2014*

19. *"Natural Gas Infrastructure Adequacy: An Electric System Perspective", joint meeting of the Committee on Regional Electric Power Cooperation, State-Provincial Steering Committee and Western Interconnection Regional Advisory Body, Tempe, Arizona, March 25, 2014*

20. *"Investigating a Higher Renewables Portfolio Standard for California", 19th Annual Power Conference on Energy Research and Policy, University of California Energy Institute, Berkeley, California, March 17, 2014*

21. *"Investigating a 50 Percent Renewables Portfolio Standard in California", invited panelist, Northwest Power and Conservation Council, Portland, Oregon, March 12, 2014*

22. *"Investigating a 50 Percent Renewables Portfolio Standard in California", invited panelist, Western Systems Power Pool, Spring Operating Committee Meeting, Whistler, B.C., March 5, 2014*

23. *"Investigating a Higher Renewables Portfolio Standard for California", invited speaker, Western Electric Coordinating Council, Transmission Expansion Planning and Policy Committee, Salt Lake City, Utah, February 25, 2014*

24. *"Investigating a 50 Percent Renewables Portfolio Standard in California", invited speaker, Committee on Regional Electric Power Cooperation, State-Provincial Steering Committee and Western Interconnection Regional Advisory Body, Webinar, February 12, 2014*

25. *"Flexibility Planning: Lessons From E3's REFLEX Model", EUCI Conference on Fast Ramp and Intra-Hour Market Incentives, San Francisco, California, January 29-30, 2014*

26. *"The Effect of High Renewable Penetration on California Markets and Carbon Balance", EUCI Conference on California Carbon Policy Impacts on Western Power Markets, January 27-28, San Francisco, California, 2014*

27. *"Reliance on Renewables: A California Perspective", invited panelist at Harvard Electricity Policy Group, Seventy-Third Plenary Session, Tucson, Arizona, December 13, 2013*

28. *"The Role of Renewables in Meeting Long-Term Greenhouse Gas Reduction Goals", State Bar Of California, Energy And Climate Change Conference, Berkeley, California, November 14, 2013*

29. *"Benefits, Costs and Cost Shifts from Net Energy Metering", invited expert panelist at Washington Utilities and Transportation Commission Workshop on Distributed Generation, Olympia, Washington, November 13, 2013*

30. *Pacific Northwest Utilities Conference Committee (PNUCC) California Power Industry Roundtable, invited panelist, Portland, Oregon, September 6, 2013*

31. *"After 2020: Prospects for Higher RPS Levels in California", invited speaker at Northwest Power and Conservation Council's California Power Markets Symposium, Portland, Oregon, September 5, 2013*

32. *"Determining Flexible Capacity Needs for the CAISO Area", invited speaker at Northwest Power and Conservation Council's California Power Markets Symposium, Portland, Oregon, September 5, 2013*

33. *"California Climate Policy and the Western Energy System", invited speaker at the Western Interstate Energy Board annual meeting, Reno, Nevada, June 13, 2013*

34. *"Determining Power System Flexibility Need", EUCI Conference on Resource Planning and Asset Valuation, Westminster, Colorado, May 21, 2013*

35. *"California Policy Landscape and Impact on Electricity Markets", EUCI Conference on Resource Planning and Asset Valuation, Westminster, Colorado, May 21, 2013*

36. *"Determining Power System Flexibility Need", EUCI Conference on Fast and Flexi-ramp Resources, Chicago, Illinois, April 23, 2013*

37. *"State-Provincial Steering Committee WECC Low Carbon Scenarios Tool", 3 Interconnections Meeting, Washington, DC, February 6, 2013*

38. *"Distributed Generation Benefits and Planning Challenges", Committee on Regional Electric Power Cooperation/State-Provincial Steering Committee, Resource Planners' Forum, San Diego, California, October 3, 2012*

39. *"Thoughts on the Flexibility Procurement Modeling Challenge", invited speaker at the California Public Utilities Commission, Long-Term Procurement Planning Workshop, San Francisco, California, September 19, 2012*

40. *"Generation Capital Cost Recommendations for WECC 10- and 20-Year Studies", Western Electric Coordinating Council, Transmission Expansion Planning and Policy Committee, Technical Advisory Subcommittee, Webinar, August 15, 2012*

41. *"Renewable Energy Benefits", California Energy Commission, Integrated Energy Policy Report Workshop, Sacramento, California, April 12, 2012*

42. *"The Role of Policy in WECC Scenario Planning", Western Electric Coordinating Council, Scenario Planning Steering Group, San Diego, CA, November 1, 2011*

43. *"WECC Energy Imbalance Market Benefit Study", Western Electric Coordinating Council, Board of Directors, Scottsdale, Arizona, June 22, 2011*

44. *"Renewable Portfolio Standard Model Methodology and Draft Results", California Public Utilities Commission Workshop, San Francisco, California, June 17, 2010*

45. *"Draft Results from 33% Renewable Energy Standard Economic Modeling", California Air Resources Board Workshop, Sacramento, California, May 20, 2010*

46. *"Market Opportunities for IPPs in the WECC", invited speaker at the Independent Power Producers of British Columbia Annual Meeting, Vancouver, British Columbia, November 2, 2009*

47. *"A Low-Transmission Alternative for Meeting California's 33% RPS Target", EUCI Webinar, July 31, 2009*

48. *"Remote Renewable and Low-Carbon Resource Options for the Pacific Northwest", Center for Research on Regulated Industries Conference, Monterey, California, June 19, 2009*

49. *"Engineers are from Mars, Policy-Makers are from Venus: The Effect of Policy on Long-Term Transmission Planning", invited speaker at the Western Electric Coordinating Council Long Term Transmission Planning Seminar, Phoenix, Arizona, February 2, 2009*

50. *"The Long-Term Path to a Stable Climate, and its Implications for BPA", invited speaker at the Bonneville Power Administration Managers' Retreat, Portland, Oregon, April 29, 2008*

51. *"Load-Resource Balance in the Western Interconnection: Towards 2020", Western Electric Industry Leaders Group, Las Vegas, Nevada, January 18, 2008*

52. *"Integrated Resource Planning for BPA Customers", invited speaker at the Bonneville Power Administration Allocation Conference, Portland, Oregon, September 19, 2006*

53. *"Idaho's Current Energy Picture", Energy, Environment and Technology Interim Committee, Boise, Idaho, July 11, 2006*

54. *"Locational Marginal Pricing – The Very Basics", Committee on Regional Electric Power Cooperation, San Diego, California, April 30, 2002*

55. *"Effect of 2000-2001 Energy Crisis on Washington's Economy", Conference on Business Economics, Seattle, Washington, July 19, 2001*

Research Reports

1. *Natural Gas Infrastructure Adequacy in the Western Interconnection: An Electric Sector Perspective, Phase 2, July 2014, project lead and contributing author,* *https://ethree.com/public_projects/wieb.php*

2. *Natural Gas Infrastructure Adequacy in the Western Interconnection: An Electric Sector Perspective, Phase 1, March 2014, project lead and contributing author,* *https://ethree.com/public_projects/wieb.php*

3. Investigating a Higher Renewables Portfolio Standard for California, January 2014, technical lead and lead author, http://www.ethree.com/public_projects/renewables_portfolio_standard.php

4. Optimal Investment in Power System Flexibility, E3 White Paper, December 2013, https://ethree.com/documents/Olson_Flexibility_Investment_2013-12-23.pdf

5. Cost and Performance Review of Generation Technologies: Recommendations for WECC 10- and 20-Year Study Process, October 2012, editor and contributor, http://www.wecc.biz/committees/BOD/TEPPC/TAS/121012/Lists/Minutes/1/121005_GenCapCostReport_finaldraft.pdf.

6. Economic Assessment of North/South Transmission Capacity Expansion in Alberta, January 2012, contributor.

7. WECC EDT, Phase 2 EIM Benefits, Analysis & Results, October 2011, contributor, http://www.wecc.biz/committees/EDT/EDT%20Results/EDT%20Cost%20Benefit%20Analysis%20Report%20-%20REVISED.pdf

8. High Plains Express Initiative, Stage 2 Feasibility Report, April 2011, contributor, http://www.highplainsexpress.com/site/stakeholderMeetingDocuments/HPX_Stage-2_Feasibility-report.pdf

9. State of Wyoming Wind Energy Costing Model, June 2010, author, http://legisweb.state.wy.us/2010/WyomingWindModel_7_01_2010.pdf

10. Recommendations for Documentation of Seattle City Light Energy Delivery Capital Expenditures, February 2010, contributor, http://clerk.seattle.gov/~ordpics/31219exA.pdf

11. California Public Utilities Commission, 33% Renewables Portfolio Standard Implementation Analysis, Preliminary Results, June 2009, contributor, http://www.cpuc.ca.gov/NR/rdonlyres/1865C207-FEB5-43CF-99EB-A212B78467F6/0/33PercentRPSImplementationAnalysisInterimReport.pdf

12. California Public Utilities Commission, Energy Division Straw Proposal on LTPP Planning Standards, June 2009, contributor, http://www.cpuc.ca.gov/NR/rdonlyres/1865C207-FEB5-43CF-99EB-A212B78467F6/0/33PercentRPSImplementationAnalysisInterimReport.pdf

13. California Public Utilities Commission, Survey of Utility Resource Planning and Procurement Practices for Application to Long-Term Procurement Planning in California, September 2008, http://www.cpuc.ca.gov/NR/rdonlyres/029611EA-D7C7-4ACC-84D6-D6BA8515723A/0/ConsultantsReportonUtilityPlanningPracticesandAppendices09172008.pdf.

14. Remote Renewable and Low-Carbon Resource Options for BPA, May 2008, author, http://www.ethree.com/public_projects/BPA_options.html

15. Load-Resource Balance in the Western Interconnection: Towards 2020, Western Electric Industry Leaders Group, January 2008, co-author,

http://www.weilgroup.org/E3_WEIL_Complete_Study_2008_082508.pdf

16. *Umatilla Electric Cooperative 2008 Integrated Resource Plan, January 2009, author.*

17. *Lower Valley Energy 2007 Integrated Resource Plan Update, February 2007, author.*

18. *Idaho Legislative Council Interim Committee on Energy and Technology and Energy and Environmental Economics, Inc., 2007 Idaho Energy Plan, January 2007. http://www.legislature.idaho.gov/sessioninfo/2007/energy_plan_0126.pdf*

19. *Base Case Integrated Resource Plan for PNGC Power, April 2006, author.*

20. *Integrated Resource Planning for Coos-Curry Electric Cooperative, August 2005, author.*

21. *Integrated Resource Planning for Lower Valley Energy, December 2004, author.*

22. *"A Forecast Of Cost Effectiveness: Avoided Costs and Externality Adders", prepared for the California Public Utilities Commission, February 2004, contributor.*

23. *Stepped Rate Design Report, prepared for BC Hydro and filed with the BCUC, May 2003, contributor.*

24. *Convergence: Natural Gas and Electricity in Washington, editor and principal author. Washington Office of Trade and Economic Development, May 2001. http://www.energy.cted.wa.gov/Papers/Convergence.htm*

25. *2001 Biennial Energy Report: Issues and Analyses for the Washington State Legislature, contributing author. Washington Office of Trade and Economic Development, February 2001. http://www.energy.cted.wa.gov/BR2001/default.htm*

26. *Study of Electricity Taxation, contributing author. Washington Department of Revenue, December 1999. http://www.energy.cted.wa.gov/papers/taxstudy.doc*

27. *Washington Energy Indicators, author. Washington Department of Community, Trade and Economic Development, February, 1999. http://www.energy.cted.wa.gov/Indicators99/Contents.htm*

28. *Washington State Electricity Study, contributing author. Washington Department of Community, Trade and Economic Development and Washington Utilities and Transportation Commission, January 1999. http://www.energy.cted.wa.gov/6560/finalapp.htm*

29. *Our Energy Future: At a Crossroads. 1997 Biennial Energy Report, contributing author. Washington Department of Community, Trade and Economic Development, January 1997. http://www.energy.cted.wa.gov/BIENREPO/CONTENTS.HTM*

30. *Washington State Energy Use Profile 1996, contributing author. Washington State Energy Office, June, 1996. http://www.energy.cted.wa.gov/FILES/PRFL/BASE02.HTM*

31. *Model Documentation Report: Transportation Sector Model of the National Energy Modeling System, contributing author. Decision Analysis Corporation of Virginia. Prepared for Energy Information Administration, March 1994.*