Review of Recent Cost-Benefit Studies Related to Net Metering and Distributed Solar

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Executive Summary

Net energy metering (NEM) has helped fuel the adoption of distributed solar across the country. As deployment of solar and other distributed energy resources (DERs) continues to grow, regulators and stakeholders are investigating issues such as how current NEM rate structures reflect the costs and benefits of distributed solar, whether different tariff mechanisms could better align compensation with the value of distributed solar, and how a broader valuation framework could facilitate the maximization of system benefits from DER adoption.

Numerous cost-benefit studies related to NEM have been conducted by a variety of entities, and these studies have often produced widely differing results. This meta-analysis examines a geographically diverse and broad selection of studies from 15 States that explore the costs and benefits of distributed solar. It is not meant to be comprehensive, but rather reviews a representative sample of the most recently published material. The studies represent an evolution of approaches to solar value analysis, and, while the selection captures different approaches and methodologies, every study either identifies or quantifies a defined set of cost-benefit categories related to net metering or distributed solar.

Eighteen categories that could represent positive values (avoided costs) or negative values (incremental costs) are considered in two or more of the studies. Overall, studies tend to converge on at least three value categories: avoided energy generation, avoided generation capacity, and avoided transmission capacity. Common components were more likely to affect the bulk system, have a large net impact, and be readily quantifiable. Less commonality is found across value categories affecting the distribution system, which have incremental impacts and may require more complex approaches to quantification. The set of value categories included, and whether these categories represent costs or benefits, significantly affects the overall results of a given study.

Figure 1. Comparison of value categories across studies

Included	●
Discussed but not monetized/quantified	○
Included/represented in another category	●
For NY, included in VDER Phase One	○

		Arkansas - Crossborder Energy 2017	Nevada - E3 2016	Louisiana - Acadian Consulting Group 2015	South Carolina - E3 2015	Mississippi - Synapse 2014	Vermont - VT Public Service Dept 2014	Washington DC - Synapse 2017	Georgia - Southern Company 2017	Hawaii - Clean Power Research 2015	Maine - Clean Power Research 2015	Oregon - Clean Power Research 2015	Minnesota - Clean Power Research 2014	Utah - Clean Power Research 2014	New York - BCA Framework 2016 + VDER Phase One	California - LNBA Framework 2016	Total
Utility System Impacts																	
G	Avoided Energy Generation	●	●	●	●	●	●	○	○	●	○	○	●	○	○		15
	Avoided Generation Capacity	●	●	●	●	●	●	○	○	●	○	○	●	○	○		15
	Avoided Environmental Compliance	●	●			●	●	●	○		●	○		●		○	10
	Fuel Hedging	●			●	●		●		○	●	○	●	●			9
	Market Price Response	●					●	●		○	●				○		6
	Ancillary Services		●		●	○		○	○	○					○	○	8
T	Avoided Transmission Capacity	●	●	●	●	●	●	●	○	○	●	○	○	●	○	○	15
	Avoided Line Losses	●	●		●	●	●	●	○			○		●	○	○	11
D	Avoided Distribution Capacity	●	●	●	●	●	●	●		○	○	○	○	●	○	○	14
	Avoided Resiliency & Reliability	○				○		○							○	○	5
	Distribution O&M			●					○						○	○	4
	Distribution Voltage and Power Quality									○	○	○	○		○	○	6
C	Integration Costs	●	●	●	●	○		●	○	○	●	○	○		○	○	13
	Lost Utility Revenues	●	●	●	●	●	●								○		7
	Program and Administrative Costs		●	●	●	●	●	○							○		7
Societal Impacts																	
S	Avoided Cost of Carbon	●					●	●		○	●		○		○	○	8
	Other Avoided Environmental Costs	●	●			○		○		○	●		○		○	○	9
	Local Economic Benefit	●				○		○									3

Values that are numerically quantified are represented in the chart with a solid dot. Values that are discussed, but not quantified, are represented in the chart with an open dot. Some studies combined more than one value into a broader category and, where possible, these rolled-up values are noted with a solid red dot. For a more detailed discussion of this chart, see the section "Comparison of Value Categories."

Other important differences led studies to arrive at diverse conclusions. Some differences are caused by variables that are geographically and situationally dependent, while other differences are driven by the input assumptions used to estimate their value. Studies use a range of assumptions for factors that influence results, such as marginal unit displacement, solar penetration, integration costs, externalities, and discount rates. Furthermore, the stakeholder perspective—whether costs and benefits are examined from the view of customers, the utility, the grid, or society at large—is a key influencer of the methodology employed by the studies and their resulting direction and outcomes.

Overall observations from this analysis show, not surprisingly, that a major challenge in studying and developing an approach to NEM, the value of solar, and DER valuation is that some value components are relatively easy to quantify, while others are more difficult to represent by a single metric or measure. This meta-analysis highlights the different value categories, approaches, and assumptions used in NEM cost-benefit analysis, value of solar studies, and DER valuation frameworks, emphasizing commonalities and differences between them, and how they are evolving over time.

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Definitions of Key Terms

Some key terms used throughout this report are defined below.

Behind-the-meter: A generating unit, multiple generating units, or other resource(s) at a single location (regardless of ownership), of any nameplate size, on the customer's side of the retail meter that serve all or part of the customer's retail load with electric energy. All electrical equipment from, and including, the generation set-up to the metering point is considered to be "behind-the-meter."[1]

Distributed energy resource (DER): A DER is a resource sited close to customers that can provide all or some of their immediate electricity and power needs, and also can be used by the system to either reduce demand (such as energy efficiency) or provide supply to satisfy the energy, capacity, or ancillary service needs of the distribution grid. The resources, if providing electricity or thermal energy, are small in scale, connected to the distribution system, and located close to the load. Examples of different types of DER include solar photovoltaic, wind, combined heat and power, energy storage, demand response, electric vehicles, microgrids, and energy efficiency.[2]

Distributed solar: Small-scale photovoltaic facilities installed behind-the-meter, typically at residential or commercial sites.

Interconnection cost: The one-time cost (for hardware, labor, etc.) of connecting a distributed photovoltaic system or other DER installation to the local distribution grid, usually to allow the installation's owner to sell any excess electricity production to the local utility. This cost is usually paid by the installation owner, and should be distinguished from the cost of "interconnection studies," which the utility also may require the owner to fund. Such studies may be required, for example, to ensure that connecting the additional distributed photovoltaic system on a given distribution feeder will not affect local voltage stability or otherwise disrupt service to other customers on that feeder.

Net energy metering [or net metering] (NEM): Congress defined "net [energy] metering service" as "service to an electric consumer under which electric energy generated by that consumer from an eligible on-site generating facility and delivered to the local distribution facilities may be used to offset electric energy provided by the electric utility to the electric consumer during the applicable billing period."[3]

Value of solar (VOS): Value of solar is an alternative to NEM. The VOS method calculates each of the benefits and costs that distributed solar provides to, or imposes on, the electric system to arrive at a single VOS rate, typically expressed in cents per kilowatt-hour. This is the rate at which customers are

[1] North American Electric Reliability Corporation (NERC). February 2017. *Distributed Energy Resources: Connection Modeling and Reliability Considerations*. Available at http://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/Distributed_Energy_Resources_Report.pdf.
[2] National Association of Regulatory Utility Commissioners (NARUC). 2016. *Distributed Energy Resources Rate Design and Compensation Manual*. Available at https://pubs.naruc.org/pub/19FDF48B-AA57-5160-DBA1-BE2E9C2F7EA0.
[3] Energy Policy Act of 2005, Sec. 1251, Net Metering and Additional Standards, (a)(11). For additional information, see *Reference Manual and Procedures for Implementation of the "PURPA Standards" in the Energy Policy Act of 2005*, Kenneth Rose and Karl Meusen, March 22, 2006, p. 10.

compensated for electricity generated by their grid-connected distributed photovoltaic systems. Unlike NEM, the VOS tariff dissociates the customer payments for electricity consumed from the compensation they receive for solar electricity generated. Under a VOS tariff, the utility purchases some (i.e., the net excess) or all of the generation from a solar installation at a rate that is independent of retail electricity rates.[4]

[4] National Renewable Energy Laboratory (NREL), U.S. DOE. 2015. *Value of Solar: Program Design and Implementation Considerations*. Available at https://www.nrel.gov/docs/fy15osti/62361.pdf.

Introduction

Net energy metering (NEM) is a method that adapts traditional monthly metering and billing practices to compensate owners of distributed generation facilities for electricity exported to the grid. The customer can offset the electricity they draw from the grid throughout the billing cycle. The net energy consumed from the utility grid over the billing period becomes the basis for the customer's bill for that period. The level of compensation varies by State, depending on the policies in place. In some States, utilities compensate NEM customers for excess generation at the full retail rate, while other States specify something other than the retail rate.[5]

NEM is credited with being one of the main policy drivers behind the widespread and rapidly increasing adoption of distributed solar photovoltaic (PV) across the United States. According to the U.S. Energy Information Administration (EIA), residential small-scale solar PV capacity has increased significantly in recent years, reaching 7.4 gigawatts (GW) in 2016, a 43 percent increase from 2015. Small-scale PV capacity (systems less than 1 megawatt [MW]) in the commercial and industrial sectors has also grown, with combined capacity in those two sectors increasing 26 percent in 2016, reaching nearly 5.8 GW. This growth is projected to continue, with EIA forecasts reaching 13.7 GW in the residential sector and 8.2 GW in the commercial and industrial sectors in 2018.[6]

NEM has traditionally been used as a mechanism for compensating PV customers, typically residential and commercial customers with behind-the-meter solar, for electricity they produce onsite. However, opportunities and challenges associated with the increasing penetration of solar and other distributed energy resources (DERs) are causing utilities and policymakers to examine methods to address the full range of costs and benefits associated with these behind-the-meter resources.

New economic conditions that arise with the introduction of distributed solar in a utility service territory can affect utilities and ratepayers, and are some of the main challenges leading to investigations of NEM. Concerns related to the ability of the utility to recover its fixed costs for operating the grid have led to questions about how NEM affects cost recovery. Similarly, the impact that net-metered PV may have on non-solar customers has initiated analyses of how NEM and other solar pricing models may affect retail electricity prices. Nevertheless, NEM has been introduced as an effective mechanism to compensate customers with onsite PV generation and has successfully enabled increased deployment of distributed solar PV.

Stakeholders across the country are debating the future of NEM, and many States are undertaking policy actions to amend NEM laws and rules or to study the value of solar (VOS) through cost-benefit analysis.[7] In addition, some States are engaged in legislative, regulatory, and rate design discussions related to NEM successor tariffs, including States with currently low penetrations of distributed PV. As the

[5] For additional information on net metering, see National Renewable Energy Laboratory (NREL), U.S. DOE. State, Local, & Tribal Governments, Net Metering. Available at https://www.nrel.gov/technical-assistance/basics-net-metering.html.

[6] U.S. Energy Information Administration (EIA). July 11, 2017. "EIA adds small-scale solar photovoltaic forecasts to its monthly Short-Term Energy Outlook." Available at https://www.eia.gov/todayinenergy/detail.php?id=31992.

[7] North Carolina Clean Energy Technology Center. 2017. *The 50 States of Solar: Q4 2016 Quarterly Report & Annual Review, Executive Summary.* Available at https://nccleantech.ncsu.edu/wp-content/uploads/Q42016_ExecSummary_v.3.pdf.

deployment of other distributed resources, such as storage, energy efficiency measures, demand response, and electric vehicles, is expected to grow, some regulators and utilities are working on broader valuation methodologies to provide a foundation for understanding the comprehensive benefits and costs associated with increased DER deployment on the grid. This understanding can then be used to inform pricing, program, and procurement strategies that serve multiple objectives, including maximizing benefits for all customers.

These policy and regulatory trends have spurred a significant amount of analysis by States, utilities, and other stakeholders to examine the costs and benefits of net metering and the value of DERs more broadly. In this report, ICF reviews a selection of 15 studies to identify broad themes and highlight emerging issues that influence how stakeholders are studying the impacts of net metering and distributed solar.

The studies that are the focus of this meta-analysis have different objectives, ask different questions, and arrive at different results. In summary, the review demonstrates a historic lack of consensus around a preferred methodology for valuing the costs and benefits of distributed solar, and emphasizes how choices about input assumptions and the perspective from which value is assessed is a strong influencer of study results. The meta-analysis also demonstrates a shift toward more comprehensive and defined approaches to valuing distributed solar and DERs more broadly.

Approach

This report is a meta-analysis of 15 studies related to the costs and benefits of NEM and distributed solar. The selection was made by collecting a broad list of more than 40 relevant studies, and narrowing it based on a set of criteria to ensure that the sample reviewed represents a balanced cross section of the most recently available material from a variety of stakeholder groups and prepared by various research firms. The following criteria guided study selection:

- The study identifies a set of value categories that can be applied to distributed PV.
- The study was released in 2014, or later, and was not included in earlier meta-analyses.
- The selection includes studies from different regions of the country.
- The selection includes studies from jurisdictions with different amounts of PV adoption.
- The selection includes studies prepared by different research firms or utilities.
- The selection includes studies that were sponsored or commissioned by different organizations (e.g., State utility commissions, utility companies, consumer advocates, environmental groups).

Each study was carefully reviewed and categorized using a matrix to allow for comparison and to uncover trends.

This report begins with a summary of key observations. Next, it describes how the studies were selected and groups them into three types: NEM cost-benefit analyses, VOS/NEM successor studies, and broader DER value frameworks. Then, it identifies and defines the value categories included and notes factors that influence how values are quantified. After that, the report provides a more detailed comparison of the value categories and discusses some of the methodological elements and input assumptions that can cause findings to vary. The last section provides brief summaries of each of the studies reviewed.

Key Observations

Studies represent an evolution of approaches to solar value analysis.
States, through their regulated utilities, have historically relied on NEM as a mechanism for compensating distributed solar; however, the increasing penetration of solar and associated technologies is causing utilities and policymakers to examine how NEM addresses the full range of costs and benefits of distributed solar. As distributed solar penetration continues to rise, some regulators and utilities have started developing broader valuation methodologies and frameworks that can be applied to distributed solar, as well as other distributed resources, in a technology-neutral way. These valuation frameworks can then be used to inform how these resources might be compensated for the services they provide through appropriate pricing, programs, and procurement strategies for PV and other DERs. The studies in this review represent an evolution of approaches and include studies that analyze NEM, studies on VOS, and documents that establish broader DER value frameworks. These frameworks are currently in development and, in many ways, are a work in progress.

Evolution of Value to the Distribution System

Assessing the value of DERs requires analysis of broader impacts on the wholesale system and locational net benefits on the distribution system. Bulk system value categories, such as avoided energy generation, avoided generation capacity, and avoided transmission capacity, are relatively common and generally simple to quantify.

Similarly, incorporating distribution system value components in a staged order, starting with values that are the largest and most readily quantifiable, is a practical approach to capturing near-term value. For example, distribution capacity deferral represents a value component with long-term and substantial value that may be a good first step, and several States, including New York and California, have quantified it. As a second step, States may look toward the additional value of increasingly complex components such as reliability, resilience, and voltage management.

The main takeaway is that the quantification of locational value beyond avoided or delayed investment in capital costs is an ongoing process that continues to evolve. For more information on the evolutionary pathway of distribution system value components, see *Missing Links in the Evolving Distribution Markets* (De Martini, et al., 2016).

Overall value depends substantially on which costs and benefits are included and monetized in a study.
ICF's review identified 18 value categories considered in two or more of the studies. Three value categories, all on the wholesale power system, are included in all studies: avoided energy generation, avoided generation capacity, and avoided transmission capacity. Ten or more of the studies included value categories related to avoided environmental compliance costs, avoided line losses (including transmission and distribution), avoided distribution capacity, and integration costs (a negative value). Less common value categories tended to be those that are more challenging to quantify. The set of value categories included, and whether these categories represent costs or benefits, have a significant impact on the overall results of a given study.

Approaches to defining the value categories and methods for quantifying them vary across studies and affect the results.
Common terms and definitions of those terms are not uniformly applied across the studies to refer to the value categories, and the categories are not always defined to include the same elements.

Furthermore, not all studies include a quantitative value; some only discuss how a value could be calculated. Still, there is some degree of alignment across many, but not all, of the categories, which makes it potentially possible to establish common definitions and identify similar or otherwise nuanced approaches to quantifying values for categories across the studies. This review identifies examples of how studies differ in their definitions of categories and quantification approaches to demonstrate how these decisions can affect the findings.

The perspective from which value is assessed affects which value categories are included and how they are quantified.

Cost and benefit considerations change depending on the perspective from which the value is being assessed. Depending on the perspective taken—a utility's business perspective, the ratepayer's consumer perspective, or the grid operator's technical perspective—particular value categories may be more or less relevant. Furthermore, an analysis focused only on utility and ratepayer values will produce different results from an analysis that considers broader policy goals affecting society at large. The perspective also influences whether some categories are included as costs or as benefits. Many of the studies consider multiple perspectives by applying a range of cost-effectiveness tests typically used by utilities to assess the costs and benefits of energy efficiency programs for different stakeholder groups.[8] In analyzing the results or findings from the selection of studies, it is important to consider to whom the benefits and costs accrue and how that perspective affects outcomes.

Studies use a range of input assumptions for factors that influence results, such as marginal unit displacement, solar penetration, integration costs, externalities, and discount rates.

A range of input assumptions are used in quantifying values for the cost-benefit categories. This review identifies several assumptions used in the studies for important factors such as marginal unit displacement, solar PV penetration, integration costs, externalities and societal values, and discount rates associated with the analysis. Just as values are sensitive to differences in which value categories are included, how they are quantified, and where the value accrues, they are also influenced by choices in input assumptions. Each of these factors are discussed in the section "Input Assumptions."

Selection of Studies Analyzed

ICF conducted a literature search to determine relevant studies from across the country to include in this meta-analysis. After identifying more than 40 relevant studies prepared over the past decade, the list was narrowed to a selection of 15.[9] The goal was not to analyze an exhaustive list, but to review a sample that represents a balanced cross section of the most recently available analyses sponsored by organizations with different perspectives and prepared by various research firms. Table 1 lists the selection of studies reviewed.[10] Appendix A provides a citation and brief summary of each study

[8] The traditional cost-effectiveness tests—the Participant Cost Test (PCT), Utility Cost Test (UCT), Rate Impact Measure (RIM), Total Resource Cost (TRC) Test, and Societal Cost Test (SCT)—and the perspectives addressed by each test are discussed further in the section "Stakeholder Perspective."

[9] The full list of studies considered for inclusion is included as Appendix C.

[10] We use the term "studies" to refer to the documents reviewed in the meta-analysis for simplicity; however, some may be more accurately described as reports or other materials. For some States, we relied on utility commission orders, staff reports, working group recommendations, or other documentation of the costs and benefits currently being considered by regulators. For other States, we relied on documents that provide only a

analyzed. Note that more than one document was reviewed in New York and California as a reflection of ongoing regulatory activities.

Table 1. Selection of studies analyzed

State	Year	Study Sponsor	Prepared by
Arkansas	2017	Sierra Club	Crossborder Energy
District of Columbia	2017	Office of the People's Counsel	Synapse Energy Economics
Georgia	2017	Southern Company	Southern Company
California	2016	California Public Utility Commission (CPUC)	CPUC/Energy and Environmental Economics (E3)
Nevada	2016	State of Nevada Public Utilities Commission	E3
New York	2016	New York Public Service Commission (PSC)	NY Department of Public Service (DPS) Staff
Hawaii	2015	Interstate Renewable Energy Council	Clean Power Research
Louisiana	2015	Louisiana Public Service Commission	Acadian Consulting Group
Maine	2015	Maine Public Utility Commission	Clean Power Research
Oregon	2015	Portland General Electric	Clean Power Research
South Carolina	2015	South Carolina Office of Regulatory Staff	E3
Minnesota	2014	Minnesota Department of Commerce	Clean Power Research
Mississippi	2014	Public Service Commission of Mississippi	Synapse Energy Economics
Utah	2014	Utah Clean Energy	Clean Power Research
Vermont	2014	Public Service Department (PSD) Staff	VT PSD

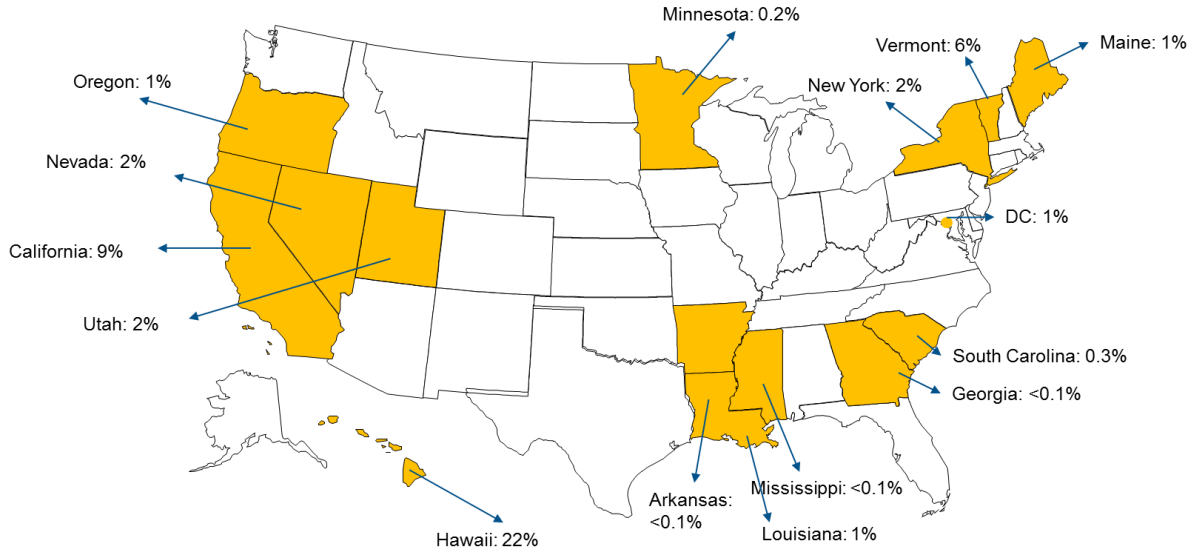
All of the studies reviewed are from 2014 or later. Half were commissioned by State utility commissions and the remaining studies were commissioned by utility companies, consumer advocates, environmental groups, research organizations, or other State agencies. A handful of firms specialize in preparing cost-benefit studies, and this report includes a sample prepared by different firms. However, some firms prepared more than one study of the 15 studies reviewed here; Synapse Energy Economics prepared two studies, Energy and Environmental Economics (E3) was involved in three of the studies, and Clean Power Research prepared five studies.

The selection reflects geographic diversity and includes States with different amounts of distributed PV adoption and growth. Five studies are specific to a single utility service territory, with the remaining studies focused on a single State or the service territories of multiple utilities in the same State. Figure 2 indicates States where the studies came from and the estimated penetration of NEM PV nameplate capacity as a percentage of peak load in those States in 2016.[11]

methodology for assessing costs and benefits in a certain jurisdiction, rather than verifying whether benefits outweigh the costs or vice versa.

[11] We estimate PV penetration by dividing NEM PV capacity (MW) by peak load (MW). For NEM PV capacity, data by State was obtained from EIA at https://www.eia.gov/electricity/data/eia861. For peak load, we map States by the National Energy Modeling System (NEMS) region and use *Annual Energy Outlook* (AEO) 2016 sales data (MWh), adjusted for transmissions losses, to calculate net energy needed to meet load in the State. Net energy is divided by the load factor for the NEMS region to derive peak load. Transmission losses and load factor are obtained from

Figure 2. Geographic diversity of studies and estimated PV penetration, 2016



While the selection captures different approaches and valuation methodologies, every study either identifies or quantifies a defined set of cost-benefit categories related to net metering or distributed solar. In general, cost of service studies are not considered because they are fundamentally different from cost-benefit analyses.[12] Cost of service studies are used to estimate and allocate the embedded and operating costs across groups of customers, and are more geared toward cost allocation and rate design than distributed solar and DER valuation.[13]

As part of a broader literature review, ICF reviewed existing meta-analyses of solar studies, checked the individual studies included for relevance, and avoided replicating evaluation of studies that had been previously reviewed, where possible.[14] For more information on solar PV cost-benefit studies prepared

U.S. Energy Information Administration (EIA). 2016. *Annual Energy Outlook*. Available at https://www.eia.gov/outlooks/aeo/pdf/0383(2016).pdf.

[12] The studies from Louisiana and South Carolina include sections on cost of service; however, our review did not address these components. In addition, New York ordered utilities to calculate utility marginal cost of service (MCOS) to determine distribution value components in their Value of DER Phase One tariff.

[13] Barbose, Galen; John Miller; Ben Sigrin; Emerson Reiter; Karlynn Cory; Joyce McLaren; Joachim Seel; Andrew Mills; Naïm Darghouth; and Andrew Satchwell. 2016. *On the Path to SunShot: Utility Regulatory and Business Model Reforms for Addressing the Financial Impacts of Distributed Solar on Utilities.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-65670. Available at http://www.nrel.gov/docs/fy16osti/65670.pdf.

[14] Existing meta-analyses of solar studies include Weissman, Gideon, and Bret Fanshaw. 2016. *Shining Rewards: The Value of Rooftop Solar Power for Consumers and Society.* Available at https://environmentamerica.org/sites/environment/files/reports/AME%20ShiningRewards%20Rpt%20Oct16%201.1.pdf; Institute for Energy Innovation. 2017. *Solar Energy in Michigan: The Economic Impact of Distributed Generation on Non-Solar Customers.* Available at https://www.instituteforenergyinnovation.org/impact-of-dg-on-nonsolar-ratepayers; and Rocky Mountain Institute (RMI). 2013. *A Review of Solar PV Benefit & Cost Studies.* Available at https://rmi.org/wp-content/uploads/2017/05/RMI_Document_Repository_Public-Reprts_eLab-DER-Benefit-Cost-Deck_2nd_Edition131015.pdf.

prior to 2014, see the Rocky Mountain Institute's meta-analysis, *A Review of Solar PV Benefit & Cost Studies*.[15]

Types of Studies

The studies in this review represent an evolution of approaches to solar value analysis and can be broadly grouped into three types: NEM cost-benefit analysis, VOS/NEM successor studies, and broader DER value frameworks. In general, these groupings reflect differences in policy context as many States have considered changes to NEM policies in recent years. Table 2 identifies how the studies were grouped and the following discussion summarizes the three types.

Table 2. Grouping of study types

Type of Study	Number Reviewed	Description of Study Type	States/Prepared by
NEM Cost-Benefit Analysis	6	Evaluate costs and benefits of a NEM program; study whether NEM is creating a cost-shift to non-participating ratepayers.	▪ Arkansas (Crossborder) ▪ Louisiana (Acadian) ▪ Mississippi (Synapse) ▪ Nevada (E3) ▪ South Carolina (E3) ▪ Vermont (VT PSD)
VOS/NEM Successor	7	Discuss the impacts of NEM and consider options for reforming or realigning rates with the net impacts of distributed solar in ways that go beyond net metering.	▪ District of Columbia (Synapse) ▪ Georgia (Southern Company) ▪ Hawaii (CPR) ▪ Maine (CPR) ▪ Minnesota (CPR) ▪ Oregon (CPR) ▪ Utah (CPR)
DER Value Frameworks	2	Reflect the elements of regulatory activities that look at VOS as part of a more precise approach within a framework that can be applied to other DERs.	▪ California LNBA (CPUC) ▪ New York BCA (Department of Public Service Staff)

Six of the studies can be considered NEM cost-benefit analyses. These tend to evaluate the impact of extending an existing or launching a new NEM program, or study whether an existing NEM program is creating an unfair cost-shift to non-participating ratepayers. This issue, sometimes called cross-subsidization, refers to a potential shift in costs away from solar PV customers, who might avoid paying for some fixed grid costs, toward non-PV customers, who make up the difference of these grid costs in their rates.[16,17] For example, the study from Vermont included an analysis of "the existence and magnitude of any cross subsidy created by the current net metering program."

[15] Rocky Mountain Institute (RMI), 2013.

[16] For more information on the cost recovery and cost-shift issues associated with DER in rate making, see NARUC, 2016, *Distributed Energy Resources Rate Design and Compensation Manual*.

[17] A 2017 report from the Lawrence Berkeley National Laboratory (LBNL) explored the potential rate impacts of distributed solar and concluded that the effects are small compared to other issues, such as the impact of energy efficiency and natural gas prices on retail electricity prices. However, the study found that for States and utilities

Seven of the studies can be considered VOS/NEM successor studies. These analyses tend to discuss the impacts of NEM and consider options for reforming or realigning rates to account for the net impacts of distributed solar in ways that may go beyond NEM. For example, Minnesota passed legislation in 2013 requiring the development of a methodology to calculate a VOS tariff as an alternative to NEM. The Minnesota study included in this review documents the methodology approved by the Minnesota Public Utilities Commission, which would be used by utilities to calculate the rate at which electricity generated by PV customers is compensated.[18]

The New York and California studies can be considered broader DER value frameworks, which look at VOS within a methodological framework that can be applied to other, customer-sited technologies in addition to solar. In New York, the Department of Public Service (DPS) staff developed a benefit-cost analysis framework, known as the "BCA Framework," for utilities to evaluate DER alternatives as substitutes for traditional investments. More recently, DPS established the Phase One Value of DER (VDER) methodology, which transitions away from traditional NEM and provides the basis for a "Value Stack" tariff, under which compensation is calculated using five of the most readily quantifiable DER values. Efforts are currently underway in Phase Two of VDER to develop a Value Stack tariff for smaller residential rooftop solar and other DER technologies. Similarly, in California, the California Public Utilities Commission (CPUC) set up the Locational Net Benefit Analysis (LNBA) Working Group to develop a methodology for the three investor-owned utilities to use to value DER by location. CPUC approved the LNBA for use by utilities in demonstration projects and the framework continues to be refined.

Instead of a single valuation methodology for distributed solar, these frameworks are evolving to account for the temporal and locational value associated with DER projects at specific locations and with specific generation profiles and characteristics, and are being used to inform the next approach to compensating DER in these States. In the DPS report from New York that was reviewed for this meta-analysis, the authors describe NEM as an important and easy-to-understand compensation mechanism that effectively fostered solar PV in the State, but say that NEM provides an "imprecise and incomplete signal of the full value and costs of DERs."[19] The ongoing proceedings are aimed at developing pricing for DERs that better reflect the actual values they create.

While all of the studies provide a methodology for considering the costs and benefits of distributed PV, the three types of studies have different objectives, ask different questions, and arrive at different results. The NEM studies tend to apply the value categories (which are discussed in detail in the next section) to investigate the fairness of a compensation structure. The VOS studies use the value categories to administratively determine a compensation rate that is more precise than the NEM approach. The Value of DER frameworks apply the value categories in a way that aligns compensation

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with exceptionally high distributed solar penetration levels, the effects could begin to approach the same scale as other important drivers. See Barbose, Galen. 2017. *Putting the Potential Rate Impacts of Distributed Solar into Context*. p. 31. Available at https://emp.lbl.gov/sites/default/files/lbnl-1007060.pdf. Note: LBNL's study is not included in this meta-analysis because it does not attempt to provide a cost-benefit analysis of distributed solar, support an approach to defining a value of solar, or provide a valuation framework for other DERs.

[18] Minnesota Public Utilities Commission (MN PUC). 2014. Order Approving Distributed Solar Value Methodology. Docket No. E-999/M-14-65. April 1, 2014. Available at https://www.edockets.state.mn.us/EFiling/edockets/searchDocuments.do?method=showPoup&documentId=%7bFC0357B5-FBE2-4E99-9E3B-5CCFCF48F822%7d&documentTitle=20144-97879-01.

[19] New York Department of Public Service (NY DPS), 2016(b), p. 4.

with system value and grid services provided, while also providing a method for integrating the value of DERs into utility system planning processes. Several studies derive an actual VOS, while others present an approach to quantification, but do not derive specific values to populate those categories.

These fundamental differences in scope and objective make it difficult to directly compare outcomes because studies do not always have a common goal or seek to investigate the same issue(s). Grouping the studies into three types based on objective (NEM, VOS, or DER Value Frameworks) helps to compare studies that are similar to each other; however, not all studies fit squarely into one of the three types. For example, the study from the District of Columbia is classified as VOS, but it also includes a NEM cost-shift analysis. The study from Georgia is classified as VOS, but it is intended to be a broad framework that is also applicable to utility-scale solar. Summaries of each study are provided in Appendix A and clearly indicate the analytical goal or objective of a study and the related outcomes.

In addition to different objectives driving varied outcomes, the perspective from which value is assessed influences which value categories are included and is likely to produce different results. Further still, regional factors, including regulatory structures, weather conditions, and wholesale and distribution grid characteristics, can drive differences and, in some cases, the application of the same analytic method in different areas can produce dissimilar results. The goal of the study, the perspective from which costs and benefits are evaluated, and relevant regional factors are not always explicitly stated in a study, further complicating direct comparison.

With these issues in mind, the selection of studies result in a range of findings related to the costs and benefits of NEM and distributed solar. Of the six NEM studies, two demonstrate that total benefits exceed total costs, two conclude that costs exceed overall benefits, and two found that NEM-related cost-shifting was either *de minimus* or "close to zero." Of the seven VOS studies, three quantify a State-specific VOS, while four provide a methodology but do not produce a specific estimate. Lastly, the two Value of DER frameworks provide a methodology for assessing costs and benefits, but do not produce a specific estimate. Table 3 summarizes the principal findings of the studies reviewed.

Table 3. Summary of principal findings

State	Year	Prepared by	Principal Findings
NEM Cost-Benefit Analysis			
Arkansas	2017	Crossborder	Benefits of residential distributed generation (DG) exceed the costs; do not impose a burden on other ratepayers.
Nevada	2016	E3	Cost-shift amounts to a levelized cost of $0.08/kWh for existing installations.
Louisiana	2015	Acadian	Costs associated with solar NEM installations outweigh their benefits.
South Carolina	2015	E3	NEM-related cost-shifting was *de minimus* due to the low number of participants.
Mississippi	2014	Synapse	NEM provides net benefits under almost all of the scenarios and sensitivities analyzed.
Vermont	2014	PSD	NEM results in "close to zero" costs to non-participating ratepayers, and may be a net benefit.
VOS/NEM Successor			
District of Columbia	2017	Synapse	Utility system VOS is $132.66/MWh (2015$); cost-shifting remains relatively modest.
Georgia	2017	Southern Company	Provides a methodology for assessing costs and benefits; no specific estimate is produced.
Hawaii	2015	CPR	Provides a methodology for assessing costs and benefits. Preliminary results suggest a net benefit.
Maine	2015	CPR	Value of distributed PV is $0.337/kWh (levelized).
Oregon	2015	CPR	Provides a methodology for assessing costs and benefits; no specific estimate is produced.
Minnesota	2014	CPR	Provides a methodology for assessing VOS; no specific estimate is produced.
Utah	2014	CPR	VOS is $0.116/kWh levelized.
DER Value Frameworks			
California	2016	CPUC	Provides a methodology for assessing costs and benefits; no specific estimate is produced.
New York	2016	NY DPS	Provides a methodology for assessing costs and benefits; no specific estimate is produced.

Value Category Definitions

ICF's review identified 18 value categories that were considered in two or more of the studies.[20] Studies differed greatly in the selection of categories, approaches to quantification, and the selection of assumptions. This section presents a set of common definitions to define and refer to categories, and discusses important characteristics about each category, such as which assumptions matter to its resulting value. Table 4 lists the value categories and identifies the parts of the system that reflect these

[20] An assortment of miscellaneous categories were not assessed in more than one study. Some provide a slightly different take on one of the more common categories described later in this section. Examples include an "SREC SIPE" category used in the District of Columbia study to address the potential Supply Induced Price Effect associated with solar renewable energy certificates; a "generation remix" category used in the framework from Georgia to represent the impact that a large penetration of renewable resources could have on system commitment, dispatch, and future generation build-out; and a net non-energy benefits category used in the BCA in New York, which relates to avoided utility or grid operations (e.g., avoided service terminations, avoided uncollectible bills, avoided noise and odor impacts), or incurred costs (e.g., indoor emissions, noise disturbance).

values, including the value to the generation system (G), the transmission system (T), the distribution system (D), the cost categories (C), and the external value to society (S).[21] The table also shows whether the category represents a cost or a benefit, and the frequency with which each value category is addressed in the studies.

Table 4. Summary of value categories used in studies

Value Category		Benefit (+) or Cost (-)	Number of Studies Addressing this Category
Utility System Impacts			
G	Avoided Energy Generation	+	15
	Avoided Generation Capacity	+	15
	Avoided Environmental Compliance	+	10
	Fuel Hedging	+	9
	Market Price Response	+	6
	Ancillary Services	+/-	8
T	Avoided Transmission Capacity	+	15
	Avoided Line Losses	+	11
D	Avoided Distribution Capacity	+	14
	Avoided Resiliency & Reliability	+	5
	Distribution O&M	+/-	4
	Distribution Voltage and Power Quality	+/-	6
C	Integration Costs	-	13
	Lost Utility Revenues	-	7
	Program and Administrative Costs	-	7
Societal Impacts			
S	Avoided Cost of Carbon	+	8
	Other Avoided Environmental Costs	+	9
	Local Economic Benefit	+	3

The number of studies addressing a value category is the sum of the studies that quantify an actual value (including a zero value) or provide an approach to quantifying the value within a methodology. Two studies provided "placeholders" for certain categories and these are considered "addressed" and included in the sum, where applicable. Categories that were not addressed are those that are entirely absent or explicitly not intended for inclusion in valuation. For a more detailed look at which studies addressed a particular value category, see Figure 3 in a following section, "Comparison of Value Categories."

[21] Most studies did not indicate a system level for cost categories, so we do not assign one.

Utility System Impacts

Generation

Avoided Energy Generation

This value category reflects the avoided cost of generating energy from system resources due to the output of distributed solar PV or other DERs. The cost of operating the displaced marginal generating resource is the primary driver of determining the value, and this value is sensitive to several assumptions about what that marginal unit is and therefore what comprises the cost of that avoided generation. The price of fuel for the generation resource displaced on the margin is a dominant factor in the value. Studies from regions with Independent System Operators (ISOs) tend to calculate avoided energy generation based on wholesale market prices. In non-ISO regions, natural gas is typically assumed to fuel the marginal unit, and most studies rely on natural gas price forecasts and standard assumptions for heat rates, depending on whether the marginal unit is assumed to be combined cycle or a combustion turbine.

Avoided energy also can address additional factors, including assumptions about variable costs for the displaced marginal unit, such as variable operations and maintenance costs, which are generally low.[22] Depending on the study, the avoided cost of energy also can include avoided environmental compliance costs and other factors that are part of the wholesale price. For example, in California, utilities can use locational marginal prices to determine avoided energy costs, and the avoided cost of carbon allowances from its cap and trade program are embedded in the wholesale energy value.[23] In contrast, the study from Nevada uses the hourly marginal wholesale value of energy, excluding the regulatory price of carbon dioxide emissions.[24] All of the studies evaluated include the avoided wholesale energy category, but with different assumptions. Studies that use locational marginal prices are also implicitly accounting for transmission congestion on the system to supply wholesale power to that node or aggregation of nodes.

Avoided Generation Capacity

This value category reflects the amount of central generation capacity that can be deferred or avoided due to the installation of distributed PV or other DERs. Key drivers include the effective capacity of a DER (i.e., coincidence with system peak) and system capacity needs.[25] The value is calculated based on the avoided cost of the marginal capacity resource and the effective capacity of the distributed resource. Similar to avoided energy generation, some studies assume natural gas combustion turbines

[22] Rocky Mountain Institute (RMI), 2013, p. 25.

[23] California Public Utilities Commission (CPUC). 2016(a). *Assigned Commissioner's Ruling (1) Refining Integration Capacity and Locational Benefit Analysis Methodologies and Requirements; and (2) Authorizing Demonstration Projects A and B.* Rulemaking 14-08-013. Order Instituting Rulemaking Regarding Policies, Procedures and Rules for Development of Distribution Resources Plans Pursuant to Public Utilities Code Section 769. pp. 23, 27. Available at http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M161/K474/161474143.PDF.

[24] Price, S.; Z. Ming; A. Ong; and S. Grant. 2016. *Nevada Net Energy Metering Impacts Evaluation 2016 Update*. San Francisco, CA: Energy and Environmental Economics, Inc. p. 32. Available at http://pucweb1.state.nv.us/PDF/AxImages/DOCKETS_2015_THRU_PRESENT/2016-8/14264.pdf.

[25] Rocky Mountain Institute (RMI), 2013.

and sometimes combined cycle units for the plant being deferred, while others use estimates from capacity markets if they exist in the region.

Several studies apply an Effective Load Carrying Capacity (ELCC) method to measure the amount of additional load that can be met by the distributed resource. For solar PV, the ELCC can be significant because PV generation may be reliably available at peak times and can effectively increase the grid's generating capacity.[26] On the other hand, in places where solar generation is more variable or not coincident with the peak, and in places with increasing solar penetration, solar may not provide capacity at times when it is needed. Assumptions about future load growth, future solar growth, and their impact on the shape and timing of the system peak also affect the ability of variable distributed resources to avoid or defer system capacity needs. All studies include this category.

Avoided Environmental Compliance

This value category reflects the avoided cost of complying with Federal, regional, State, and local environmental regulations. This could include the compliance costs of either existing or anticipated carbon emissions standards or standards related to other criteria pollutants. Several studies include avoided environmental compliance within the avoided energy generation value category, which eliminates the need for this separate value category. Some studies may address the avoided cost of purchasing renewable energy to comply with State renewable portfolio standard (RPS) requirements; this meta-analysis includes those avoided costs here. The value depends on State-specific targets and the current generation mix. This value does not include any avoided societal costs, which includes the social cost of carbon, and is addressed separately and discussed in the Societal Benefits section below. Ten out of the 15 studies include avoided environmental compliance. Three specifically address avoided RPS costs and only the study from the District of Columbia quantifies it.[27]

Fuel Price Hedging

This value category reflects the avoided costs to the utility based on reduced risk and exposure to the volatile fuel prices of conventional generation resources. Because renewable generation has no fuel costs, the cost of solar generation is not subject to fluctuations in fuel price. The forecasted price of fuel for the displaced marginal resource is the primary driver of this component. This value can be assessed as a benefit to the utility or a broader benefit to society. From the utility perspective, the value reflects their reduced risk in fuel price volatility. From the societal perspective, it can reflect the benefit that all customers may experience from reduced utility rate fluctuations. Nine studies include the fuel hedging category.

Market Price Response

This value category reflects a change in wholesale energy or capacity market prices due to increased penetration of renewable generation. As PV penetration increases, the demand for conventional

[26] The ELCC of a power generator represents its ability to effectively increase the generating capacity available to a utility or a regional power grid without increasing the utility's loss of load risk. See Perez, R.; R. Margolis; M. Kmiecik; M. Schwab; and M. Perez. 2006. *Update: Effective Load-Carrying Capability of Photovoltaics in the United States.* Conference Paper. Golden, CO: National Renewable Energy Laboratory. NREL/CP-620-40068. Available at https://www.nrel.gov/docs/fy06osti/40068.pdf.

[27] This category does not apply in all States. For the District of Columbia, there is a solar carve-out within their RPS, which sets a specific target for solar PV generation from grid-connected systems and significantly affects the value.

generation and capacity resources may be reduced, which could have the effect of lowering energy prices. Six studies include market price response. Most studies approximate the market price suppression effect using analysis based on the 2013 Avoided Energy Supply Cost (AESC) study.[28]

Ancillary Services

This value category reflects any increase or decrease in costs associated with the need for generation reserves to provide grid support services such as reactive supply, voltage control, frequency regulation, spinning reserve, energy imbalance, and scheduling. The ability to monitor and control distributed PV and other DERs is an important factor that affects the ability of these variable resources to provide ancillary services at the time of need.

Regions of the country with established markets for ancillary services may find it easier to include and quantify this category. Some of the frameworks reviewed gave an approach to quantifying avoided ancillary services. For example, E3 uses 1 percent of avoided energy in the South Carolina study.[29] In New York, the BCA uses a 2-year average of ancillary service costs, but recognizes that a case-by-case approach would be more accurate.[30] Eight studies include this value category. Some studies may assume an increase in ancillary services as a component of integration costs, discussed below.

Transmission

Avoided Transmission Capacity

This category reflects the avoided costs of transmission constraints from the addition of distributed PV or other DERs, which may or may not defer planned transmission infrastructure upgrades or replacements. The characteristics of the bulk system and DER penetration levels may influence this component. All studies include this value category, although several combine it with avoided distribution capacity and apply a single value for avoided transmission and distribution capacity.[31] The studies took various approaches to calculate the avoided cost of transmission capacity as a result of the installation of NEM eligible solar PV systems. Most commonly, the benefits were calculated by assessing the utility's marginal cost of load-related transmission capacity, as opposed to any specific line cost analysis. Inputs to the calculation include historical transmission capacity expenditures, which can be

[28] The 2013 AESC study was prepared by Synapse and was sponsored by a group representing the major electric and gas utilities in New England, as well as efficiency program administrators, energy offices, regulators, and advocates. Synapse conducted prior AESC studies in 2007, 2009, and 2011, and is currently conducting a 2018 study (http://www.synapse-energy.com/project/avoided-energy-supply-costs-new-england).

[29] Patel, K.; Z. Ming; D. Allen; K. Chawla; and L. Lavin. 2015. *South Carolina Act 236: Cost Shift and Cost of Service Analysis*. San Francisco, CA: Energy and Economics, Inc. p. 11. Available at http://www.regulatorystaff.sc.gov/electric/industryinfo/Documents/Act%20236%20Cost%20Shifting%20Report.pdf.

[30] New York Department of Public Service (NY DPS), 2016(a), Appendix C, p. 7.

[31] Stanton, E.; J. Daniel; T. Vitolo; P. Knight; D. White; and G. Keith. 2014. *Net Metering in Mississippi: Costs, Benefits, and Policy Considerations*. Cambridge, MA: Synapse Energy Economics, Inc. Available at https://www.synapse-energy.com/sites/default/files/Net%20Metering%20in%20Mississippi.pdf; Dismukes, D. 2015. *Estimating the Impact of Net Metering on LPSC Jurisdictional Ratepayers.* Baton Rouge, LA: Acadian Consulting. Available at http://lpscstar.louisiana.gov/star/ViewFile.aspx?Id=f2b9ba59-eaca-4d6f-ac0b-a22b4b0600d5; Norris, B. 2014. *Value of Solar in Utah*. Clean Power Research. Available at https://pscdocs.utah.gov/electric/13docs/13035184/255147ExAWrightTest5-22-2014.pdf; and Patel, et al., 2015.

based on publicly available Federal Energy Regulatory Commission (FERC) Form 1 data or data provided by the utility, and the load-carrying contribution made by solar PV.

Avoided Line Losses

This category reflects the value of energy that would otherwise be lost due to inefficiencies in transmitting and distributing energy over long distances from the central station to the point of consumption. EIA estimates that electricity transmission and distribution losses average about 5 percent of the electricity that is transmitted and distributed annually in the United States.[32] Losses are generally calculated by developing an average loss factor, and they vary based on time of day and the characteristics of the utility system. Avoided line losses also may be reflected in other value categories. For example, several of the studies prepared by Clean Power Research employ a loss savings factor approach instead of using a separate value category to address line losses.[33] Studies may include both energy-related and capacity-related losses. Eleven studies include this value category.

Distribution

Avoided Distribution Capacity

This category reflects the avoided costs due to the DER's ability to reduce load and defer or avoid planned distribution infrastructure upgrades or replacements to the distribution system. The value is sensitive to load growth rate at the distribution feeder or substation level, locational load shape characteristics, and penetration of DERs and their coincidence with load on that feeder or substation. All studies except one include this value category. Some studies combine it with avoided transmission capacity and apply a single value for avoided transmission and distribution capacity.

Avoided Reliability and Resiliency Costs

This category reflects avoided costs to the distribution system from the reduction in the frequency and duration of utility grid outages and the provision of back-up services, which reduce the impacts on customers. Five studies include this category; however, it is challenging to quantify, and no study in this review calculates a specific value.[34] The study from Mississippi includes a discussion of the value categories that it did not monetize and describes how avoided outage costs could be represented in cost-benefit analyses using a value of lost load estimation, or the amount that customers would be willing to pay to avoid interruption of their electric service. However, the study indicates that there is not "sufficient evidence to estimate the extent to which solar NEM would improve reliability" at this time.[35] The study from the District of Columbia discusses reliability in terms of outage frequency, duration, and breadth in its treatment of societal benefits, but indicates that it is difficult to "credibly forecast" when smart inverters will be deployed, how they will be used in reducing outages for

[32] U.S. Energy Information Administration (EIA). Frequently Asked Questions, How much electricity is lost in transmission and distribution in the United States? Available at https://www.eia.gov/tools/faqs/faq.php?id=105&t=3.

[33] For a detailed description of the loss savings factor approach, see Norris, 2015(a), p. 17.

[34] The terms "resilience" and "reliability" are sometimes used interchangeably and are not clearly defined or distinguished in the studies.

[35] Stanton, et al., 2014, p. 35.

distributed solar customers, and how these deployments may result in lower expenditures for the utility.[36]

Distribution Operations and Maintenance (O&M)
This category can be assessed as either a cost or a benefit. It generally reflects any increase or decrease in O&M costs associated with utility investments in distribution assets and infrastructure services as a result of deploying distributed solar on the distribution system. Four studies include distribution O&M as either a cost or a benefit. In some studies, the negative value could be assumed to be included in the integration cost category, discussed later in this section.

Distribution Voltage and Power Quality
This category can be assessed as either a cost or a benefit. It generally reflects any increase or decrease in the costs of maintaining voltage and frequency on the distribution system within acceptable ranges during electric service delivery, and to potentially improve power quality. Six studies include the value of distribution voltage and/or power quality costs, but none of the studies quantify it. Some studies may address this value within ancillary services or integration costs, discussed in the next section.

Costs

Integration Costs
This category reflects costs incurred by the utility to integrate and manage distributed solar and other DERs on the utility grid. For example, investments may be required to support voltage regulation, upgrade transformers, increase available fault duty, and provide anti-islanding protection.[37] Integration costs may include scheduling, forecasting, and controlling DERs, as well as procurement of additional ancillary services such as reserves, regulation, and fast-ramping resources.[38] Most studies do not specify what specific investments are assumed to be included in integration costs or whether integration costs are assumed to apply at the distribution or transmission level. However, the studies from the District of Columbia, Louisiana, and South Carolina include interconnection costs, which is typically a distribution system-level consideration. Thirteen studies include this category.[39]

Lost Utility Revenues
This category reflects the loss of revenues to the utility due to reduced retail customer loads associated with customer-sited DERs. Lost revenues are the result of NEM participants paying smaller electric bills and are equivalent to customer bill savings. The value represents a potential cost-shift, and is applied when determining whether utility rates for all customers will increase, which some studies evaluated

[36] Whited, M.; A. Horowitz; T. Vitolo; W. Ong; and T. Woolf. 2017. *Distributed Solar in the District of Columbia: Policy Options, Potential, Value of Solar, and Cost-Shifting*. Cambridge, MA: Synapse Energy Economics. p. 49. Available at http://www.synapse-energy.com/sites/default/files/Distributed-Solar-in-DC-16-041.pdf.
[37] Bird, L.; M. Milligan; and D. Lew. 2013. *Integrating Variable Renewable Energy: Challenges and Solutions.* Available at https://www.nrel.gov/docs/fy13osti/60451.pdf.
[38] National Efficiency Screening Project (NESP). 2017. *National Standard Practice Manual for Assessing Cost-Effectiveness of Energy Efficiency Resources.* Available at https://nationalefficiencyscreening.org/wp-content/uploads/2017/05/NSPM_May-2017_final.pdf.
[39] The framework developed in Georgia does not specifically reference "integration costs" but it includes costs associated with support capacity, which we consider costs associated with integration. Similarly, the study from Louisiana does not specifically reference integration costs, but it does include interconnection costs and we consider that value as a cost associated with integration.

using the Rate Impact Measure (RIM) test.[40] Seven studies include this value category, while others argue that lost revenues are not a new cost created by net-metered systems.[41]

Program and Administrative Costs
This category reflects the costs incurred by the utility to administer various DER incentive programs. It can include both the cost of State incentive payments and the cost of administering them, compliance and reporting activities, personnel, billing costs, and other administrative costs to implement and maintain a formal program. Seven studies include this value category.

Societal Impacts

Benefits

Avoided Cost of Carbon
This category reflects avoided costs to society from reduced carbon emissions. It does not include avoided costs to the utility related to carbon emissions otherwise included in avoided energy costs or avoided environmental compliance value categories. This category is meant to capture additional avoided costs that accrue to broader society from mitigating climate change. Eight studies include this value category and three quantify it based on the Social Cost of Carbon developed by the U.S. Environmental Protection Agency. Studies may use a netting out process, such as the one described in the study from Maine, to ensure that this value category only reflects the net social costs of carbon and does not double-count avoided utility costs associated with carbon emissions that are embedded in energy prices.[42]

Other Avoided Environmental Costs
This category reflects the societal value of reduced environmental impacts related to public health improvements from reduced criteria air pollutants (SO_2, NOx, etc.), methane leakage, and impacts on land and water. Avoided criteria pollutants are addressed in nine of studies as a separate category from the impact of emissions prices on allowance markets that may be included in the avoided generation cost category. Four studies discuss avoided impacts on land and water. Two studies discuss avoided methane leakage.

Economic Development
This category reflects economic growth benefits such as jobs in the solar industry, local tax revenues, or other indirect benefits to local communities resulting from increased distributed solar deployment. Local economic benefit is challenging to quantify and is heavily influenced by assumptions. Three studies

[40] The purpose of the RIM test is to indicate whether a resource will increase or decrease electricity or gas rates. When regulators take steps to allow utilities to recover lost revenues through rate cases, revenue decoupling, or other means, then the recovery of these lost revenues will create upward pressure on rates. If this upward pressure on rates exceeds the downward pressure from reduced utility system costs, then rates will increase, and vice versa (NESP, 2017).
[41] Stanton, et al., 2014, p. 33.
[42] Norris, B.; P. Gruenhagen; R. Grace; P. Yuen; R. Perez; and K. Rabago. 2015. *Maine Distributed Solar Valuation Study*. Prepared for Maine Public Utilities Commission by Clean Power Research, Sustainable Energy Advantage, LLC, and Pace Law School Energy and Climate Center. p. 35. Available at http://www.maine.gov/mpuc/electricity/elect_generation/documents/MainePUCVOS-FullRevisedReport_4_15_15.pdf.

discuss this value category; only the study from Arkansas quantifies a value and includes it in its assessment of societal costs.[43]

Comparison of Value Categories

Included	●
Included/represented in another category	●
Discussed but not monetized/quantified	○
For NY, included in VDER Phase One	○

The following section provides a more detailed comparison of how the categories are treated across the studies. Figure 3 identifies which studies include each category. Values that are numerically quantified in the study are represented on the chart with a solid dot. Values that are discussed, but not quantified, are represented on the chart with an open dot. Some studies combined more than one value into a broader category and, where possible, these rolled-up values are noted with a solid red dot. For New York, the BCA includes a broader set of value categories than the Value of DER (VDER) Phase One Tariff. An open red dot indicates that the value category is also included in VDER Phase One.[44]

[43] Beach, R. Thomas, and Patrick G. McGuire. 2017. *The Benefits and Costs of Net Metering Solar Distributed Generation on the System of Entergy Arkansas, Inc*. Crossborder Energy. p. 28. Available at https://drive.google.com/file/d/0BzTHARzy2TINbHViTmRsM2VCQUU/view.

[44] For Phase One of VDER, five categories make up the Value Stack: energy, capacity, environmental, demand reduction value, and locational system relief value. Because VDER uses locational marginal prices (LMPs), we assume that the common value categories associated with "avoided transmission capacity" and "avoided line losses" are included, because transmission congestion and losses are implicitly embedded in the LMP. However, the LMP does not factor in avoided costs from deferring transmission upgrades nor apply a specific line loss percentage. For the two distribution system values—demand reduction and locational system relief—we use the common value category associated with "avoided distribution capacity" as a rough substitute, but VDER values are more specifically aimed at measuring peak load reduction in higher value areas.

Figure 3. Comparison of value categories across studies

		Arkansas - Crossborder Energy 2017	Nevada - E3 2016	Louisiana - Acadian Consulting Group 2015	South Carolina - E3 2015	Mississippi - Synapse 2014	Vermont - VT Public Service Dept 2014	Washington DC - Synapse 2017	Georgia - Southern Company 2017	Hawaii - Clean Power Research 2015	Maine - Clean Power Research 2015	Oregon - Clean Power Research 2015	Minnesota - Clean Power Research 2015	Utah - Clean Power Research 2014	New York - BCA Framework 2016 + VDER Phase One	California - LNBA Framework 2016	**Total**
Utility System Impacts																	
G	Avoided Energy Generation	●	●	●	●	●	●	●	○	○	●	○	○	●	○	○	**15**
	Avoided Generation Capacity	●	●	●	●	●	●	●	○	○	●	○	○	●	○	○	**15**
	Avoided Environmental Compliance	●	●			●	●	●	○		●	○		●		○	**10**
	Fuel Hedging	●			●	●		●		○	●	○	●	●			**9**
	Market Price Response	●					●	●		○	●				○		**6**
	Ancillary Services		●		●	○		○	○	○					○	○	**8**
T	Avoided Transmission Capacity	●	●	●	●	●	●	●	○	○	●	○	○	●	○	○	**15**
	Avoided Line Losses	●	●		●	●	●	●	○			○		●	○	○	**11**
D	Avoided Distribution Capacity	●	●	●	●	●	●	●		○	○	○	○	●	○	○	**14**
	Avoided Resiliency & Reliability	○				○		○							○	○	**5**
	Distribution O&M			●					○						○	○	**4**
	Distribution Voltage and Power Quality									○	○	○	○		○	○	**6**
C	Integration Costs	●	●	●	●	○		●	○	○	●	○	○		○	○	**13**
	Lost Utility Revenues	●	●	●	●	●	●								○		**7**
	Program and Administrative Costs		●	●	●	●	●	○							○		**7**
Societal Impacts																	
S	Avoided Cost of Carbon	●					●	●		○	●		○		○	○	**8**
	Other Avoided Environmental Costs	●	●			○		○		○	●		○		○	○	**9**
	Local Economic Benefit	●				○		○									**3**

Included	●
Included/represented in another category	●
Discussed but not monetized/quantified	○
For NY, included in VDER Phase One	○

The most common categories were impacts on the bulk power system: avoided energy generation, avoided generation capacity, and avoided transmission capacity (all the studies include them). The second most common categories, included in 10 or more studies, were avoided environmental compliance, avoided line losses (including transmission and distribution), avoided distribution capacity, and integration costs.

The least common cost-benefit categories, included in five or fewer studies, were distribution O&M, avoided resiliency and reliability, and economic development. Avoided resiliency and reliability, as well as economic development benefits, have proven to be somewhat challenging to calculate, which may explain why a number of studies did not include them. Studies that emphasize locational value, such as New York and California, may consider the resilience, reliability, and other benefits at the distribution level more effectively than studies taking statewide or system-level approaches.

Studies that do include these values describe their approaches to calculating it. The California LNBA measures system reliability/resilience by monitoring System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), and Momentary Average Interruption Frequency Index (MAIFI) results.[45, 46] Similarly, the New York BCA Framework includes reliability/resilience values in terms of net avoided restoration costs and net avoided outages. Net avoided restoration costs are calculated by comparing the number of outages and the speed and costs of restoration before and after a project is implemented to find the difference. Avoided outage costs are similarly calculated by determining how a project affects the number and length of an outage and multiplying by the estimated costs of an outage. The estimated cost is determined by customer class and geographic region. For both avoided restoration costs and avoided outages, some portion of this value is already factored in the transmission and distribution (T&D) infrastructure costs, and this category represents the net avoided cost.[47]

Figure 4 shows the range of magnitude of value categories as a percentage of net impact. Figure 5 shows value stacks from five studies that clearly document values.[48] Avoided energy tended to provide the largest share of benefits out of all the categories. Avoided generation capacity and fuel hedging also tended to make up significant portions of the value stack. For studies that include societal benefits such as the avoided cost of carbon and other avoided environmental costs, these components can make up significant portions of the value stack, such as in the Arkansas and Maine studies, or they may have more modest values, such as in the District of Columbia and Utah studies. The size of avoided carbon

[45] California Public Utilities Commission (CPUC), 2016(a), p. 29.

[46] The LNBA currently includes the value of increased reliability from DERs where DERs can defer or avoid an otherwise necessary investment to bring reliability up to an acceptable level; however, consensus has not been reached on whether the non-capacity benefits of increased reliability associated with the frequency, duration, or magnitude of customer outages should be factored in. See California Public Utilities Commission (CPUC). 2017. *Locational Net Benefit Analysis Working Group Final Report.* Rulemaking 14-08-013. Order Instituting Rulemaking Regarding Policies and Rules for Development of Distribution Resources Plans Pursuant to Public Utilities Code 769, and Related Matters. March 8. p. 36. Available at http://drpwg.org/wp-content/uploads/2016/07/R1408013-et-al-SCE-LNBA-Working-Group-Final-Report.pdf.

[47] New York Department of Public Service (NY DPS, 2016(a), Appendix C, pp. 2, 14.

[48] Four studies presented quantified values that we were not able to draw upon, either because they would have required visual assumptions or were otherwise incomparable.

and other environmental values depends on a number of factors, such as the generation mix being displaced by distributed PV in the region and the approach used to calculate the social cost of carbon.

Figure 4. Range of magnitude of value categories as a percentage of net impact

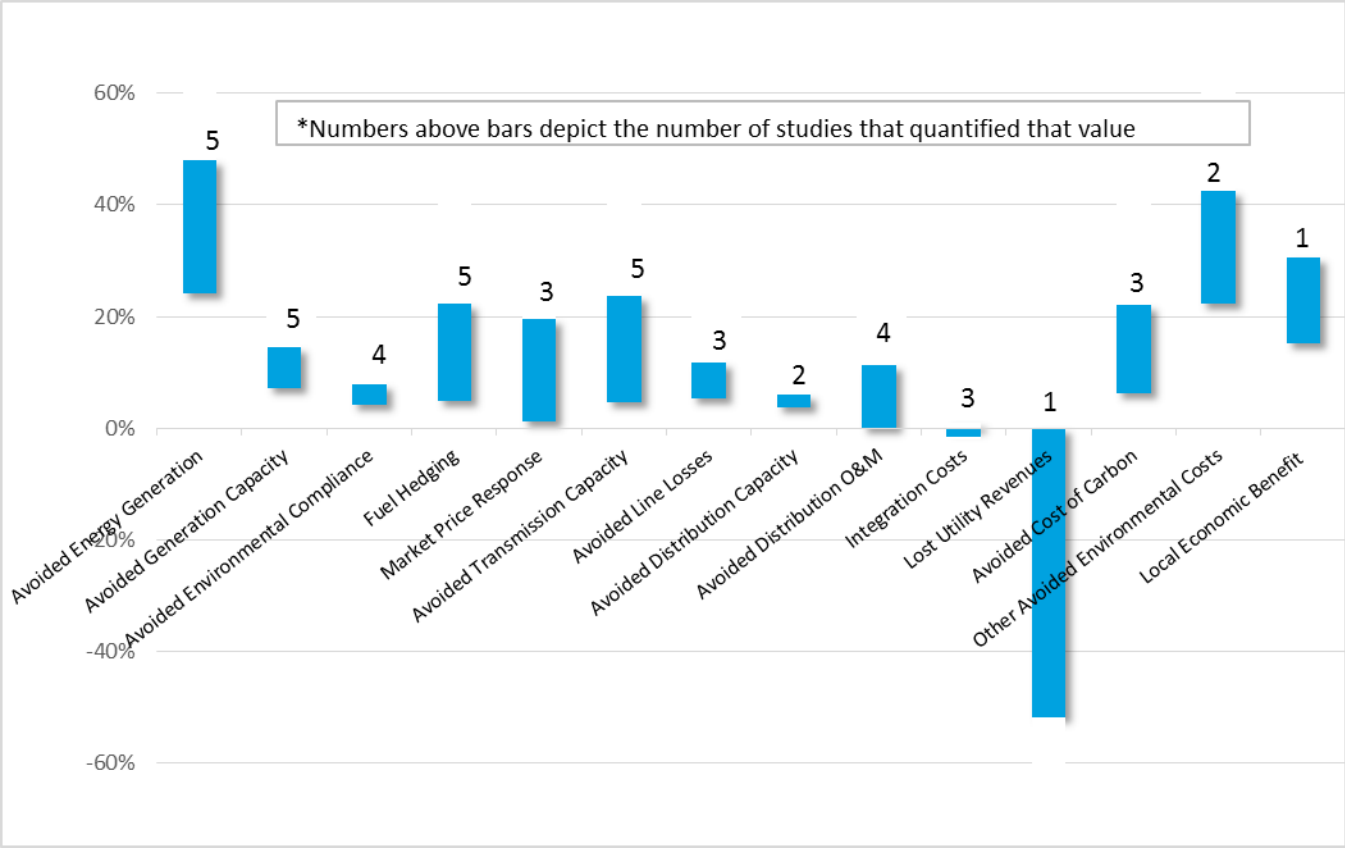
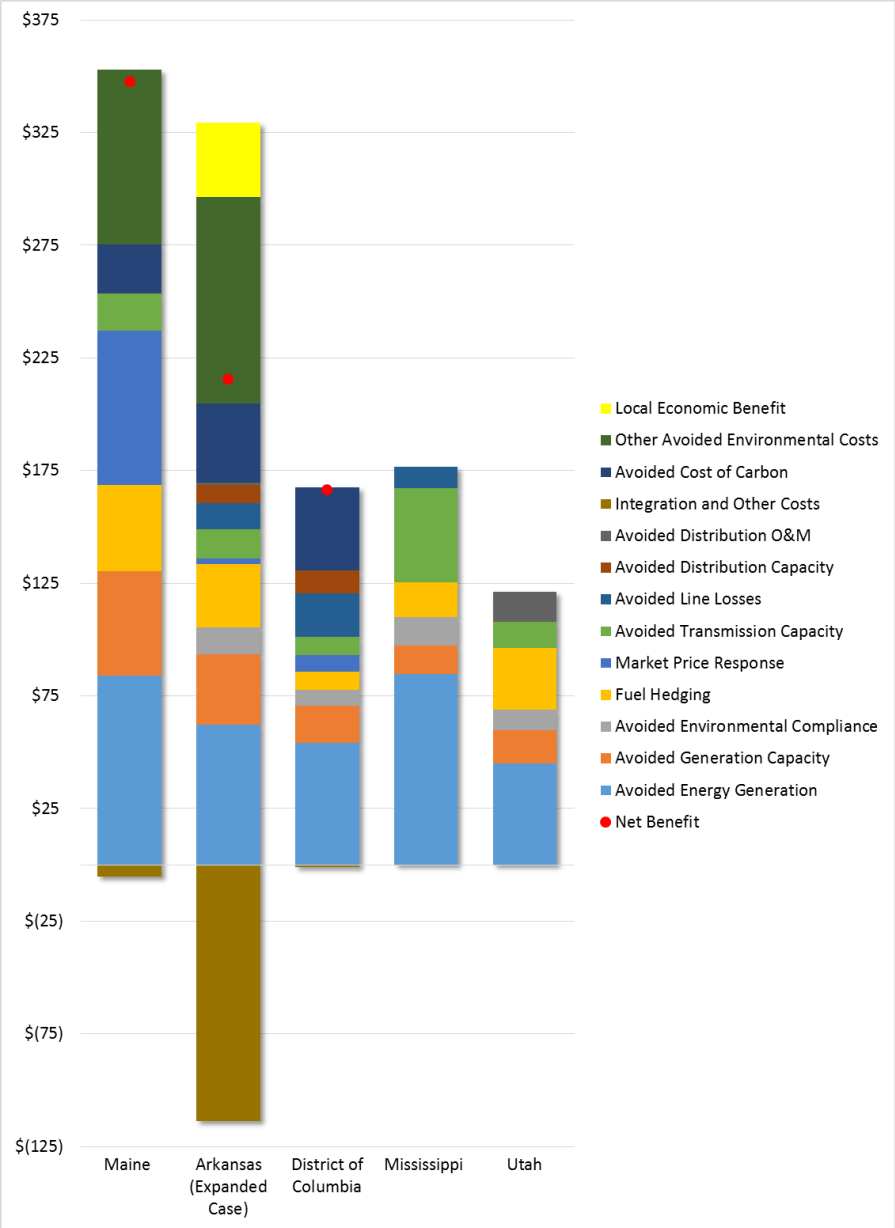


Figure 5. Comparison of value stacks (for studies that documented values)



* Values expressed in 2017 dollars per MWh, levelized over 25 years (except for the District of Columbia, which used 24 years). Studies that expressed values in varying dollar years and in dollars per KWh were converted. The Arkansas study looked at two sets of avoided costs, including an "expanded case," which includes a broader set of categories and is shown here. The District of Columbia's cost categories are included, but are not visible because the value is small. The Mississippi study considered two cost categories (reduced revenue and administrative costs) but neither value is shown because the detailed data were not found in the study. Utah did not include separate cost categories. Louisiana is not represented in the figure because costs and benefits are presented in net present value terms and do not lend themselves to comparison.

Stakeholder Perspective

In addition to the differences in value categories described above, there are differences in the perspectives of the studies that can affect the value categories included. For example, when assessing the value of NEM, distributed solar, and other DERs, it is important to recognize where the benefits or

costs accrue. Costs and benefits can accrue at least to three different stakeholder groups—ratepayers, the utility, and the grid—with most studies evaluating multiple stakeholder perspectives. Some of the differences among these perspectives are discussed in this section.

From the ratepayer perspective, a customer with a PV system can experience a certain set of costs and benefits. Benefits can include a reduction in utility bills as a result of self-generation and financial incentives from the utility in the form of NEM. Costs include the capital investment in the PV system and costs associated with ongoing maintenance of the system. However, customers without PV systems also may be affected and may experience costs and benefits as a result of the systems installed by others. For example, if the utility's cost for implementing NEM exceeds the estimated benefit, the utility could increase rates for all customers to make up for the shortfall, and customers without PV would pay more as a result of the NEM program. At least five of the studies explore concerns about potential "cross subsidization" between those customers installing rooftop solar and those who do not.

From the utility's perspective, its business can experience both benefits and costs due to NEM and distributed solar. Some values that constitute a benefit for the ratepayer can present themselves as a cost to the utility. For example, the benefit of bill savings to the customer is the same as lost revenue to the utility. If and how that lost revenue is captured though different rate designs can affect both participating (i.e., with PV systems) and non-participating (i.e., without PV systems) customers.

From a grid perspective, NEM and distributed PV and other DERs can provide benefits and incur costs to the electric grid as a function of the resource's location and operational characteristics. The benefits and costs of a particular resource reflect distribution system factors such as load relief, reliability, power quality, voltage regulation, and resilience. In addition, the net benefits of these resources can reflect issues on the bulk system, such as resource adequacy and system flexibility, as well as societal benefits related to emission reductions, health impacts, and environmental justice.

Nine studies also consider a fourth perspective—the perspective of a broader society—which can result in variations in the costs and benefits assessed. For example, the value category associated with the cost of carbon can be assessed for its utility system value and its societal value. From the utility perspective, the cost of carbon reflects an emissions allowance price, either in an observed market or one used by the utility for planning purposes. The value component takes on a different, and potentially more substantial, value when it is assessed from the societal perspective, where it reflects the benefit that all society may experience from lower carbon emissions. This concept is further discussed in a later section, "Societal Values."

Many of the studies in this meta-analysis accounted for multiple perspectives in their assessments. The inclusion or omission of a given perspective is sometimes determined by the jurisdiction in which the study is being performed, either legislatively or in regulatory dockets. The following excerpt from the South Carolina study provides an example:

> "While advocates of renewable energy point to numerous environmental and societal benefits that could be included in an analysis of the Value of DER, the directive of Act 236 was to develop a methodology that would 'ensure that the electrical utility recovers its cost of providing electrical service to customer-generators and customers who are not customer-generators.' Therefore, the Methodology is limited to the quantifiable benefits and costs currently

> experienced by the Utility. Likewise, the analysis performed for this report focuses on the quantifiable benefits and costs to the Utility with recognition that those benefits and costs experienced by the Utility are ultimately passed on to its ratepayers."[49]

One approach, taken by seven of the studies, to assess various stakeholder perspectives is to apply one or more of the set of cost-effectiveness tests that are typically applied to energy efficiency programs. These include the Total Resource Cost (TRC) test, Utility Cost Test (UCT), Participant Cost Test (PCT), Societal Cost Test (SCT), and Rate Impact Measure (RIM) Test. Figure 6 provides an overview of the tests. For more information on these cost tests, see the National Efficiency Screening Project's 2017 *National Standard Practice Manual*.[50]

Figure 6. Overview of cost-effectiveness tests (adapted from the National Efficiency Screening Project)

Test	Perspective	Key Question Answered	Summary Approach
Utility cost	The utility system	Will utility system costs be reduced?	Includes the costs and benefits experienced by the utility system
Total Resource Cost	The utility system plus participating customers	Will utility system costs plus program participants' costs be reduced?	Includes the costs and benefits experienced by the utility system, plus costs and benefits to program participants
Societal Cost	Society as a whole	Will total costs to society be reduced?	Includes the costs and benefits experienced by society as a whole
Participant Cost	Customers who participate in an efficiency program	Will program participants' costs be reduced?	Includes the costs and benefits experienced by the customers who participate in the program
Rate Impact Measure	Impact on rates paid by all customers	Will utility rates be reduced?	Includes the costs and benefits that will affect utility rates, including utility system costs and benefits plus lost revenues

[49] Patel, et al., 2015 p. 7.
[50] NESP, 2017.

Figure 7 notes which of the five traditional cost-effectiveness tests were used by the studies in this meta-analysis as an indicator of the perspectives considered. For studies that did not apply cost-effectiveness tests, either cost-effectiveness was not assessed or other analytical methods were used such as the Cost of Service or Revenue Requirements approaches. When evaluating the results of the studies, the perspective of which stakeholders' lens or lenses were applied should be noted.

Figure 7. Summary of cost-effectiveness test used in studies

			Cost-Effectiveness Test				
State	Year	Prepared by	PCT	UCT	RIM	TRC	SCT
Arkansas	2017	Crossborder	√	√	√	√	√
District of Columbia	2017	Synapse		√			√
Georgia	2017	Southern Company					
California	2016	CPUC	√		√		
Nevada	2016	E3	√	√	√	√	√
New York	2016	NY DPS		√	√		√
Hawaii	2015	CPR					
Louisiana	2015	Acadian					
Maine	2015	CPR					
Oregon	2015	CPR					
South Carolina	2015	E3			√		
Minnesota	2014	CPR					
Mississippi	2014	Synapse	√			√	
Utah	2014	CPR					
Vermont	2014	PSD					

Input Assumptions

This section includes a discussion of input assumptions that can cause studies to arrive at different outcomes, including assumptions about the displaced marginal unit, PV penetration levels, treatment of integration costs, inclusion of externalities, and choices about discount rates.

Displaced Marginal Unit

Generation from distributed solar is assumed to displace the marginal generation unit, resulting in avoided energy costs. Generators are generally dispatched in merit or lowest cost order to meet load, and the resource displaced on the margin is the next highest cost generator that can reduce its output in response to solar output. More than one method is used in the studies to estimate which plants are on the margin. Some studies use a typical generator, such as a combined-cycle gas turbine, or a blended mix of generators, as a simple proxy for the avoided generator. Most studies use wholesale market prices based on historical locational marginal prices. A third approach is to use a dispatch model or some other form of production simulation run to estimate what resource is on the margin when distributed solar is expected to displace generation.

Assumptions about the efficiency of the marginal unit (heat rates) and the price of fuel for the marginal unit are dominant factors in avoided energy input costs. In most cases, natural gas was assumed to be

the marginal fuel. Most studies estimate future natural gas prices using EIA's *Annual Energy Outlook* or some other source, such as New York Mercantile Exchange (NYMEX) gas futures. In Hawaii, oil-fired generation is predominant and the study recommends using futures for oil instead of natural gas, and transportation to the island would have to be factored in. The study from Maine also acknowledged that fuel oil may occasionally be the marginal fuel and, in such cases, natural gas displacement was used as a simplifying assumption.[51] In New York, Locational Based Marginal Pricing (LBMP) is used, which represents the cost of the marginal generator plus congestion pricing.[52] The Georgia study uses an hourly approach to estimate the cost of avoided energy, and does not assume a single fuel or technology.[53] For a more detailed look at assumptions from the individual studies on displaced marginal units, see Appendix C.

Solar Penetration

A 2012 report from the Lawrence Berkeley National Laboratory (LBNL) examined changes in the economic VOS PV at relatively high penetration levels and identified a decrease in value components as penetration increases.[54] For penetrations of 0 percent to 10 percent, LBNL found that the primary driver was a decrease in capacity value because additional PV is less effective at avoiding new non-renewable generation capacity at high penetration than at low penetration. For penetrations of 10 percent and higher, the primary driver was a decrease in energy value because additional PV starts to displace generation with lower variable costs at higher penetration levels. In California, a glut of solar generation in the middle of the day from both the central station and distributed solar has contributed to a situation where solar generation is exported to surrounding States during high solar/low load periods.

ICF reviewed the studies for considerations related to PV penetration and to identify what ranges of PV penetration levels were considered. Penetration level is expressed in terms of total distributed solar nameplate capacity as a percentage of total peak capacity. The 15 studies generally considered current or near-term penetration levels with estimates ranging from 0.2 percent to 6 percent, as shown in Table 5. The table also indicates estimated penetration of NEM PV capacity as a percentage of peak load in 2016 for the States where the studies came from.[55]

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[51] Norris, B. 2015(b). *Valuation of Solar + Storage in Hawaii: Methodology*. Prepared for the Interstate Renewable Energy Council (IREC) by Clean Power Research. p. 11. Available at http://www.irecusa.org/wp-content/uploads/2015/06/IREC-Valuation-of-Solar-Storage-in-HI_Methodology_2015.pdf; Norris, et al., 2015, p. 19.

[52] New York Department of Public Service (NY DPS), 2016(a), Appendix C, p. 5.

[53] Southern Company. 2017. *A Framework for Determining the Costs and Benefits of Renewable Resources in Georgia.* Revised May 12, 2017. p. 9. Available at http://www.psc.state.ga.us/factsv2/Document.aspx?documentNumber=167588.

[54] Mills, Andrew, and Ryan Wiser. 2012. *Changes in the Economic Value of Variable Generation at High Penetration Levels: A Pilot Case Study of California.* Berkeley, CA: Lawrence Berkeley National Laboratory. p. 7. Available at https://emp.lbl.gov/sites/all/files/lbnl-5445e.pdf. Table ES.1 shows decomposition of the marginal economic value of PV in 2030, with increasing penetration from 0 percent to 30 percent.

[55] We estimate PV penetration by dividing NEM PV nameplate capacity (MW) by peak load (MW). For NEM PV capacity, data by State was obtained from EIA at https://www.eia.gov/electricity/data/eia861. For peak load, we map States by NEMS region and use AEO 2016 sales data (MWh), adjusted for transmissions losses, to calculate net energy needed to meet load in the State. Net energy is divided by the load factor for the NEMS region to derive peak load. Transmission losses and load factor are obtained from AEO 2016.

Table 5. PV penetration assumed in studies reviewed

State	Year	Prepared by	PV Penetration Specified in Study	Estimated PV Penetration (2016)
Arkansas	2017	Crossborder	Below 5%	0.1%
District of Columbia	2017	Synapse	Current levels	1%
Georgia	2017	Southern Company	Unspecified	<0.1%
California	2016	CPUC	Unspecified	9%
Nevada	2016	E3	Approx. 3%	2%
New York	2016	NY DPS	Unspecified	2%
Hawaii	2015	CPR	Unspecified	22%
Louisiana	2015	Acadian	0.5%	1%
Maine	2015	CPR	Approx. 0.2%	1%
Oregon	2015	CPR	Unspecified	1%
South Carolina	2015	E3	2% in 2021	0.3%
Minnesota	2014	CPR	Near-term level	0.2%
Mississippi	2014	Synapse	0.5%	<0.1%
Utah	2014	CPR	Unspecified	2%
Vermont	2014	PSD	Approx. 6%	6%

Studies that only present methodologies or valuation frameworks tended not to specify assumptions about penetration levels, but some discuss the need to reflect penetration increases. For example, in Minnesota, the change in PV penetration level is accounted for in an annual adjustment to account for the impact of higher solar penetration on hourly utility load profiles and Effective Load Carrying Capacity (ELCC) and Peak Load Reduction (PLR) calculations.[56] ELCC and PLR are used in some studies in calculations of avoided generation capacity and avoided transmission and distribution capacity.

Some studies also may consider higher penetration rates in considerations related to integration costs. For example, the studies from Arkansas and Oregon reference a 2014 report by the Pacific Northwest National Laboratory (PNNL) for Duke Energy that indicated a trend of increasing PV integration costs at successively higher PV levels in the utility's service territory.[57] While solar generation for the nation is likely to remain below 3 percent over the next 5 years, some States are expected to reach much higher levels.[58] Nevada, California, Hawaii, and Vermont are all projected to have more than 20 percent of their generation from solar by 2021, which could affect value categories.[59]

Integration Costs

The majority of studies include costs incurred by the utility to integrate distributed solar; however, very few specify which costs they are referring to or differentiate between costs on the bulk power system or

[56] Norris, B.; M. Putnam: and T. Hoff. 2014. *Minnesota Value of Solar: Methodology.* Prepared for the Minnesota Department of Commerce, Division of Energy Resources by Clean Power Research. pp. 5–6, p. 17. Available at https://www.cleanpower.com/wp-content/uploads/MN-VOS-Methodology-2014-01-30-FINAL.pdf.
[57] Beach and McGuire, 2017, p. 34; Norris, 2015(a), p. 25; and Pacific Northwest National Laboratory (PNNL). n.d. *Duke Energy Photovoltaic Integration Study: Carolinas Service Areas.* Available at http://www.pnucc.org/sites/default/files/Duke%20Energy%20PV%20Integration%20Study%20201404.pdf.
[58] Feldman, D.; D. Boff; and R. Margolis. 2016. *Q3/Q4 2016 Solar Industry Update*. Available at https://www.nrel.gov/docs/fy17osti/67639.pdf.
[59] Ibid., p. 9.

the distribution system. A 2015 National Renewable Energy Laboratory (NREL) report defines integration costs as the change in production costs associated with a system's ability to accommodate the variability and uncertainty of the net load.[60] That report investigated four components of production costs: cycling costs, non-cycling variable operations and maintenance costs (VO&M), fuel costs, and reserves provisioning costs. It did not include capital and other fixed costs.

Four studies reviewed in the meta-analysis quantify values for integration costs that ranged from $1.00/MWh to $5.00/MWh. Several studies rely on existing literature to either estimate their integration costs or reference findings with modifications based on assumptions about PV penetration levels.[61] Existing literature discussed in the selection of studies as a basis for integration cost include:

- A 2014 study by PNNL prepared for Duke Energy on PV integration in the Carolinas, which estimates integration costs in the range of $1.43/MWh to $9.82/MWh based on the level of penetration.[62]
- A 2014 study by Idaho Power to estimate the costs of the operational modifications necessary to integrate intermittent generation from solar plants, which estimates costs ranging from $0.40/MWh to $2.50/MWh for PV capacity ranging from 100 MW to 700 MW.
- A 2013 study prepared by Xcel Energy on the costs and benefits of distributed PV on the Public Service Company of Colorado system.[63]
- The 2014 integrated resource plan of Arizona Public Service, which estimated integration costs on its system of $2.00/MWh in 2020.[64]
- A 2010 New England Wind Integration Study (NEWIS) prepared for ISO-New England by GE, Enernex, and AWS Truepower.[65]

Some studies identify the need for further research and evaluation on the costs of integrating increased solar PV to accurately account for the cost burden on the utility.[66] In California, the LNBA Working Group's report indicates that "bulk-system-level costs" associated with renewable integration are

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[60] Stark, Gregory B., P.E. 2015. *A Systematic Approach to Better Understanding Integration Costs.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-5D00-64502. Available at https://www.nrel.gov/docs/fy15osti/64502.pdf.

[61] Beach and McGuire, 2017; Price, et al., 2016; and Norris, et al., 2015.

[62] PNNL, n.d.

[63] Xcel Energy Services, Inc. 2013. *Costs and Benefits of Distributed Solar Generation on the Public Service Company of Colorado System*. Available at http://www.eei.org/issuesandpolicy/generation/NetMetering/Documents/Costs%20and%20Benefits%20of%20Distributed%20Solar%20Generation%20on%20the%20Public%20Service%20Company%20of%20Colorado%20System%20Xcel%20Energy.pdf.

[64] Arizona Public Service (APS). 2014. *Integrated Resource Plan.* Available at http://www.azenergyfuture.com/getmedia/c9c2a022-dae4-4d1b-a433-ec96b2498e02/2014_IntegratedResourcePlan.pdf/?ext=.pdf.

[65] GE Energy. 2010. *New England Wind Integration Study.* Available at https://www.iso-ne.com/static-assets/documents/committees/comm_wkgrps/prtcpnts_comm/pac/reports/2010/newis_report.pdf. NEWIS results were considered in the Maine study (p. 37) as an upper bound on solar integration costs. NEWIS assessed the operational effects of large-scale wind integration in New England, and the Maine analysis assumes that distributed solar will have lower variability than wind because of its more distributed nature.

[66] Whited, et al., 2017; Norris, et al., 2014; New York Department of Public Service (NY DPS), 2016(b); Norris, 2015(a); and Stanton, et al., 2014.

included, but there is no consensus on whether this category should represent costs associated with increasing hosting capacity or facilitating interconnection.[67] Two studies—Vermont and Utah—did not address integration costs.

Societal Values

The decision to include externalities—such as carbon emissions, criteria pollutants, economic development, or other values that accrue to society—can have a significant impact on study results, and agreement was not found across the studies on the inclusion or exclusion of these values. The study from Mississippi describes these externality costs as "environmental damages incurred by society (over and above the amounts 'internalized' in allowance prices)" and indicates that avoided costs from displaced air emissions are "a benefit to the State and can be considered in benefit and cost analysis without necessarily including these non-market costs in an avoided cost rate."[68] Still, the study does not monetize these benefits.

The study from Hawaii describes the issue further: "In general, it is more difficult to obtain consensus on the inclusion or exclusion of environmental components and other societal values. This is partly due to the fact that they are not the utility avoided costs (i.e., they are not expenses incurred by the utility or collected in rates) and partly because the methodologies rely on more speculative assumptions."[69]

Overall, nine studies include societal benefits. The studies from Oregon, Louisiana, Utah, South Carolina, and Georgia explicitly do not include societal benefits. A common rationale for this exclusion is that societal benefits do not accrue as savings in the form of avoided costs to the utility, which means the benefits cannot be passed along to ratepayers. This choice is a general reflection of the perspectives considered in a study.

Carbon Emissions

Most studies include avoided costs to the utility of complying with carbon regulations, either within the avoided energy generation component of the value categories, or a separate category for avoided environmental compliance. However, only some consider the societal value of reduced carbon emissions. Three studies—Arkansas, Maine, and the District of Columbia—calculate societal values related to carbon emissions. Each used the Social Cost of Carbon developed by the U.S. Environmental Protection Agency as a starting point for estimating the value.[70] Table 6 shows the range of values.

Table 6. Range of societal carbon values ($/MWh)

State	Unadjusted Societal Value of Carbon	Dollar Year of Unadjusted Value	Adjusted Value to 2017$
Arkansas	$35.90	2018$	$35.15
Maine	$21.00	2015$	$21.72
District of Columbia	$36.00	2016$	$36.76

[67] California Public Utilities Commission (CPUC), 2017, p. 20.
[68] Stanton, et al., 2014, p. 34.
[69] Norris, 2015(b), p. 14.
[70] The source for estimates of the social cost of carbon is the Federal Government's Interagency Working Group on the Social Cost of Greenhouse Gases. See *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866* (Updated August 2016). Available at https://www.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf.

Criteria Pollutants and Other Avoided Environmental Costs

Of the nine studies that include societal values for other avoided environmental costs besides carbon, two included values related to criteria pollutants, which tended to be higher than the societal value ascribed to carbon. For example, in the Arkansas study, avoided carbon costs were valued at $35.90/MWh compared to $84.40/MWh for criteria pollutants.[71] Similarly, in the study from Maine, avoided carbon costs were valued at $21.00/MWh compared to $75.00/MWh for criteria pollutants.[72] A few studies discussed other benefits, such as avoided methane leakage, water use, and land use benefits, but only the Arkansas study estimated non-zero values for these categories. The values were $8.00/MWh in reduced methane leakage and $1.20/MWh in avoided water use benefits. Land use benefits were described as "small and positive" but could vary.

Economic Development

The studies from Mississippi and the District of Columbia discussed the societal value of increased economic development, but only the study from Arkansas estimated a non-zero value. In the Mississippi study, economic development benefits, "including job creation and the potential for increased home value," were not monetized because a societal cost test analysis was not performed.[73] The District of Columbia study indicated that increased distributed solar "may contribute new jobs to the District, resulting in reduced unemployment and need for social services while increasing tax revenue," but these benefits were not given a value due to insufficient data.[74] For Arkansas, economic development value was estimated at $33.60/MWh based on an assumption that 22 percent of residential system PV costs are spent in the local economy where the systems are located.[75]

In addition, the study from Louisiana included a solar installation benefits category, which included economic benefits calculated using the Jobs and Economic Development Impact (JEDI) model developed by the National Renewable Energy Laboratories.[76] The study does not differentiate these benefits as societal impacts, but does indicate the portion that is direct, indirect, or induced.

Discount Rate

Discount rates are applied in calculations of the utility's avoided costs and in calculation of societal benefits, if they are included. The higher the discount rate, the lower the value of the long-term benefits of distributed PV and other DERs. For more information on how benefits can be affected by different discount rates, and a summary of the types of discount rates that could be used, see the National Efficiency Screening Project's 2017 *National Standard Practice Manual*.[77]

In general, studies take similar approaches to applying discount rates. For avoided costs from the utility perspective, most studies use a utility-specific weighted average capital cost (WACC) rate as the discount rate. The District of Columbia study was an exception, which found that an alternative discount rate (below Pepco's WACC) was justified because many avoided costs are not capital costs and the

[71] Beach and McGuire, 2017, pp. 26–27.
[72] Norris, et al., 2015, p. 49.
[73] Stanton, et al., 2014, p. 44.
[74] Whited, et al., 2017, p. 151.
[75] Beach and McGuire, 2017, p. 29.
[76] Dismukes, 2015, p. 121.
[77] NESP, 2017, p. 73.

District's policy goals place a strong emphasis on long-term benefits. For avoided costs from the societal perspective, most studies use the societal discount rate of 3 percent in real dollars.

Conclusion

This meta-analysis examines a representative sample of recent studies on the costs and benefits of NEM. It finds that, with widely varying goals and policy contexts, as well as differences in the categories included and the assumptions used, these studies support a range of conclusions regarding NEM policies' net benefits, cost-shifting impacts, and alignment with DER-driven values. The perspective from which value is assessed drives methodology, and decisions on value categories, quantification methods, and input assumptions have significant impacts on findings.

Because the distribution grid and retail service are regulated at the individual State level, it is understandable that there is not one common valuation framework for evaluating the costs and benefits of distributed solar and DER more broadly. That said, we believe that the development of a common set of definitions and categories would help in assisting States, utilities, and other stakeholders to work from a common starting point when endeavoring to determine the net benefit of distributed solar and DER.

Despite these significant methodological differences, the 15 studies analyzed in this paper converge on at least three common value categories, all at the wholesale or bulk power level: avoided energy generation, avoided generation capacity, and avoided transmission capacity. Methodological approaches to calculating these common categories are generally well established, similar, and agreed upon, with the quantified result potentially differing based on a wide range of regional factors and assumptions.

Overall observations from this analysis show, not surprisingly, that a major challenge in studying and developing an approach to NEM, VOS, and DER valuation is that some value components are relatively easy to quantify, while others are more difficult to represent by a single metric or measure. Given the relative newness of evaluating the cost, performance, and therefore net benefit to the distribution grid, the majority of differences between the studies occur in this area. Still, avoided or deferred distribution capacity over a longer term planning horizon is relatively easier to quantify as opposed to the less common value categories that were identified as difficult to calculate or forecast based on data availability or lack of a widely accepted quantification process.

As States and utilities deploy new technologies that can assist in gaining a more detailed understanding of the locational and temporal value of DERs across the electricity system, it will enhance the ability to more accurately assess the costs and benefits of deploying DER on the system. This meta-analysis demonstrates how specific variables, approaches, and assumptions related to the costs and benefits of distributed PV were treated in a selection of studies from a snapshot in time, during a period when frameworks are rapidly evolving and best practices are still being defined.

Appendix A: Summaries of Selected Studies

This section includes short summaries of each study. The summaries follow a standard format, starting with the citation and continuing with three common elements: (1) the study's analytical goal or purpose; (2) any results or answers found in response to the analytical goal; and (3) the takeaways, in bullet form, that are noteworthy for the purposes of the meta-analysis.

Summaries are grouped by type of study and then presented in alphabetical order by State.

Type of Study	States (Prepared by)
NEM Cost-Benefit Analysis	▪ Arkansas (Crossborder) ▪ Louisiana (Acadian) ▪ Mississippi (Synapse) ▪ Nevada (E3) ▪ South Carolina (E3) ▪ Vermont (VT PSD)
VOS/NEM Successor	▪ District of Columbia (Synapse) ▪ Georgia (Southern Company) ▪ Hawaii (CPR) ▪ Maine (CPR) ▪ Minnesota (CPR) ▪ Oregon (CPR) ▪ Utah (CPR)
DER Value Frameworks	▪ California LNBA (CPUC) ▪ New York BCA (DPS Staff)

NEM Cost-Benefit Analysis

Arkansas

Beach, R., and P. McGuire. 2017. *The Benefits and Costs of Net Metering Solar Distributed Generation on the System of Entergy Arkansas, Inc.* Crossborder Energy. Available at https://drive.google.com/file/d/0BzTHARzy2TINbHViTmRsM2VCQUU/view.

This report provides a cost-benefit analysis of "the impacts on ratepayers of the net metering of solar distributed generation [DG] in the service territory of Entergy Arkansas, Inc. (EAI)."[78] The goal of the report is to "contribute to the Commission's review" of net metering issues in response to recent legislation directing the Arkansas Public Service Commission (PSC) to evaluate the rates, terms, and conditions of net metering in Arkansas.[79]

The report concludes that "the benefits of residential DG on the EAI system exceed the costs, such that residential DG customers do not impose a burden on EIA's other ratepayers."[80] The study summarizes the results based on the application of five cost-effectiveness tests (i.e., participant test, RIM test, program administrator cost test, total resource cost test, and societal cost test).

Noteworthy takeaways include:

- The report was commissioned by the Sierra Club and submitted to the Arkansas PSC as part of the *Joint Report and Recommendations of the Net-Metering Working Group* in Docket No. 16-027-R.[81]
- Benefits equal or exceed the costs in the total resource cost, program administrator cost, and societal cost tests.[82]
- The RIM test was used to determine that net metering does not cause a cost-shift to non-participating ratepayers.[83]
- As the cost of integration, the study uses an estimate of "$2 per MWh as the cost of additional ancillary services that may be needed to integrate solar DG into the grid."[84]
- The study found "significant, quantifiable societal benefits" from solar DG.[85]

Louisiana

Dismukes, D. 2015. *Estimating the Impact of Net Metering on LPSC Jurisdictional Ratepayers*. Baton Rouge, LA: Acadian Consulting. Available at http://lpscstar.louisiana.gov/star/ViewFile.aspx?Id=f2b9ba59-eaca-4d6f-ac0b-a22b4b0600d5.

[78] Beach and McGuire, 2017, p. 1.
[79] Act 827 of 2015 tasked the PSC with addressing various issues associated with net metering.
[80] Beach and McGuire, 2017, p. 2.
[81] Arizona Public Service (APS). 2017. *Joint Report and Recommendations of the Net-Metering Working Group*. Docket 16-027-R-Doc. 228. Available at http://www.apscservices.info/pdf/16/16-027-R_228_1.pdf.
[82] Ibid., p. 3.
[83] Ibid.
[84] Ibid., p. 2.
[85] Ibid., p. 4.

The goal of this report is "to quantify the impacts and implications of NEM policies currently being used by the Louisiana Public Service Commission [LPSC] for smaller scale residential and commercial solar energy installations." Three different empirical models are used to estimate the impacts on the ratepayers of LPSC-regulated utilities: a benefit-cost analysis, a cost of service analysis, and an analysis of the income levels of customers installing solar NEM systems.

The cost-benefit analysis was the primary focus in this meta-analysis. It concludes that "the estimated costs associated with solar NEM installations outweighs their estimated benefits."[86] For instance, costs are 1.5 times higher than benefits under the baseline scenario, resulting in negative total net benefits to LPSC ratepayers of $89 million in net present value (NPV) terms.[87]

Noteworthy takeaways include:

- The study looked at three scenarios: (1) a baseline condition including just solar NEM installations to date, (2) a condition in which NEM installations would grow at their historic rate until the installed capacity reached a mandated cap of 0.5 percent of system peak for each utility and then remained flat, and (3) a case in which NEM installations grow unbounded at the utility-specific 2012–2013 growth rate until 2017, after which growth rates slow to 10 percent per year until 2020 as a result of the tax credit phase-out.
- The study also performs three sensitivity analyses (i.e., high natural gas price, high electric capacity price, and carbon price) to test for conditions under which NEM would result in ratepayer benefits. The sensitivities did not shift the results in a direction that was favorable for ratepayers.[88]
- Avoided energy benefits are substantially greater than avoided capacity benefits due to the low effective capacity VOS in Louisiana. Avoided capacity benefits represent the third largest source of benefits.[89]
- Avoided T&D benefits are relatively small, at less than $1 million, because the unit cost of avoided T&D is smaller than generation, and the effective capacity of solar NEM is relatively small. [90]
- Direct, indirect, and induced "solar installation impacts represent the single largest source of total NEM program benefits." These benefits are modeled using the Jobs and Economic Development Impact (JEDI) solar PV model developed by NREL.[91]

Mississippi

Stanton, E.; J. Daniel; T. Vitolo; P. Knight; D. White; and G. Keith. 2014. *Net Metering in Mississippi: Costs, Benefits, and Policy Considerations.* Cambridge, MA: Synapse Energy Economics, Inc. Available at https://www.synapse-energy.com/sites/default/files/Net%20Metering%20in%20Mississippi.pdf.

[86] Dismukes, 2015, p. ii.
[87] Ibid., p. 186.
[88] Ibid.
[89] Ibid., p. 131.
[90] Ibid.
[91] Ibid., pp. 122, 132.

This report provides a description of a potential net metering policy for Mississippi and the issues surrounding it, focusing on residential and commercial rooftop solar. The report models and analyzes the impacts of installing rooftop solar equivalent to 0.5 percent of the State's peak historical demand, with a goal of estimating the potential benefits and costs of a hypothetical net metering program.

The report concludes that "net metering provides net benefits under almost all of the scenarios and sensitivities analyzed."[92]

Noteworthy takeaways include:

- At the time the report was prepared, Mississippi was one of five States without a net metering policy.[93]
- Of the value categories considered, the study finds that avoided energy costs provided the greatest benefit, followed by avoided T&D costs, and the value associated with reduced risk.
- Reduced risk includes transmission costs, T&D losses, fuel prices, and other costs. A 10 percent adder was applied to calculate avoided costs in the study.[94]
- In sensitivity analyses, variations in avoided T&D cost generated the most noticeable impact on the benefits of NEM. Projected capacity value and projected CO_2 costs had some impact, while fuel prices had a minor impact.[95]
- Of the cost-effectiveness tests used for energy efficiency in Mississippi (the TRC, RIM, and UCT), the study finds that the TRC test best reflects and accounts for the benefits of distributed generation. The authors do not recommend the use of the RIM test to analyze the efficacy of NEM.[96]
- Generation from rooftop solar panels in Mississippi will most likely displace generation from the State's peaking resources—oil and natural gas combustion turbines.[97]
- Results show that NEM participants would need to receive a rate beyond average retail in order to pursue NEM and suggest that policymakers consider an alternative to NEM, such as a solar tariff structure similar to Minnesota and the Tennessee Valley Authority.[98]

Nevada

Price, S.; Z. Ming; A. Ong; and S. Grant. 2016. *Nevada Net Energy Metering Impacts Evaluation 2016 Update.* San Francisco, CA: Energy and Environmental Economics, Inc. Available at http://pucweb1.state.nv.us/PDF/AxImages/DOCKETS_2015_THRU_PRESENT/2016-8/14264.pdf.

[92] Stanton, et al. 2014, pp. 2–3. See graph summarizing finding on p. 5.
[93] Walton, Robert. December 7, 2015. "Mississippi regulators approve state's first net metering plan." Utility Dive. Available at https://www.utilitydive.com/news/mississippi-regulators-approve-states-first-net-metering-plan/410341/.
[94] Stanton, et al. 2014, p. 30. For the purposes of the meta-analysis, this value is reflected in the "Fuel Hedging" category; however, it is noteworthy that the component is intended to include additional factors.
[95] Ibid., pp. 45–47.
[96] Ibid., p. 41.
[97] Ibid., pp. 1, 21.
[98] Ibid., p. 50.

This report provides an update to the 2014 report, *Nevada Net Energy Metering Impacts Evaluation*, which calculated the costs and benefits of renewable generation systems under the State's NEM program.

The goal is to "investigate the impact of existing NEM PV systems as well as the projected impact of future NEM PV systems," following the same methodological framework as the 2014 report, but incorporating the most up-to-date utility data. It evaluates the cost-effectiveness of NEM from five different perspectives to assess the costs and benefits of the NEM program.

The report concludes with the following base case results for each of the five perspectives of cost-effectiveness:

- Participant Cost Test (PCT): Solar is not cost-effective for customers who install PV systems; however, the net cost to participating customers is relatively small, at $0.02/kWh, for existing systems.[99]
- Ratepayer Impact Measure (RIM): There is a cost-shift from NEM customers to non-participating customers that amounts to a levelized cost of $0.08/kWh for existing installations.[100]
- Program Administrator Cost Test (PACT): Existing and future NEM systems cause total bills collected by NV Energy to decrease.[101]
- Total Resource Cost (TRC) Test: NEM generation increases total energy costs for Nevada at a net cost to the State of $0.13/kWh for existing systems.[102]
- Societal Cost Test (SCT): The societal perspective does not significantly change the results for the costs and benefits of NEM overall.[103]

Noteworthy takeaways include:

- The finding that NEM generation is a costlier approach is mainly due to utility-scale solar power purchase agreement prices having dropped precipitously in recent years, which greatly lessens the costs avoided by NEM generation, while distributed solar costs have not dropped commensurately.[104]

South Carolina

Patel, K.; Z. Ming; D. Allen; K. Chawla; and L. Lavin. 2015. *South Carolina Act 236: Cost Shift and Cost of Service Analysis*. San Francisco, CA: Energy and Economics, Inc. Available at http://www.regulatorystaff.sc.gov/electric/industryinfo/Documents/Act%20236%20Cost%20Shifting%20Report.pdf.

The goal of this report is "to investigate and report to the Public Service Commission of South Carolina the extent to which cost shifting can be attributed to DER adoption within current rate making practices." The cost-shifting analysis examines the effects of NEM in the context of three scenarios:

[99] Price, et al., 2016, p. 6.
[100] Ibid., p. 7.
[101] Ibid., p. 8.
[102] Ibid., p. 9.
[103] Ibid., p. 10.
[104] Ibid., p. 13.

(1) historical DER adoption, (2) future DER adoption without utility incentives offered through DER programs, and (3) future DER adoption with incentives from DER program participation.

The report concludes that prior to Act 236, NEM-related cost-shifting was *de minimus* due to the low number of participants.[105] Furthermore, it states that "if utilities were to reach the DER adoption targets set in Act 236 without additional incentives, the cost shifting would be small and difficult to isolate." Finally, the report finds that "although more data is required to draw widespread conclusions, the utilities rate structures may need to evolve to be more economically efficient and to alleviate the potential for cost shifting or for uneconomic bypass of the utilities fixed cost recovery. Specifically, fixed charges may need to increase or alternative rate designs may need to be considered."[106]

Noteworthy takeaways include:

- This report evaluates the impacts of DER in the South Carolina Electric and Gas, Duke Energy Carolinas, and Duke Energy Progress service territories.
- The study used three scenarios—low value, base value, and high value—"to capture the uncertainty associated with the future value of DER."[107] The low-value scenario is based on fewer components in the methodology (avoided energy and avoided losses). The base-value scenario "includes most components" (avoided energy, avoided losses, avoided ancillary services, avoided T&D capacity, and avoided criteria pollutants). The high-value scenario includes all of the components in the base-value scenario and approximates a value for a carbon cost placeholder.
- The report was presented to the Office of Regulatory Staff to fulfill its requirements for South Carolina's 2008 Distributed Energy Resource Program Act (Act 236).

Vermont

Vermont Public Service Department (PSD). 2014. *Evaluation of Net Metering in Vermont Conducted Pursuant to Act 99 of 2014.* Available at http://publicservice.vermont.gov/sites/dps/files/documents/Renewable_Energy/Net_Metering/Act%2099%20NM%20Study%20FINAL.pdf.

The goal of this report is to address a legislative request directing the Public Service Department to "complete an evaluation of net metering in Vermont." It provides background describing changes to net metering contained in Act 99 of 2014, and the current status and pace of net metering deployment in Vermont. It includes an updated analysis of the existence and magnitude of any cross subsidy created by the current net metering program pursuant to Act 125 of 2012. It also provides guiding principles for net metering program design based on a review of recent literature.

The "analysis of the existence and degree of potential cross-subsidy" was the primary focus in this meta-analysis. It concludes that "the aggregate net cost over 20 years to non-participating ratepayers due to net metering under the current policy framework is close to zero, and there may be a net benefit."

[105] Patel, et al., 2015, p. ii.
[106] Ibid.
[107] Ibid., p. 12.

Noteworthy takeaways include:

- Based on an analysis of the differences among utilities, which found that winter-peaking utilities will incur a larger share of costs, Vermont PSD recommends that the Board consider whether changes to the current program structure to allow flexibility for the program to vary by utility would better serve the State.[108]
- The report presented the results for six types of systems:
  - 4-kW fixed solar PV system, net metered by a single residence
  - 4-kW two-axis tracking solar PV system, net metered by a single residence
  - 4-kW wind generator, net metered by a single residence
  - 100-kW fixed solar PV system, net metered by a group
  - 100-kW two-axis tracking solar PV system, net metered by a group
  - 100-kW wind generator, net metered by a group
- The report provides results from the perspective of the ratepayer and a statewide/societal perspective. The ratepayer perspective uses a higher discount rate (7.44 percent) and includes a renewable energy credit (REC) value. The statewide/societal calculation uses a lower discount rate (4.95 percent), includes avoided externalized greenhouse gas costs, and does not include a REC value.[109]

VOS/NEM Successor

District of Columbia

Whited, M.; A. Horowitz; T. Vitolo; W. Ong; and T. Woolf. 2017. *Distributed Solar in the District of Columbia: Policy Options, Potential, Value of Solar, and Cost-Shifting.* Cambridge, MA: Synapse Energy Economics, Inc. Available at http://www.synapse-energy.com/sites/default/files/Distributed-Solar-in-DC-16-041.pdf.

This report provides both a VOS study framework (Part III) and a cost-shifting analysis (Part IV). The goal of the VOS study framework is "to determine the value of solar to the utility system and all electric customers in the District," using a "cost-benefit analysis in which all relevant costs and benefits are quantified and analyzed."[110] The goal of the cost-shifting analysis is to conduct a long-term rate impact analysis to understand the effects of cost-shifting from distributed solar customers to non-solar customers, which result in higher bills for non-solar customers.[111] It is "related to the value of solar conducted in Part III, but is a separate analysis that provides an entirely different perspective on customer impacts stemming from distributed solar."

The report concludes that "the utility system total value of solar for 2017–2040, when levelized with a 3 percent discount rate, is $132.66/MWh (2015$)." The societal total VOS for the same time period and

[108] Vermont Public Service Department (PSD). 2014. *Evaluation of Net Metering in Vermont Conducted Pursuant to Act 99 of 2014*. p. 28. Available at http://publicservice.vermont.gov/sites/dps/files/documents/Renewable_Energy/Net_Metering/Act%2099%20NM%20Study%20FINAL.pdf.
[109] Ibid., p. 16.
[110] Whited, et al., 2017, p. 115.
[111] Ibid., p. 157.

discount rate is $194.40/MWh.[112] The cost-shifting analysis concludes in the base-case scenario that "the typical residential non-solar customer in the District would experience an additional cost of $0.28 per year on average due to distributed solar." In all cases examined, the study finds that "cost-shifting remains relatively modest at less than $1.00 annual impact per residential customer."113

Noteworthy takeaways include:

- Eighteen value categories of potential costs and benefits associated with solar PV are considered. Sixteen were categorized as "utility system" impacts, meaning that the cost or benefit affects all customers in the utility system. Two categories (outage frequency duration and breadth, and social cost of carbon) were deemed "societal" in that they also impact people outside of the District.[114]
- The results are "highly dependent on future gas prices." The avoided energy category, which includes losses and costs associated with risk, represents about half of the utility VOS (and more than a third of the societal value).[115]
- The societal VOS is "quite dependent on the social cost of carbon," which represents a quarter of total societal value.[116]
- The report recommends a continuous update of the VOS model, acknowledging that as solar penetration increases above 10 percent of peak load, so does the likelihood that integration costs will increase.

Georgia

Southern Company. 2017. *A Framework for Determining the Costs and Benefits of Renewable Resources in Georgia.* Revised May 12, 2017. Available at http://www.psc.state.ga.us/factsv2/Document.aspx?documentNumber=167588.

This report provides a framework for determining the costs and benefits of renewable resources on the Southern Company electric system, known as the Renewable Cost Benefit (RCB) Framework. The goal of the report is to describe the RCB Framework and how it will be used, specifically related to the Georgia Power Company. The report considers 23 cost-benefit components for potential inclusion in the RCB Framework, defines and discusses each component, and makes a recommendation on whether the component should be included as a cost or a benefit. The framework provides a methodology to calculate some of the components.

The report finds 18 "in-scope renewable cost benefit components."[117]

Noteworthy takeaways include:

[112] Ibid., p. 10.
[113] Ibid., p. 14.
[114] Ibid., p. 10.
[115] Ibid., p. 12.
[116] Ibid.
[117] Ibid.

- The document recognizes five different categories of solar to differentiate the type being evaluated (i.e., utility-scale transmission, utility-scale distribution, distributed greenfield, distributed metered, and distributed behind-the-meter).[118]
- The framework finds five cost categories: distribution operations costs, ancillary services – reactive supply and voltage control, ancillary services – regulation, support capacity (flexible reserves), and bottom-out costs. A sixth category, generation remix, may be either a benefit or a cost.[119]
- The avoided energy cost category includes a number of components and represents the "energy-related costs that are avoided on the Southern Company electric system in any given hour (including components associated with marginal replacement fuel costs, variable operations and maintenance, fuel handling, compliance-related environmental costs, intra-day commitment costs, and transmission losses)."[120]
- The Framework does not include societal costs or other externalities.[121]

Hawaii

Norris, B. 2015(b). *Valuation of Solar + Storage in Hawaii: Methodology.* Prepared for the Interstate Renewable Energy Council (IREC) by Clean Power Research. Available at http://www.irecusa.org/wp-content/uploads/2015/06/IREC-Valuation-of-Solar-Storage-in-HI_Methodology_2015.pdf.

The goal of this report is to provide a preliminary "methodology that could be used to value solar energy coupled with battery storage in Hawaii."[122] The methodology is "intended to estimate the value (i.e., the net benefits minus costs, which accrue to the utility and its customers from grid connected, behind-the-meter distributed hybrid solar/storage resources." The report "proposes a strawman of benefit categories" and an overview of the computation of those categories.[123]

The report concludes that the methodology "advances the prior art developed for solar-only valuation studies," and if certain new elements related to hybrid resources are incorporated, "a state-of-the-art evaluation could be performed that would determine the benefit provided by solar energy dispatched after sundown to meet Hawaii's evening peak."[124]

Noteworthy takeaways include:

- The study draws extensively on methods used to value solar-only resources, but adds requirements to incorporate storage.
- An estimate of the benefits of distributed solar alone (including energy benefit and other benefits) is not included. However, the study suggests that readers could "suppose the benefit

[118] Southern Company, 2017, p. 3.
[119] Ibid.
[120] Ibid., p. 7.
[121] Ibid., p. 30.
[122] Norris, 2015(b), p. 1.
[123] Ibid., p. 10.
[124] Ibid., p. 21.

of solar alone is $0.20 per kWh." Then the analysis suggests that "net generation coming from the hybrid system would have a value of $0.20 + $0.103 = $0.303 per kWh."[125]

- The study suggests a more comprehensive analysis, "including the use of actual utility system load and cost data, a model of hourly dispatch, and other factors rather than the simplified assumptions," is required. The study serves as an example to give a rough approximation.[126]
- Frequency regulation is included as a benefit and identified as a value component that "has not been included in solar-only studies" but indicates that "storage has the ability to charge and discharge in response to signals from the grid operator in order to help regulate frequency."[127]
- The Avoided Distribution Capacity Cost category "may be problematic for Hawaii because HECO [Hawaiian Electric Company] is facing the possibility of cost increases in order to support solar in the distribution system."[128]

Maine

Norris, B.; P. Gruenhagen; R. Grace; P. Yuen; R. Perez; and K. Rabago. 2015. *Maine Distributed Solar Valuation Study.* Prepared for the Maine Public Utilities Commission by Clean Power Research, Sustainable Energy Advantage, LLC, and Pace Law School Energy and Climate Center. Available at http://www.maine.gov/mpuc/electricity/elect_generation/documents/MainePUCVOS-FullRevisedReport_4_15_15.pdf.

This goal of this report is to provide a methodology to value distributed solar for three utility territories in Maine: Central Maine Power, Emera Maine's Bangor Hydro District, and Maine Public District. The report concludes the overall value of distributed PV is $0.337/kWh.[129]

Noteworthy takeaways include:

- The distributed PV value is calculated for a set of benefit-cost categories for Central Maine Power and levelized over 25 years. Levelized results for the other two utility service territories are not shown.
- The results indicate that the levelized value of avoided market costs (including energy supply, transmission delivery, and distribution delivery) is lower than the levelized value of societal benefits (net social cost of carbon, SOx and NOx, market price response, and avoided fuel price uncertainty).
- Avoided energy costs, market price response, and net social cost of SOx deliver the largest values.
- Market price response and avoided fuel price uncertainty are included as societal benefits.
- This study includes placeholders for three value components:
  - Avoided natural gas pipeline costs, not included but left as a future placeholder if the cost of building future pipeline capacity is built into electricity prices

[125] Ibid., p. 3.
[126] Ibid.
[127] Ibid., p. 16. The inclusion of frequency regulation in this study is represented in the meta-analysis within the broader category of "ancillary services." However, it is noteworthy that the value was only included as a value component because of the storage element.
[128] Ibid., p. 12.
[129] Norris, et al., 2015. See summary table on p. 56.

- Avoided distribution capacity cost, not included but left as a future placeholder if the peak distribution loads begin to grow (requiring new capacity)
- Avoided costs of voltage regulation, not included but left as a future placeholder if new interconnection standards come into existence, allowing inverters to control voltage and provide voltage ride-through to support the grid

Minnesota

Norris, B.; M. Putnam; and T. Hoff. 2014. *Minnesota Value of Solar: Methodology.* Prepared for the Minnesota Department of Commerce, Division of Energy Resources by Clean Power Research. Available at https://www.cleanpower.com/wp-content/uploads/MN-VOS-Methodology-2014-01-30-FINAL.pdf.

This report provides the methodology to be used by Minnesota utilities adopting a VOS tariff as an alternative to net metering. The goal of the VOS tariff is "to quantify the value of distributed PV electricity." The report provides the methodology and details each step of the calculation.

The report concludes that the methodology can be used to develop a credit for solar customers. An example calculation shows a value of $0.135/kWh.

Noteworthy takeaways include:

- This study was commissioned in response to 2013 legislation and provides an optional alternative compensation mechanism for utilities to adopt customer-owned distributed PV in place of current NEM.
- Some of the value components correspond to minimum statutory requirements, including "the value of energy and its delivery, generation capacity, transmission capacity, transmission and distribution line losses, and environmental value."[130]
- Any "non-required components" were selected only if they were based on known and measurable evidence of the cost to the utility.[131]
- The tariff is updated annually for enrolling customers based on new PV penetration data.
- The avoided fuel cost value "implicitly includes both the avoided cost of fuel, as well as the avoided cost of price volatility risk that is otherwise passed from the utility to customers through fuel price adjustments."[132]
- In the example calculation, avoided fuel cost contributes to approximately 50 percent of the value.[133]
- Avoided voltage control cost and solar integration cost components are included as placeholders and are "reserved for future updates to the methodology." Solar integration costs are "expected to be small, but possibly measurable."[134]
- Credit for systems installed at "high value locations (identified in the legislation as an option)" is included as optional and is addressed in the "Distribution Capacity Cost" section. This is the value component "most affected by location."[135]

[130] Norris, et al., 2014, p. 3.
[131] Ibid.
[132] Ibid.
[133] Ibid., p. 49.
[134] Ibid., pp. 40, 3.
[135] Ibid., p. 3.

Oregon

Norris, B. 2015(a). *PGE Distributed Solar Valuation Methodology.* Prepared for Portland General Electric by Clean Power Research. Available at https://www.portlandgeneral.com/-/media/public/our-company/energy-strategy/documents/2015-08-13-distributed-solar-valuation.pdf?la=en.

The goal of this report is to provide "a methodology to calculate the avoided costs that result from distributed solar production delivered to the Portland General Electric (PGE) distribution system." The resulting methodology is "designed primarily for determining the benefits and costs of the gross energy produced by a PV system prior to netting with local load," and methods for calculating export energy are not included. These considerations should be taken into account when applying this methodology in valuing energy provided by NEM systems.[136]

The report concludes with a methodology that gives a levelized value of distributed solar denominated in dollars per kWh, based on "several distinct value components, each calculated using separate procedures."

Noteworthy takeaways include:

- Avoided energy includes three components: avoided fuel costs, avoided variable O&M cost, and avoided fixed O&M cost.
- For solar integration costs, Clean Power Research recommends that PGE should either estimate a dollar amount per MWh cost using best judgment from the available studies performed elsewhere, develop its own integration cost methodology, or assume that the cost is negligible.[137]
- Clean Power Research does not recommend to PGE whether any of the societal benefits should be included or excluded from a benefit-cost study.[138]
- The treatment of avoided fuel price uncertainty would be different, depending upon metering arrangements. If solar generation is used to serve loads behind-the-meter, then this benefit accrues to the solar customer by avoiding energy purchased from the utility. If the energy is delivered to the grid directly for use by PGE in serving its customers, then the benefit accrues to all customers.[139]
- The study analysis period is 20 years.[140]
- The methodology is concerned primarily with the benefits and costs for distributed solar generation, but also can be modified for use with utility-scale resources (connected to transmission) by eliminating avoided transmission and distribution costs, and the loss savings factor.
- The methodology can be used for other generation technologies other than solar, but it does not include dispatch strategies or other methods to produce an assumed generation profile. (A profile is needed as an input to the methodology).

[136] Norris, 2015(a), p. 6.
[137] Ibid., p. 25.
[138] Ibid., p. 36.
[139] Ibid., p. 34.
[140] Ibid., p. 9.

Utah

Norris, B. 2014. *Value of Solar in Utah.* Clean Power Research. Available at https://pscdocs.utah.gov/electric/13docs/13035184/255147ExAWrightTest5-22-2014.pdf.

The goal of this report is to estimate the value of solar in Utah for the territory served by Rocky Mountain Power. The results conclude that the total levelized VOS with all components included is $0.116/kWh, assuming a 25-year system lifetime.

- The value is based on avoided utility costs from the electricity produced by distributed PV.
- The VOS is the sum of six value categories: fuel, plant O&M, generation capacity, T&D capacity, avoided environmental costs (compliance), and fuel price guarantee value.
- The value does not include societal benefits "because they do not represent savings to the utility."
- The value represents the "long term contract rate at which a utility would be economically indifferent, based on the assumptions of this study. In other words, if a utility were to credit customers with a fixed amount of $0.116 per kWh produced by distributed PV over 25 years, the amount paid would offset the savings to the utility in generating and delivering the energy to the customer."[141]
- Utah Clean Energy and Rocky Mountain Power provided economic and technical assumptions and data.
- The analysis is performed in separate steps. First, the economic value is calculated based on perfect load match and no losses. The result is then modified using "Load Match" factors (based on ELCC) to reflect the match between PV production profiles and utility loads. Finally, a "Loss Savings" factor is applied to reflect the distributed nature of the resource.

DER Value Frameworks

California

California Public Utilities Commission (CPUC). 2016(a). *Assigned Commissioner's Ruling (1) Refining Integration Capacity and Locational Benefit Analysis Methodologies and Requirements; and (2) Authorizing Demonstration Projects A and B.* Rulemaking 14-08-013. Order Instituting Rulemaking Regarding Policies, Procedures and Rules for Development of Distribution Resources Plans Pursuant to Public Utilities Code Section 769. Available at http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M161/K474/161474143.PDF.

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California Public Utilities Commission (CPUC). 2017. *Locational Net Benefit Analysis Working Group Final Report.* Rulemaking 14-08-013. Order Instituting Rulemaking Regarding Policies and Rules for Development of Distribution Resources Plans Pursuant to Public Utilities Code 769, and Related Matters.

[141] Norris, 2014, p. 12.

March 8. Available at http://drpwg.org/wp-content/uploads/2016/07/R1408013-et-al-SCE-LNBA-Working-Group-Final-Report.pdf.

These documents detail the most recent and significant decisions related to development and use of the Locational Net Benefit Analysis (LNBA) methodology to assess the costs and benefits of distributed solar in California. All three were reviewed for this meta-analysis. The first document provides the final report of the LNBA Working Group, a group established by CPUC with a goal of developing a methodology for investor-owned utilities to use to value DERs. The second document provides the Assigned Commissioner's Ruling, which refined and authorized the use of the LNBA methodology by utilities for demonstration projects. The third document reflects CPUC's decision to adopt a NEM successor tariff.[142]

Noteworthy takeaways include:

- In May 2016, a few months after the NEM successor tariff was adopted, CPUC approved use of the LNBA methodology in the utility's Distribution Resource Planning (DRP) Demonstration B projects.
- Some of the LNBA value categories already existed in the Distributed Energy Resources Avoided Cost Calculator (DERAC) used to calculate the cost-effectiveness of utility energy efficiency programs. CPUC adjusted DERAC and updated certain value categories, such as energy and capacity, with more location-specific inputs via locational marginal price.
- Policymakers continue to work toward approving a uniform LNBA tool. CPUC is expected to review the NEM successor tariff in 2019 and explore compensation structures other than NEM.
- In their final report, the LNBA Working Group requested clarification from CPUC on "how 'integration costs' should be captured in the tool."[143]

New York

New York Department of Public Service (NY DPS). 2016(a). *Order Establishing the Benefit Cost Analysis Framework. Case 14-M-0101 – Proceeding on Motion of the Commission in Regard to Reforming the Energy Vision.* January 21. Available at http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7bF8C835E1-EDB5-47FF-BD78-73EB5B3B177A%7d.

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[142] The NEM successor tariff (NEM 2.0) decision was adopted in January 2016 and established utility-specific interconnection fees for customer-sited DG, modified non-bypassable charges and rules related to system size, and changed NEM customers over to time-of-use rates.
[143] California Public Utilities Commission (CPUC), 2017, p. 18.

These documents provide the most recent decisions within the New York Reforming the Energy Vision (REV) proceeding related to development and use of a benefit-cost analysis (BCA) framework for utilities to evaluate DER alternatives. Both were reviewed for this meta-analysis.

The first document establishes the BCA Framework that guided utilities in developing their own, individual BCA Handbooks. The goal of the BCA Framework is to provide consistent statewide methodologies for calculating the benefits and costs of DER investments.

The second document provides the DPS staff's recommendations to establish the Phase One Value of DER (VDER) methodology, which transitions away from the traditional NEM model. It provides the basis for a "Value Stack" tariff, under which compensation is calculated using the readily quantifiable DER values from the BCA Framework.

Noteworthy takeaways include:

- The VDER methodology uses a more limited set of value categories than the BCA Framework. Five categories make up the Value Stack: energy, capacity, environmental, demand reduction, and locational system relief value.
- Staff recommendations identify some value categories that may be added in a later phase of the effort, including other distribution system values not reflected in the demand reduction value, reduced SO_2 and NOx emissions, non-energy benefits, environmental justice impacts, and wholesale price suppression.
- Subsequent versions of utility BCA Handbooks are expected to have greater locational and temporal granularity.

Appendix B: List of Possible Studies to Include

This appendix contains the full list of literature considered for inclusion in the meta-analysis. The list was compiled in November 2017. A check mark in the last column indicates whether the document was included in the meta-analysis. Note that more than one document was reviewed in New York and California as a reflection of ongoing and interrelated regulatory activities.

Title	Year	Sponsor	Prepared by	Included
The Benefits and Costs of Net Metering Solar Distribution Generation on the System of Entergy Arkansas	2017	Sierra Club	Crossborder Energy	√
Value of Solar Study: Distributed Solar in the District of Columbia	2017	Office of the People's Counsel	Synapse Energy Economics	√
A Framework for Determining the Costs and Benefits of Renewable Resources in Georgia	2017	Georgia Power	Georgia Power	√
Solar Energy in Michigan: The Economic Impact of Distributed Generation on Non-Solar Customers	2017	Institute for Energy Innovation	Institute for Energy Innovation	
PUCO Order – Investigation to Determine the Resource Value of Solar	2017	Public Utility Commission of Oregon	Public Utility Commission of Oregon	
Locational Net Benefit Analysis Working Group Final Report, Rulemaking 14-08-013, Order Instituting Rulemaking Regarding Policies and Rules for Development of Distribution Resources Plans Pursuant to Public Utilities Code 769, and Related Matters, March 8	2017	California Public Utility Commission (CPUC)	Locational Net Benefit Analysis (LNBA) Working Group	√
Testimony – Value of Distributed Generation in Arizona	2016	The Alliance for Solar Choice	Crossborder Energy	
Decision Adopting Successor to Net Energy Metering Tariff, Rulemaking 14-07-002, Order Instituting Rulemaking to Develop a Successor to Existing Net Energy Metering Tariffs Pursuant to Public Utilities Code Section 2827.1, and to Address Other Issues Related to Net Energy Metering	2016	CPUC	CPUC	√
Assigned Commissioner's Ruling (1) Refining Integration Capacity and Locational Benefit Analysis Methodologies and Requirements; and (2) Authorizing Demonstration Projects A and B, Rulemaking 14-08-013, Order Instituting Rulemaking Regarding Policies, Procedures and Rules for Development of Distribution Resources Plans Pursuant to Public Utilities Code Section 769	2016	CPUC	CPUC	√
PV Valuation Methodology Recommendations for Regulated Utilities in Iowa	2016	Midwest Renewable Energy Association	Clean Power Research	

Title	Year	Sponsor	Prepared by	Included
PV Valuation Methodology Recommendations for Regulated Utilities in Michigan	2016	Midwest Renewable Energy Association	Clean Power Research	
Nevada Net Energy Metering Impacts Evaluation 2016 Update	2016	State of Nevada Public Utilities Commission	Energy and Environmental Economics (E3)	√
Staff Report and Recommendations in the Value of Distributed Energy Resources Proceeding; Proceeding on Motion of the Commission as to the Policies, Requirements and Conditions for Implementing a Community Net Metering Program, Case 15-E-0082, New York Department of Public Service	2016	NY Public Service Commission	NY Department of Public Service Staff	√
Order Establishing the Benefit Cost Analysis Framework, Case 14-M-0101 – Proceeding on Motion of the Commission in Regard to Reforming the Energy Vision, State of New York Public Service Commission	2016		NY Public Service Commission	√
PV Valuation Methodology Recommendations for Regulated Utilities in Wisconsin	2016	Midwest Renewable Energy Association	Clean Power Research	
Valuation of Solar + Storage in Hawaii: Methodology	2015	Interstate Renewable Energy Council	Clean Power Research	√
Estimating the Impact of Net Metering on LPSC Jurisdictional Ratepayers	2015	Louisiana Public Service Commission	Acadian Consulting Group	√
Value of Distributed Generation: Solar PV in Massachusetts	2015	Acadia Center	Acadia Center	
Maine Distributed Solar Valuation Study	2015	Maine Public Utility Commission	Clean Power Research	√
Net Metering in Missouri: The Benefits and the Costs	2015	Missouri Energy Initiative	Missouri Energy Initiative	
Shining Rewards: The Value of Rooftop Solar Power for Consumers and Society	2015	Frontier Group and Environment America Research & Policy Center	Frontier Group and Environment America Research & Policy Center	
Distributed Generation-Integrated Value (DG-IV): A Methodology to Value DG on the Grid	2015	Tennessee Valley Authority		
The Benefits and Costs of Net Energy Metering in New York	2015	E3		
PGE Distributed Solar Valuation Methodology	2015	Portland General Electric	Clean Power Research	√
South Carolina Act 236: Cost Shift and Cost of Service Analysis	2015	South Carolina Office of Regulatory Staff	E3	√

Title	Year	Sponsor	Prepared by	Included
Value of Distributed Generation: Solar PV in Vermont	2015	Acadia Center	Acadia Center	
Minnesota Value of Solar: Methodology	2014	Minnesota Department of Commerce	Clean Power Research	√
Net Metering in Mississippi	2014	Public Service Commission of Mississippi	Synapse Energy Economics	√
Value of Solar in Utah	2014	Utah Clean Energy	Clean Power Research	√
Evaluation of Net Metering in Vermont Conducted Pursuant to Act 99 of 2014	2014	Public Service Department (PSD)	PSD	√
2013 Updated Solar PV Value Report	2013	Arizona Public Service Company	SAIC	
The Benefits and Costs of Solar Distributed Generation for Arizona Public Service	2013		Crossborder Energy	
Introduction to the California Net Energy Metering Ratepayer Impacts Evaluation	2013	CPUC	E3	
Evaluating the Benefits and Costs of Net Energy Metering for Residential Customers in California	2013	Vote Solar Initiative	Crossborder Energy	
Costs and Benefits of Distributed Solar Generation on the Public Service Company of Colorado System	2013	Xcel Energy Services	Xcel Energy Services	
A Review of Solar PV Benefits & Costs Studies	2013	Rocky Mountain Institute		
The Benefits and Costs of Solar Generation for Electric Ratepayers in North Carolina	2013	North Carolina Sustainable Energy Association	Crossborder Energy	
2014 Value of Solar at Austin Energy	2013	Austin Energy	Clean Power Research	
The Value of Distributed Solar Electric Generation to San Antonio	2013	U.S. DOE SunShot Initiative	Clean Power Research and Solar San Antonio	
Changes in the Economic Value of Variable Generation at High Penetration Levels: A Pilot Case Study of California	2012	U.S. DOE Office of Energy Efficiency & Renewable Energy and Office of Electricity Delivery & Energy Reliability	Lawrence Berkeley National Laboratory	
Technical Potential for Local Distributed Photovoltaics in California, Preliminary Assessment	2012	CPUC	E3	

Title	Year	Sponsor	Prepared by	Included
The Value of Distributed Solar Electric Generation to New Jersey and Pennsylvania	2012	The Mid-Atlantic Solar Energy Industries Association and The Pennsylvania Solar Energy Industries Association	Clean Power Research	
The Potential Impact of Solar PV on Electricity Markets in Texas	2012	Solar Energy Industries Association and The Energy Foundation	The Brattle Group	
Designing Austin Energy's Solar Tariff Using a Distributed PV Calculator	2012	Austin Energy	Clean Power Research and Austin Energy	

Appendix C: Input Assumptions for Displaced Marginal Unit

State	Marginal Unit	Detailed Assumptions (Avoided Energy)	Page No. From Study
Arkansas	Gas-fired generation, uses MISO LMPs	"Solar DG on the EAI [Entergy Arkansas, Inc.] system avoids marginal generation, **principally gas-fired generation** in the MISO [Midcontinent] South market area. To estimate these avoided costs, we have used **recent MISO locational marginal prices (LMPs)** for the Arkansas Hub, weighted by a standard output profile for a solar array in Little Rock, and escalated these LMPs using the long-term forecast of natural gas prices from the Energy Information Administration's (EIA) *Annual Energy Outlook 2017* (AEO 2017)."	p. 9
California	Uses DERAC values; option to use LMP prices	In the approved LNBA [Locational Net Benefit Analysis] Methodology Requirements Matrix for Demonstration Project B, utilities are required to "**use DERAC values**," also known as the 2016 Distribution Energy Resource Avoided Calculator or 2016 Avoided Cost Model.[144] "For the secondary analysis, the IOUs [independently owned utilities] may also estimate the avoided cost of energy using **locational marginal prices (LMPs)** for a particular location, as per the method described in SCE's [Southern California Edison's] application."	p. 27, CPUC, 2016(a)
District of Columbia	Uses PJM LMPs	"To calculate the total avoided energy benefit across each year, we correlate each hour's generation in PVWatts to a system marginal energy cost, based on historical data for the PJM Interconnect for 2015. This study **uses 2015 locational marginal prices for the PEPCO zone of PJM** …" and "For future years, we assume these prices follow the trajectory of regional electricity generation system prices within EIA's *Annual Energy Outlook* (AEO) 2016, released in September 2016."	p. 128
Georgia	Uses hourly production cost model	"… Avoided Energy Cost used in the Framework reflects the projected fuel and technology expected to represent the marginal unit for dispatch in any given hour in which the renewable resource is expected to be producing electricity. It does not reflect any specific single fuel or any specific single technology." "Avoided energy cost projections are developed using the Production Cost model. The Production Cost model is a complete electric utility/regional pool analysis and accounting system that is designed for performing planning and operational studies. It is an **hourly production cost model** that has the fundamental goal of minimizing total production cost while providing detailed projections of fuel cost and pool accounting, including individual unit information."	p. 9; p. 49

[144] For more information on how DERAC calculates energy price forecast, see https://drpwg.org/wp-content/uploads/2017/11/LNBA-Item-4.i-Locational-Avoided-Energy-Revised-Proposal.docx.

State	Marginal Unit	Detailed Assumptions (Avoided Energy)	Page No. From Study
Hawaii	Oil-fired generation is predominant; futures for fuel oil would be used	"In the solar-only methodologies, natural gas has been assumed as the displaced fuel. In Hawaii, **oil-fired generation is predominant**, so adjustments would have to be made accordingly. **Futures for fuel oil would be used instead of natural gas**, and transportation to the island would be factored in."	p. 11
Louisiana	Uses natural gas combustion turbine as a proxy for the marginal unit	"Natural gas-fired generating resources have dominated new incremental generation over the past decade and continue to serve as the 'marginal' unit in most regional wholesale power markets given their relatively low capital costs and operating flexibility. Thus, an **advanced natural gas-fired combustion turbine**, with an assumed thermal efficiency of 9,750 British thermal units per kWh (Btu/kWh), serves **as an appropriate proxy for the marginal unit** setting energy prices in wholesale power markets over the next decade, and correspondingly, serves as an appropriate proxy for estimating avoided energy costs. A constant natural gas price of $3.50/MMBtu was used to estimate the fuel component of this avoided energy cost."	p. 112
Maine	Assumes natural gas displacement	"This methodology assumes that **PV displaces natural gas** during PV operating hours. During some hours of the year, other fuels (e.g., oil) may be the fuel on the margin. In these cases, natural gas displacement is a simplifying assumption that is not expected to materially impact the overall value."	p. 19
Minnesota	Assumes natural gas displacement	"This methodology assumes that **PV displaces natural gas** during PV operating hours. This is consistent with current and projected MISO market experience. During some hours of the year, other fuels (such as coal) may be the fuel on the margin. In these cases, natural gas displacement is a simplifying assumption that is not expected to materially impact the calculated VOS tariff. However, if future analysis indicates that the assumption is not warranted, then the methodology may be modified accordingly. For example, by changing the methodology to include displacement of coal production, avoided fuel costs may decrease and avoided environmental costs may increase."	p. 5
Mississippi	Assumes displacement of gas and oil peaking resources (combustion turbines)	"Marginal unit: Mississippi's 2013 generation capacity includes 508 MW of natural gas and petroleum oil-based combustion turbines (CTs). While these oil units do not contribute a significant portion of Mississippi's total energy generation, they do contribute to the State's peaking capabilities. On aggregate, these peaking resources operated 335 days in 2013—most frequently during daylight hours—and had a similar aggregate load shape to potential solar resources (see Figure 7). Our benefit and cost analysis follows the **assumption that gas and oil CT peaking resources will be on the margin** when solar resources are available and, therefore, that solar net-metered facilities will displace the use of these peaking resources. At the level of solar penetration explored in our analysis (0.5 percent), it is unlikely that solar resources will displace base load units."	p. 21

State	Marginal Unit	Detailed Assumptions (Avoided Energy)	Page No. From Study
Nevada	Uses hourly marginal wholesale prices, based on production model	"Estimate of **hourly marginal wholesale value of energy**, excluding the regulatory price of carbon dioxide emissions. Source: **Production simulation runs** from NV Energy."	p. 32
New York	Uses LBMPs from the New York Independent System Operator (NYISO)	"To forecast avoided system energy costs, utilities shall use energy price forecasts for the wholesale energy market—**Location Based Marginal Prices (LBMPs)**—from the most recent final version of the NYISO's Congestion Assessment and Resource Integration Study (CARIS) economic planning process Base Case."	p. 5, Appendix C, NY PSC, 2016
Oregon	Assumes natural gas displacement	"This methodology calculates energy value as the avoided cost of fuel and O&M, assuming that **PV displaces natural gas** during PV operating hours. During some hours of the year, other fuels may be the fuel on the margin. In these cases, natural gas displacement is a simplifying assumption."	p. 9
South Carolina	Uses production simulation model based on utility's most recent IRP	"Component is the marginal value of energy **derived from production simulation runs** per the Utility's most recent Integrated Resource Planning (IRP) study and/or Public Utility Regulatory Policy Act (PURPA) Avoided Cost formulation. Based on Utility-provided forecast and E3 analysis."	p. 10
Utah	Assumes displacement of natural gas combustion turbine	"Under this study, the value is defined as the cost of **natural gas fuel** that would otherwise have to be purchased **to operate a gas turbine (CCGT) plant** and meet electric loads and overcome T&D losses. The study presumes that the energy delivered by PV displaces energy at this plant for each hour of the study period with loss calculations being based on each hour."	p. 2
Vermont	Uses hourly marginal wholesale prices, based on ISO-NE	"The Department calculated a hypothetical 2013–14 avoided energy cost on an hourly basis by multiplying the production of real Vermont generators by the **hourly price set in the ISO-NE market**. This annual total value was then updated to 2015 and beyond by scaling the annual total price according to a market price forecast."	p. 11

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