Quantifying Distributed Solar Photovoltaics Costs and Benefits: Considerations and Decision Framework for Oklahoma

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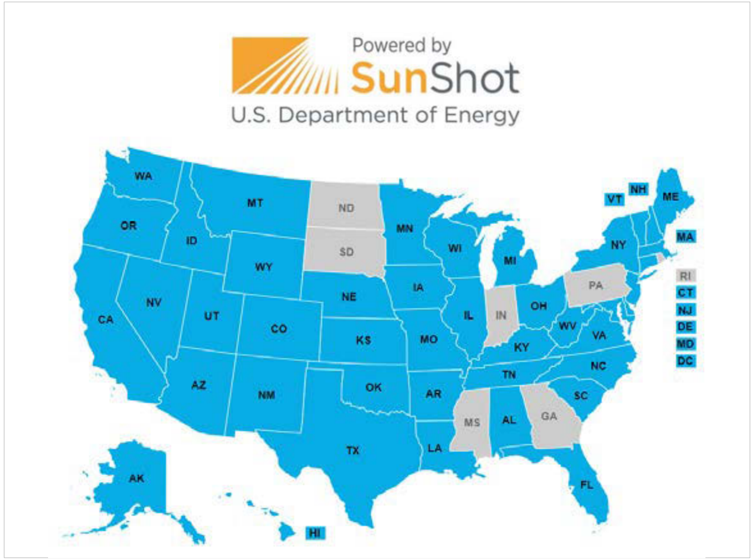
The Solar Technical Assistance Team (STAT) Network was a project of the United States Department of Energy (DOE) and was implemented by the National Renewable Energy Laboratory (NREL) from 2016 - 2018. The STAT Network provided credible, objective, and timely information to policymakers and regulators for the purpose of solar technology-, finance-, and policy-related decision support. This presentation was intended to be a starting point for additional research and consideration into the topics covered and does not constitute a comprehensive roadmap for solar deployment or specific advisory recommendations to the jurisdiction.

Solar Technical Assistance Team (STAT) Network

The Solar Technical Assistance Team (STAT) was a network of solar technology and implementation experts who provided timely, unbiased, credible, and objective solar data and analysis to state and local decision-makers.

The STAT program sunset in September 2018. A database of past projects is available online at https://www.nrel.gov/state-local-tribal/project-map/index.html.



2016-2018 STAT Network partners:

Background on Oklahoma STAT Request

The Oklahoma Office of the Secretary of Energy and Environment (OSEE) requested information and resources on distributed energy generation cost-benefit analyses, and a methodology and decision framework for estimating the costs and benefits of distributed energy resources in Oklahoma.

This presentation constitutes the second of a two-part deliverable, the first of which was a baseline study on approaches to distributed solar photovoltaic (DPV) cost-benefit frameworks and associated compensation mechanisms.

This second deliverable identifies the range of variables that could be used to develop a DPV cost-benefit methodology and decision matrix. It also includes additional detail regarding potential approaches for quantifying each variable. The following slides highlight publicly-available information about how other states have evaluated DPV costs and benefits.

Oklahoma STAT Request Methodology

- Through OSEE, the Oklahoma Distributed Generation (OK DG) Thought Group requested that NREL investigate the variety of DPV methodologies used in other states to estimate the costs and benefits of DPV.
- NREL gathered public, readily available information from other U.S. states on how they estimated the costs and benefits of DPV. Their inputs, assumptions and methodologies were captured in this document and a companion report.
- This PPT slide deck was reviewed by Nate Hausman from the Clean Energy States Alliance, and Megan Day, Elizabeth Doris, and Adam Warren from NREL.
- The inputs, assumptions, and methodologies used across the United States were then thoughtfully considered by the OK DG Thought Group. The OK DG Thought Group posed questions to the author and the slides were further refined to answer their questions.
- Preferences were expressed by OK stakeholders based on initial conversations with NREL and an in-person presentation by NREL, for the future direction of the OK analysis.
- This approach was an effective way for the OK DG Thought Group to consider the variables, inputs, assumptions and methodologies they wanted to include in an Oklahoma-specific analysis.

Oklahoma DG Thought Group Members

- Oklahoma Office of the Secretary of Energy and Environment
- Oklahoma Corporation Commission (Public Utility Division)
- Office of the Attorney General of Oklahoma
- Oklahoma Industrial Energy Consumers
- Oklahoma Sustainability Network
- Law Firms
    - Philips Murrah
    - Hall Estill
- Utilities
    - Grand River Dam Authority
    - Oklahoma Association of Electric Cooperatives
    - Oklahoma Municipal Power Authority
    - Oklahoma Gas and Electric
    - Public Service Co. of Oklahoma/ American Electric Power
    - Western Farmers Electric Cooperative

- Overarching DPV Cost-Benefit Considerations
- DPV Tariffs and DPV Studies
- DPV Energy Costs & Benefits
- DPV Generation Capacity Costs & Benefits
- DPV Transmission & Distribution Losses Costs & Benefits
- DPV Transmission Capacity Costs & Benefits
- DPV Distribution Capacity Costs & Benefits

Overarching DPV Cost-Benefit (C-B) Considerations

DPV Cost-Benefit Components and Considerations

The goal of this presentation is to clarify which factors have been, or can be, considered in a DPV cost-benefit framework, and what methodologies exist to address those variables. To help structure this section, we rely on the work of Denholm et al., 2014 and organize DPV cost-benefit components in the following categories:

- Overarching Considerations
- Energy
- Transmission & Distribution (T&D) Losses
- Generation Capacity
- Transmission Capacity
- Distribution Capacity
- Environmental
- Ancillary Services
- Other Services

The information is presented as a decision framework, stepping through a series of questions to consider in determining a DPV cost-benefit approach.

Source: Denholm et al., 2014

DPV Cost-Benefit Input Variables

Factors Considered in Determining VOS Value in Selected Jurisdictions

VOS Component	Austin (Tariff^)	Minnesota (Tariff^)	Oregon (Utility-specific Tariff^)	Maine	New Jersey and Pennsylvania	Utah	Washington, D.C.
Energy production*	✓	✓	✓	✓	✓	✓	✓
Generation capacity	✓	✓	✓	✓	✓	✓	✓
Transmission & distribution capacity deferrals	✓	✓	✓	Transmission included; distribution not included	✓	✓	✓
Transmission & distribution line losses	✓	✓	✓	✓	X	✓	✓
Environmental costs and benefits	✓	✓	Placeholder; can be developed in future	✓	✓	✓	✓
Natural gas (or other fuel) price hedge	✓	Implicitly included in avoided fuel costs methods	✓	Not included; placeholder**	✓	✓	✓
Disaster recovery (also called security/resiliency)	✓	X	X	X	✓	X	✓****
Reactive power control***	✓	X	Placeholder; can be developed in future	X	X	X	✓
Voltage control***	X	Placeholder; can be developed in future	Placeholder; can be developed in future	Not included; placeholder	X	X	✓
Solar integration costs	X	Placeholder; can be developed in future	✓	✓	✓	X	✓
Credit for local manufacturing & assembly	X	Considered, but not adopted	X	X	X	X	X
Market price reduction	X	Considered, but not adopted	✓	✓	✓	X	✓
High-value location credit for PV system	X	Optional for utility	X	X	X	X	X
Economic development value	X	X	X	X	✓	X	X

(✓ = Included, X = Not Included)

*Typically includes value of avoided energy (e.g., fuel) and other variable (e.g., operations and maintenance) costs. Often (not always), a combined cycle gas turbine plant is assumed. **Considered as avoided natural gas pipeline costs in Maine. ***Typically considered part of ancillary services ****Called "Outage Frequency and Duration Breadth" for Washington D.C. study. ^Austin, Minnesota, and Oregon have implemented VOS tariff policies; the remaining examples in Table 2 are VOS studies.

Sources: (Hoff et al. 2006) (Norris, Putnam, and Hoff 2014) (Norris et al. 2015) (Perez, Norris, and Hoff 2012) (Norris 2014) (Whitehead et al. 2017) (Public Utility Commission of Oregon 2017).

“Laundry List” of DPV Cost-Benefit Input Variables

1. Energy
   - Avoided fuel costs
   - Avoided generation losses
   - Avoided price uncertainty / hedge value
   - Market-price suppression
   - Avoided generation variable operations and maintenance (O&M)
2. Generation capacity
   - Avoided capital investment
   - Reserve capacity
   - Avoided plant fixed O&M
3. Transmission losses
4. Distribution losses
5. Transmission capacity
   - Avoided marginal cost of transmission and distribution
   - Avoided fixed O&M
6. Distribution capacity
   - Avoided fixed O&M
7. Ancillary services
8. Environmental
   - Avoided emissions
     - Net market/avoided compliance cost NO_x
     - Net market/avoided compliance cost SO_2
     - Net market/avoided compliance cost CO_2
   - Environmental compliance (renewable portfolio standards [RPS])
   - Avoided capital of emissions control
   - Avoided O&M of emissions control
   - Avoided land use
9. Value of customer choice
10. Value of portfolio diversification
11. Economic development
12. Locational value
13. Voltage regulation
14. Avoided water use costs
15. Avoided economic impact of power outages
16. Avoided natural gas pipeline costs
17. Solar integration costs
18. Program administration costs

Sources: (Hoff et al. 2006) (Norris, Putnam, and Hoff 2014) (Norris et al. 2015) (Perez, Norris, and Hoff 2012) (Norris 2014) (Whitehead et al. 2017) (Public Utility Commission of Oregon 2017).

Adjusting the Solar Costs and Benefits to Get the Math Right

Adjust the Solar Costs and Benefits

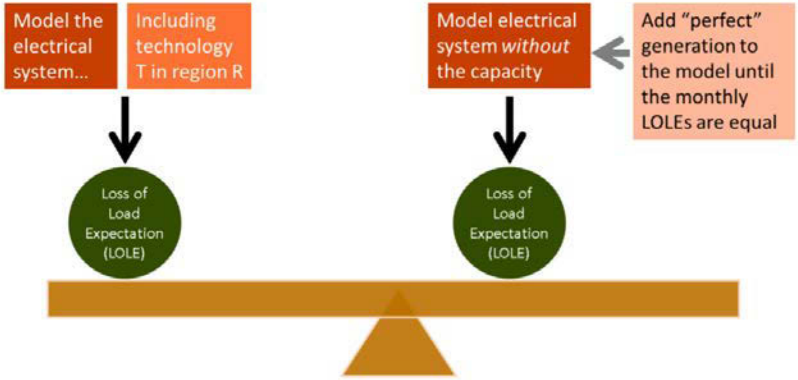
(Source: Denholm et al., 2014):

a) Derate for the Load Match Factor (i.e., how well does the resource match with the load – either hourly or during the peak?)
   i. **Transmission** – Hourly Effective Load Carrying Capacity (see figure)
   ii. **Distribution** – Peak Load Reduction (i.e., coincidence with peak)

b) Increase to account for Line Losses
   i. **Transmission*** – generally 3%-6%
   ii. **Distribution**** – generally 5%-8%

* Step-up transformer and transmission line
** Step-down transformer and distribution network
Line Loss Source: Schneider Electric (2013)

Effective Load Carrying Capacity



Source: CPUC 2014

Sources: Denholm et al., 2014, Schneider Electric 2013, CPUC 2014

Initial Questions For DG Thought Group Consideration

- What is your timeline for solar cost-benefit analysis?
- What depth of evaluation will meet your goals? Your resources?
- Which terms do you want to:
  - Include, with a cost or benefit (or both)?
  - Include for calculation later?
  - Exclude/ignore entirely?
- Who do costs/benefits accrue to? Answer influences how each individual variable can be monetized.

DPV Cost-Benefit Examples: Tariffs and Studies

Solar Cost-Benefit Examples

- DPV cost-benefit valuation input variables and their associated economic costs and benefits vary across jurisdictions.
- The following slides provide examples of the input variables considered in different DPV cost-benefit tariffs and studies, and are included in our references, Slide 81. Public reports identified in our research were included to show the breadth and depth of the analyses.
    - The first set of examples are DPV Tariffs that have been enacted. These tariffs are used to estimate the costs, benefits, and value of DPV.
    - The second set of examples are DPV studies that have been analyzed, but have not been used to assess DPV costs and benefits in those jurisdictions.
- There may be other reports that are public that exist; we cannot guarantee that these examples include all public examples.

DPV Cost-Benefit Examples: Tariffs

Solar Cost-Benefit Tariff Example: Austin 2006

- The different variables included are in the rows
- The different DPV system configurations are shown in the columns; this shows that system design matters in terms of costs and benefits provided to Austin
- Different locations will have different results

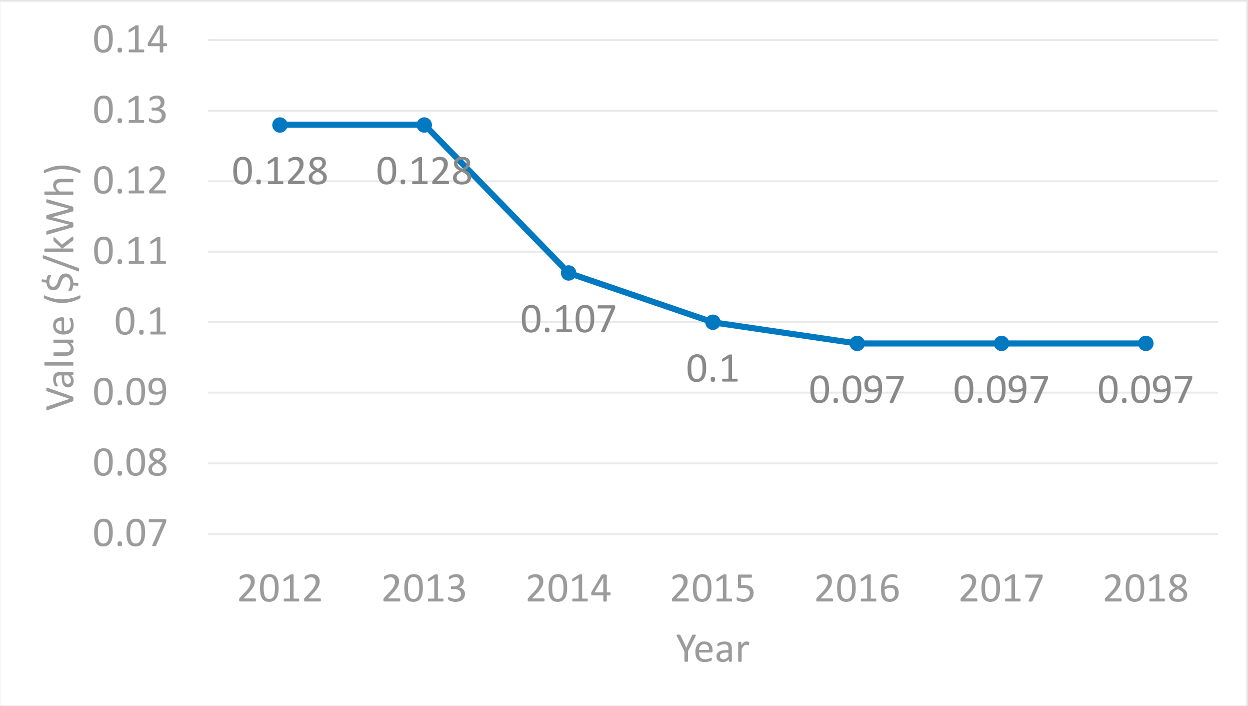
Levelized Value ($ per kWh)

	Horizontal	South 30°	SW 30°	West 30°	West 45°	1-Axis	1-Axis 30°
Energy	$0.071	$0.070	$0.071	$0.072	$0.072	$0.070	$0.070
Gen. Capacity	$0.013	$0.011	$0.014	$0.016	$0.018	$0.013	$0.012
Environment	$0.020	$0.020	$0.020	$0.020	$0.020	$0.020	$0.020
T&D Deferal	$0.001	$0.001	$0.001	$0.002	$0.002	$0.001	$0.001
Loss Savings	$0.006	$0.006	$0.006	$0.006	$0.007	$0.006	$0.006
Disaster Recovery	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
Total	***$0.111***	***$0.108***	***$0.113***	***$0.117***	***$0.118***	***$0.110***	***$0.109***

Source: Hoff et al. 2006 (CPR)

Solar Cost-Benefit Tariff Example: Austin 2012-2018

Residential Value of Solar Tariff Rate Schedule



Year	VOS Current Method (Cents/kWh)
2012 (Oct-Dec)	12.8
2013	12.8
2014	10.7
2015	10.0
2016	9.7
2017	9.7
2018 Est.	8.5
5-yr Rolling Avg.	**9.7**

Sources: Austin Energy 2017, NREL

Solar Cost-Benefit Tariff Example: Austin 2018

2018 Residential Value of Solar

	Economic Value ($/kWh)	Load Match (No Losses) (%)	Distributed Loss Savings (%)	2018 Distributed PV Value ($/kWh)
Energy Value	$0.028		4%	$0.029
Plant O&M Value	$0.005	100%	6%	$0.005
Capacity Value	$0.030	50%	6%	$0.016
Transmission Value	$0.038	50%	6%	$0.020
Environmental Value	$0.015		0%	$0.015
			Value of Solar (VOS)	**$0.085**

2018 Commercial Value of Solar

	Economic Value ($/kWh)	Load Match (No Losses) (%)	Distributed Loss Savings (%)	2018 Distributed PV Value ($/kWh)
Energy Value	$0.031		4%	$0.032
Transmission Value	$0.038	50%	6%	$0.020
Environmental Value	$0.015		0%	$0.015
			Value of Solar (VOS)	**$0.067**

Source: Austin Energy 2017

Solar Cost-Benefit Tariff Example: Minnesota

Figure 3. (EXAMPLE) VOS Levelized Calculation Chart (Required).

25 Year Levelized Value	Economic Value ($/kWh)	Load Match (No Losses) (%)	Distributed Loss Savings (%)	Distributed PV Value ($/kWh)
Avoided Fuel Cost	$0.056		8%	$0.061
Avoided Plant O&M - Fixed	$0.003	40%	9%	$0.001
Avoided Plant O&M - Variable	$0.001		8%	$0.001
Avoided Gen Capacity Cost	$0.048	40%	9%	$0.021
Avoided Reserve Capacity Cost	$0.007	40%	9%	$0.003
Avoided Trans. Capacity Cost	$0.018	40%	9%	$0.008
Avoided Dist. Capacity Cost	$0.008	30%	5%	$0.003
Avoided Environmental Cost	$0.027		8%	$0.029
Avoided Voltage Control Cost				
Solar Integration Cost				
				$0.127

Source: Norris, Putnam and Hoff 2014 (CPR)

Solar Cost-Benefit Tariff Example: Oregon – Idaho Power

Element	**RVOS as Filed in Reply Testimony** Standard Size Project ($/MWh Real Levelized)	**Revised RVOS** Standard Size Project ($/MWh Real Levelized)	**Revised RVOS Reduced Administration Cost** Standard Size Project ($/MWh Real Levelized)
1. Energy	25.30	30.00	30.00
2. Generation Capacity	13.50	13.50	13.50
3. T&D Capacity	0.54	0.54	0.54
4. Line Losses	2.05	2.43	2.43
5. Administration	(47.77)	(47.77)	(18.20)
6. Integration	(0.56)	(0.56)	(0.56)
7. Market Price Response	0.00	0.00	0.00
8. Hedge Value	1.26	1.50	1.50
9. Environmental Compliance	0.00	0.00	0.00
10. RPS Compliance	0.00	0.00	0.00
11. Grid Services	0.00	0.00	0.00
Net Levelized RVOS	**(5.68)**	**(0.36)**	**29.21**

Source: Idaho Power (2018)

Solar Cost-Benefit Tariff Example: Oregon – Portland General Electric

Figure 2 – RVOS values by element

RVOS Element	2017 $/MWh, real levelized value
Energy	24.98
Generation Capacity	7.30
T&D Capacity	8.08
Line Loss	1.48
Administration	(5.58)
Market Price Response	1.81
Integration	(0.83)
Hedge Value	1.25
Environmental Compliance	11.41
RPS Compliance	0
Grid Services	0
RVOS Total	**49.88**

*totals may not tie due to rounding

Source: Portland General Electric (2017)

Solar Cost-Benefit Tariff Example: Oregon – PacifiCorp

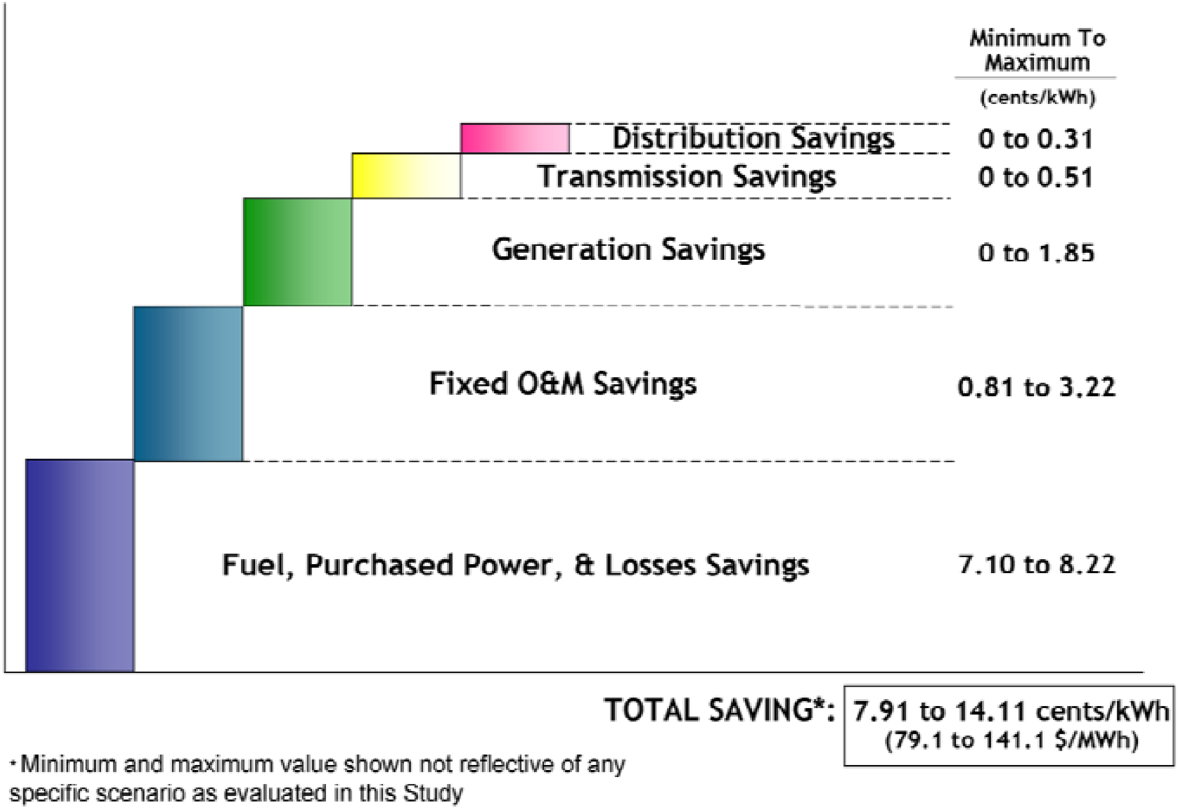
Table 1: RVOS
$/megawatt-hour (MWh) Nominal Levelized (2018-2042)

Element	Standard: 2015 IRP	PDDRR: 2017 IRP	Utility-scale starting 2030
Avoided energy cost	30.58	33.63	
Avoided generation capacity cost	12.20	17.96	
Avoided T&D capacity	0.08	0.08	
Avoided line losses	1.96	2.14	
Administration	(2.88)	(2.88)	
Integration	(0.82)	(0.82)	
Market price response	0.15	0.00	
Avoided hedge value	1.54	1.68	
Avoided environmental compliance	0.11	0.22	
Avoided renewable portfolio standard (RPS) compliance	0.00	0.00	
Grid services	0.00	0.00	
Total RVOS (Nov. 2017)	**42.92**	**52.00**	
Updates and adjustments	+2.97	+2.24	
Total RVOS (April 2018)	**45.89**	**54.23**	**37.71**

Source: PacifiCorp (2018)

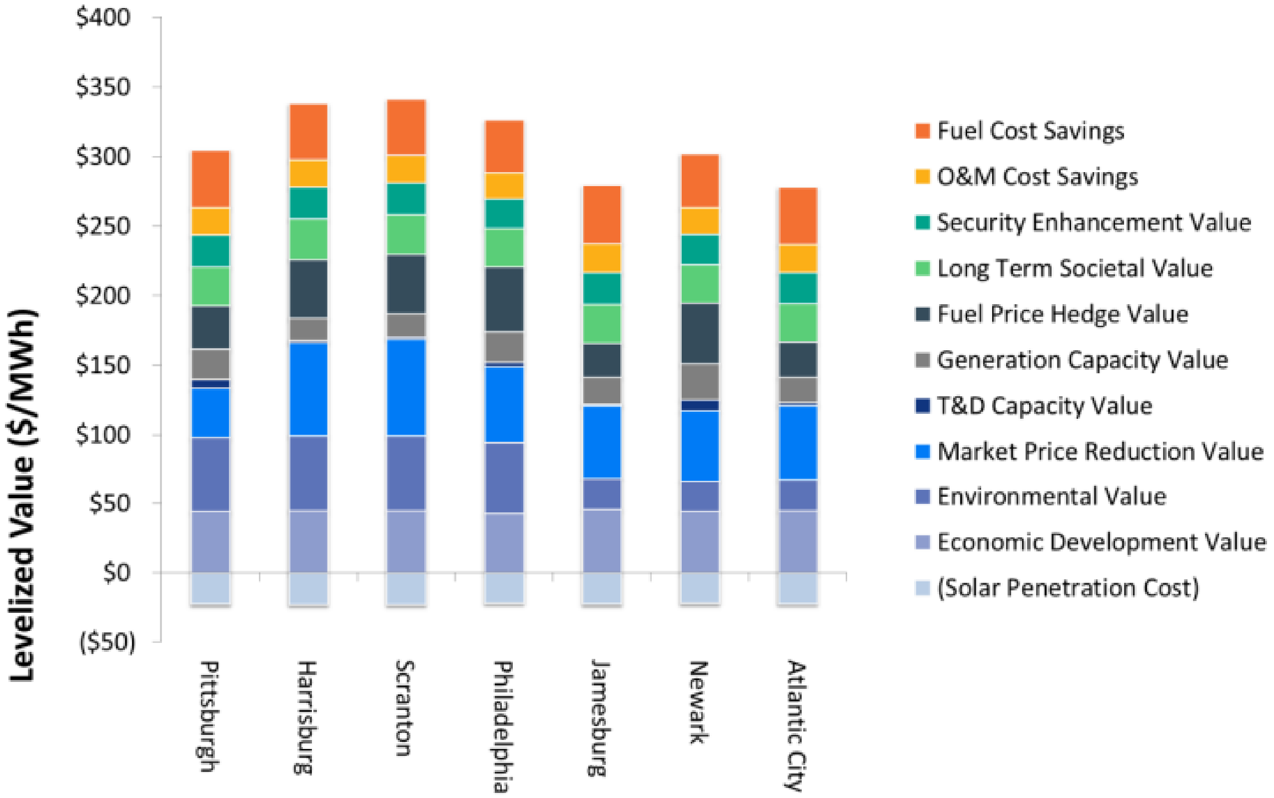
DPV Cost-Benefit Examples: Studies

Solar Cost-Benefit Study Example: New Jersey and Pennsylvania



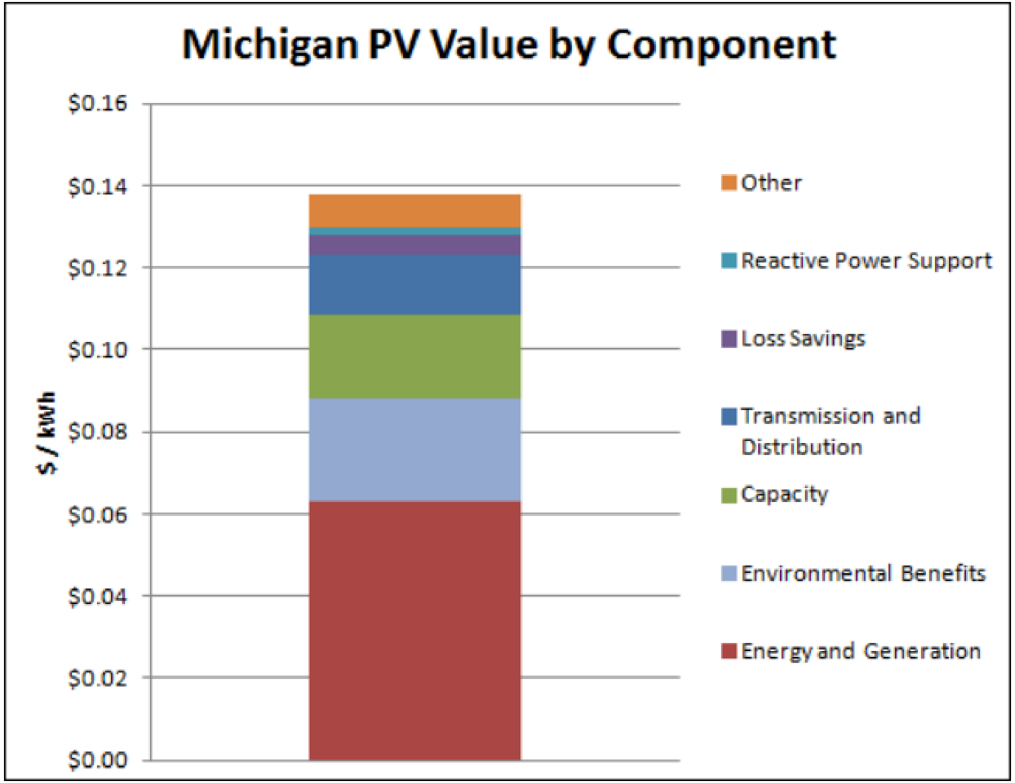
Source: R. W. Beck 2009

Solar Cost-Benefit Study Example: New Jersey and Pennsylvania



Source: Perez, Norris and Hoff 2012 (CPR)

Solar Cost-Benefit Study Example: Michigan



Source: Ong 2012 (DOE)

Solar Cost-Benefit Study Example: Utah

Table ES-2. Levelized value of ideal resource and distributed PV ($ per kWh)

	Economic Value ($/kWh)	Load Match (No Losses) (%)	Distributed Loss Savings (%)	Distributed PV Value ($/kWh)
Fuel Value	$0.037		16%	$0.043
Plant O&M Value	$0.011		16%	$0.013
Gen. Capacity Value	$0.021	53%	25%	$0.014
Avoided T&D Capacity Cost	$0.017	53%	25%	$0.011
Avoided Environmental Cost	$0.009		0%	$0.009
Fuel Price Guarantee Value	$0.022		16%	$0.026
	$0.118			$0.116

Source: Norris 2014 (CPR)

Solar Cost-Benefit Study Example: Maine

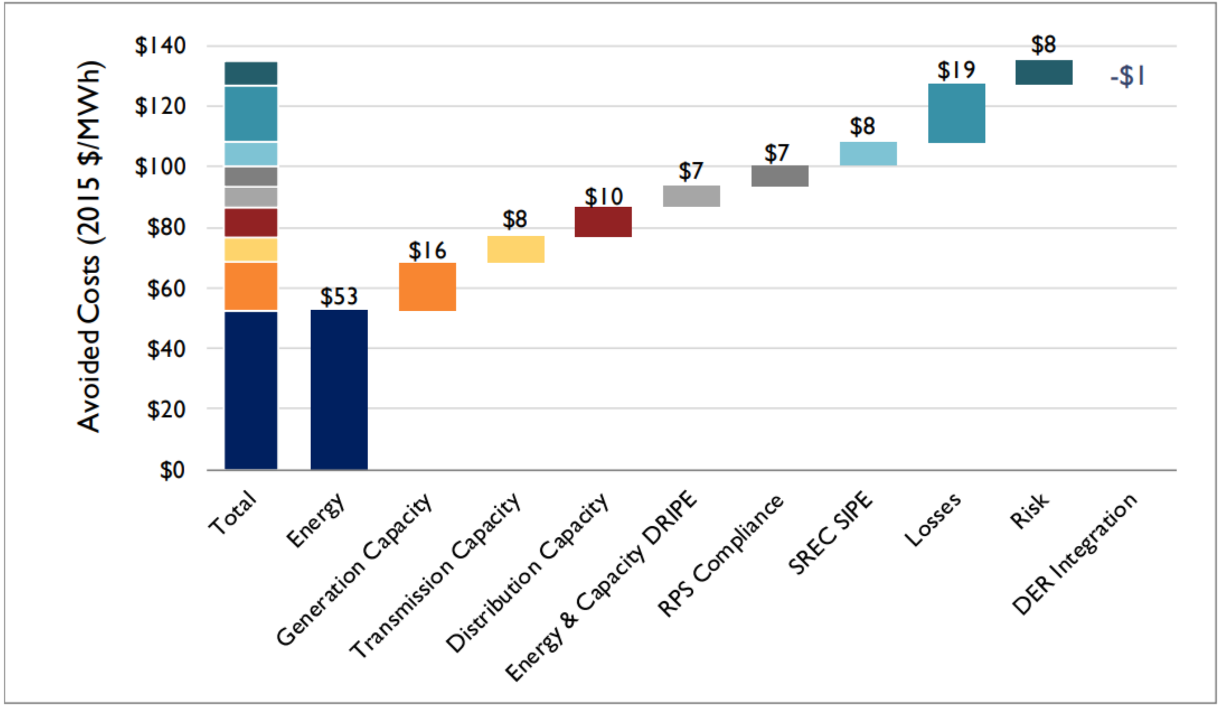
Figure ES- 2. CMP Distributed Value – 25 Year Levelized ($ per kWh)

25 Year Levelized		Gross Value A ($/kWh)	×	Load Match Factor B (%)	×	Loss Savings Factor (1+C) (%)	=	Distr. PV Value D ($/kWh)	
Energy Supply	Avoided Energy Cost	$0.076				6.2%		$0.081	Avoided Market Costs $0.138
	Avoided Gen. Capacity Cost	$0.068		54.4%		9.3%		$0.040	
	Avoided Res. Gen. Capacity Cost	$0.009		54.4%		9.3%		$0.005	
	Avoided NG Pipeline Cost								
	Solar Integration Cost	($0.005)				6.2%		($0.005)	
Transmission Delivery Service	Avoided Trans. Capacity Cost	$0.063		23.9%		9.3%		$0.016	
Distribution Delivery Service	Avoided Dist. Capacity Cost								
	Voltage Regulation								
Environmental	Net Social Cost of Carbon	$0.020				6.2%		$0.021	Societal Benefits $0.199
	Net Social Cost of SO_2	$0.058				6.2%		$0.062	
	Net Social Cost of NO_x	$0.012				6.2%		$0.013	
Other	Market Price Response	$0.062				6.2%		$0.066	
	Avoided Fuel Price Uncertainty	$0.035				6.2%		$0.037	
								$0.337	

Source: Norris et al. 2015 (CPR)

Solar Cost-Benefit Study Example: Washington D.C.

Figure ES-3. Levelized utility system value of solar by component



Source: Whitehead et al. 2017 (Synapse)

DPV Energy Costs & Benefits

Defining DPV Energy Costs and Benefits

- DPV generation offsets the need for equivalent production from another source (avoided energy).
- The costs and benefits are impacted by a variety of contextual factors that influence its overall scope.
  - Key drivers include:
    - Fuel costs
    - Fixed and variable operation and maintenance costs
    - Heat rate of offset resource.
- Avoided energy can be calculated and presented as one term, or divided between fuel costs and O&M (fixed and variable).
- Avoided energy / avoided fuel costs:
  - Often the most significant benefit associated with DPV.
  - Included in all comprehensive state energy assessments.

Source: Denholm et al., 2014

DPV Energy Cost and Benefit Considerations

- DPV generation can vary based on system design (e.g., ground mount vs. rooftop) and solar irradiance.
  - How will DPV generation be quantified?
- PV generation offsets the need for electricity at or near the point of consumption.
  - How does this generation correlate with overall system generation?
  - What generation is the PV unit actually offsetting?
    - (i.e., hypothetical unit, actual marginal system unit, subsystem unit/zone).
  - How much does that offset generation cost?

Sources: (Hoff et al. 2006) (Norris, Putnam, and Hoff 2014) (Norris et al. 2015) (Perez, Norris, and Hoff 2012) (Norris 2014) (Whitehead et al. 2017) (Public Utility Commission of Oregon 2017).

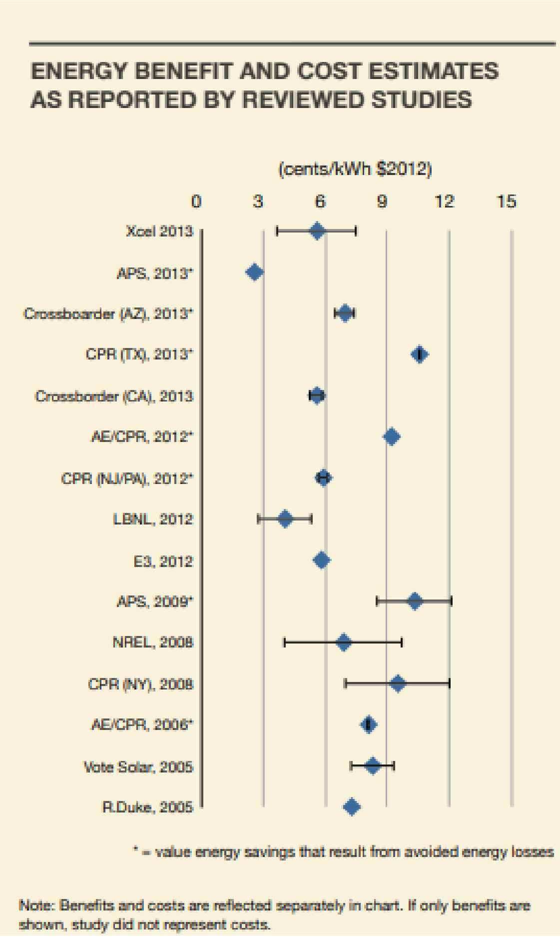
Methods to Quantify DPV Energy Costs and Benefits

- Approaches to quantifying DPV generation include:
  - Examine existing system performance
  - Model system output (for example using DGValuator or PVWatts)
  - Correlate PV generation with overall system generation (hourly or sub-hourly).
- Some common approaches to quantify offset generation cost for an “on the margin” plant include:
  - Simple avoided generator (typically a marginal natural gas plant either combustion turbine or combined cycle):
    - Cost of existing or hypothetical plant including fuel costs and operation and maintenance (O&M).
  - Market price:
    - Hourly marginal wholesale prices in ERCOT, MISO, PJM, or ISO-NE (systemwide or zonal).
  - Production simulation:
    - Hourly dispatch with and without PV generation to determine offset cost and associated costs and benefits

Source: Denholm et al., 2014

Understanding Variation in DPV Energy Costs and Benefits

- Variation can result from:
  - Fuel cost assumptions:
    - Natural gas price volatility can impact avoided costs.
      - Some use NYMEX to estimate these costs, others may rely on different, more local assumptions.
      - Price escalations beyond NYMEX may also vary.
  - Power plant efficiency (heat rate):
    - Heat rate can influence avoided energy generation costs and benefits, and this can vary by location, depending upon how this rate is applied, based on an estimate or real-time performance.
  - Methodology:
    - Basing the energy term on market prices or production simulation may generate the most precise results, but these processes are complex.



Source: Hansen, L., Lacy, V., Glick, D. (2013).

Source: Denholm et al., 2014

DPV Generation Capacity Costs & Benefits

Defining DPV Generation Capacity Costs and Benefits

- To maintain reliability, utility systems must meet load with enough generation capacity (including reserves).
- Generation capacity is the ability of that capacity (which could include DG) to reliably meet load and replace or defer capital investments in generation capacity.
- Generation capacity's benefit increases as generation coincides with greatest need for generation capacity, and vice versa (lack of correlation with greatest need, means significantly less value).

Source: Denholm et al., 2014

Two Steps to Determine the DPV Generating Capacity C-B

1. **Calculate the *capacity credit***. The capacity credit is "the actual fraction of a [DPV] system's capacity that could reliably be used to offset conventional capacity." It is "typically measured either as a value (such as kW) or percentage of nameplate rating."

2. **Translate the capacity credit into a *monetary value***. "The capacity credit calculation requires an adjustment factor to account for T&D losses. Just as generation capacity is measured at the point of transmission interconnection, [DPV] capacity [is] as well, which implies that the scale factor [is] applied to [DPV] , effectively increasing its capacity value." "Several studies have also applied an adjustment factor to account for reduced load that may reduce the system's planning reserve margin requirement."

Source: Denholm et al., 2014

DPV Generation Capacity Credit: Cost-Benefit Considerations – 1

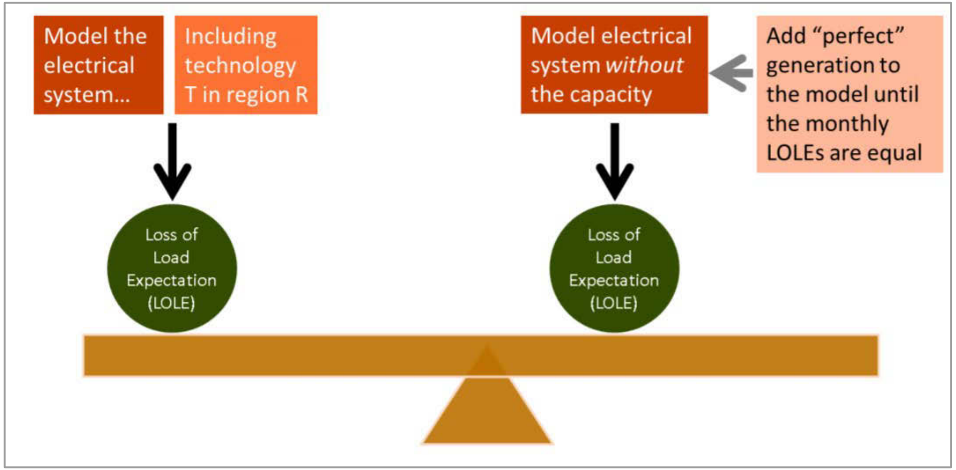
- There are four ways to calculate *capacity credit*:
  - Capacity factor approximation using net load
  - Capacity factor approximation using loss of load probability
  - Effective load-carrying capacity (ELCC) approximation
  - Full effective load-carrying capacity.

Source: Denholm et al., 2014

DPV Generation Capacity Credit: Cost-Benefit Considerations – 2

- ELCC is used in California.
  - The ELCC is a percentage that indicates how often a renewable resource can meet reliability standards (i.e., provide reliable generation capacity).
  - The ELCC approximation method is computationally simpler than the full ELCC and also yields reliable results.

Effective Load Carrying Capacity



Source: CPUC 2014

Key Steps

1. Balance the system (if necessary)
2. Model the system with technology T (you pick X MW or vary across a range)
3. Remove T and add “perfect” generation until LOLE is equal

DPV Generation Capacity Value: Costs and Benefits

- Ways to translate the capacity credit into a *monetary value*:

Name	Description	Tools Required
1. Simple avoided generator (CT)*	Assumes DGPV avoids construction of a new CT	None
2. Weighted avoided generator	Assumes DGPV avoids a mix of generators based on avoided fuel	None
3. Capacity market value	Uses cost of capacity in restructured markets	None
4. Screening curve	Uses system load and generation data to estimate avoided generation mix based on capacity factor	Spreadsheet
5. Complete valuation of DGPV versus alternative technologies	Estimates the type or mix of generators avoided in subsequent years using a capacity-expansion model	Detailed capacity-expansion model

- The *avoided cost* of new generation capacity is typically based on combined cycle combustion turbine (CCCT)
- *combustion turbine (CT)

Source: Denholm et al., 2014

DPV Energy, Transmission Losses and Generation Capacity: Ranges of Terms

Table 4.2: Estimates of Energy and Capacity Benefits in Studies Outside Oregon[19]

Benefit (in cents/kWh)	Low	Midrange"	High
Avoided Energy Cost	2.7	6 - 8	12
Avoided Transmission Losses	0	0.5	4.5
Avoided Investment in Generating Capacity	<1	1-2.5	13

Source: Oregon PUC 2014

DPV Generation Capacity: Summary of Key Concepts

- Estimating the effect new distributed generation (DG) will have on meeting load is challenging.
- Fossil-fueled DG is still typically dispatchable:
  - Variable DG (i.e., DPV) is not dispatchable.
  - Thus, it is not a 1-to-1 generation capacity replacement.
- Generally speaking, there is a lot of literature and experience calculating the generation capacity credit.

Source: Denholm et al., 2014

Key Questions for Framing DPV Generation Capacity C-B Analysis

- What is the coincidence of DG generation with the need for generation capacity?
- What type of generator would DG typically be replacing (e.g., CCCT? Peaking plant?)?

DPV Transmission & Distribution (T&D) Losses Costs & Benefits

Defining DPV T&D Losses Costs and Benefits

- Electricity is lost in transmission and distribution (T&D) as it gets converted to heat and electromagnetic energy:
  - Function of distance, current, and conductors
  - Losses increase at a rate equal to the square of the current (i.e., higher current, higher losses)
  - Peak demand increases resistance related losses
  - Losses higher during high demand periods. Impact of solar during high demand is critical assumption. Less impact, less avoided losses. (Hoff et al., 2006)
- DPV T&D loss costs and benefits are focused on technical losses (not non-technical losses) – when placed close to load, it can avoid these T&D losses.
- Average versus marginal line losses:
  - Marginal losses appear to be the more common methodology.
  - Marginal line losses are greater than average losses because marginal losses occur during the peak (thus more valuable). 1.5x – 2x greater.
  - Performing the analysis using average system losses can substantially underestimate the loss savings impact (Hoff et al., 2006).
- Actual observed losses or modeled losses?

Source: Denholm et al., 2014

Calculating DPV T&D Losses Costs and Benefits

- Four methods for estimating changes in T&D losses as a result of DPV

Name	Description	Tools Required
1. Average combined loss rate	Assumes PV avoids an average combined loss rate for both T&D	None
2. Marginal combined loss rate	Modifies an average loss rate with a non-linear curve-fit representing marginal loss rates as a function of time	Spreadsheet
3. Locational marginal loss rates	Computes marginal loss rates at various locations in the system using curve-fits and measured data	Spreadsheet
4. Loss rate using power flow models	Runs detailed time series power flow models for both T&D. Computational burden may be partially reduced using representative distribution feeders.	Two separate models: (1) distribution power flow time series and (2) PCM with optimal power flow (OPF) or dedicated OPF model

Source: Denholm et al., 2014

DPV T&D Losses C-B

Table 4.1: Summary of Nationwide Avoided Cost Study Results (per kWh) (cents/kWh)

	BENEFITS/COSTS per KWH						
	Energy	Transmission Losses	Avoided Generation	Avoided Transmission & Distribution	Grid Support	Fuel Hedge	Other
AZ	2.7		0.72	0.14			
AZ	7.91 to 11.1		0 to 1.85	0 to 0.82			
AZ	6.4 to 7.5		6.7 to 7.6	2.4 to 2.5	1.5		0.1
Austin	6		1.7	1			2
Austin	7.8	0.7	1.5	0.11			2.2
CA	6	0.2	4.5	2	0.5		2
CA	6	1	4	2	0.5		2
MN	6.7		2.4	1.1			3.1
NREL	3.2 to 2.7		1.1 to 10	0.1 to 10	0 to 1.5	0 to 0.9	0.4 to 6.2
NJ	6.1		1.6 to 2.2	1 to 8		2.5 to 4.7	2.3 to 5.5
TX	10.6		1.6 to 1.9	0.5		2.6	
CO	3.6 to 7.6	0.5 to 0.8	1.15	0.1		0.7	0.5
RMI	2.5 to 12	0 to 4.5	0 to 13	0 to 11	<1 to 1.8	0 to 4.5	0.5 to 5.5

Source: Oregon PUC 2014

Key Questions for Framing T&D Loss Cost-Benefit Analysis – 1

Are losses treated as a stand-alone category or as an adder to other categories such as environmental, energy, or capacity?

- Loss savings is an indirect benefit because it amplifies and increases the benefits of other benefits, including energy production, generation capacity, environmental, and T&D capacity (Hoff et al. 2006).
- Majority of studies treat it as an incremental benefit adder (also called multiplier or magnifier (Hansen, L., V. Lacy, and D. Glick. 2013.) – to gross up other categories.

The DC Analysis assumed: (Whitehead et al. 2017 - Synapse)

- Average transmission losses part of current utility methodology = 3%
- Marginal losses are 1.5x greater than average losses
- 3% * 1.5 = 4.5% marginal loss rates
- 4.5% is then used to gross up other components of DPV cost-benefit analysis.

Sources : Hoff et al. 2006; Hansen, L., V. Lacy, and D. Glick. 2013; Whitehead et al. 2017

Key Questions for Framing T&D Loss Analysis – 2

What are you evaluating? It is necessary to state up front which of the solar resources are being evaluated: all resources to date, next PV resource to come online, all resources anticipated over the next 20 years?

- Utah assumed the present day (Norris 2014)
- Austin Energy assumed a specific amount of resources: 15 MW (Hoff et al. 2006).
- Michigan's methodology is based on a marginal analysis of the next PV resource of unit size to come on line. (Ong 2012)

What is the analysis timeframe? One-year analysis versus 25-year levelized analysis?

- Better cost detail for one year.
- However, one year would need to be extended for the analysis timeframe.

Sources : Norris 2014; Hoff et al. 2006; Ong 2012

Summary of DPV T&D Loss Cost-Benefit Considerations

- Is DPV coincident with peak?
  - Greater loss savings if coincident.
- Average versus marginal losses – marginal.
- Observed actual losses or modeled losses.
- One year versus 20-year or 25-year levelized.
- Scenarios (current PV deployed, next resource, fixed future amount).
- Losses as an adder or a stand-alone category?

Source: Denholm et al., 2014

DPV Transmission Capacity Costs & Benefits

Defining the DPV Transmission Capacity Costs and Benefits

- Unlikely to have short-term savings for T&D capacity given the nature of transmission planning (e.g., 10-year planning cycles).
- Non-targeted PV makes it difficult to plan for T&D capacity savings.
  - There is an argument for directing DPV to specific spots on grid through pricing signals (i.e., perhaps higher VOS or locational VOS pricing).
- For there to be a benefit in transmission capacity avoidance, DPV needs to be coincident with peak use of transmission resources (RW Beck 2009).
- Dependable capacity concept (90% confidence in 5 hour window) (RW Beck 2009).
- Transmission capacity savings is very dependent on:
  - Local context
  - Time horizon
  - Where the planned DPV is expected to be installed
  - How much DPV is installed.

Source: Denholm et al., 2014

Defining DPV Transmission Capacity Costs and Benefits

Load Match

- Effective load carrying capacity (ELCC) - comparing DPV to base load (CPUC 2014):
  - 10 MW of DPV at 50% ELCC is equal to 5 MW of baseload.
  - ELCC can be thought of as a derating factor that is applied to a facility’s maximum output (Pmax) in order to determine its Qualifying Capacity.
  - ELCC reflects the contribution of a resource type towards meeting reliability needs
  - Correlated to load and forced outage rates.
- Peak-Load Reduction (PLR) - ability of DPV to reduce load at peak (peak load reduction)
  - Utah used PLR for transmission losses. (Norris 2014)
  - Minnesota used ELCC for transmission losses. (Norris, Putnam, and Hoff 2014)
- Future transmission costs tough to pinpoint, so historical costs can be used.
- Washington D.C.: choice of discount rates in can impact calculation for long term (25-year) analyses (Whitehead et al. 2017).

Sources: CPUC 2014 Norris 2014; Norris, Putnam, and Hoff 2014; and Whitehead et al. 2017)

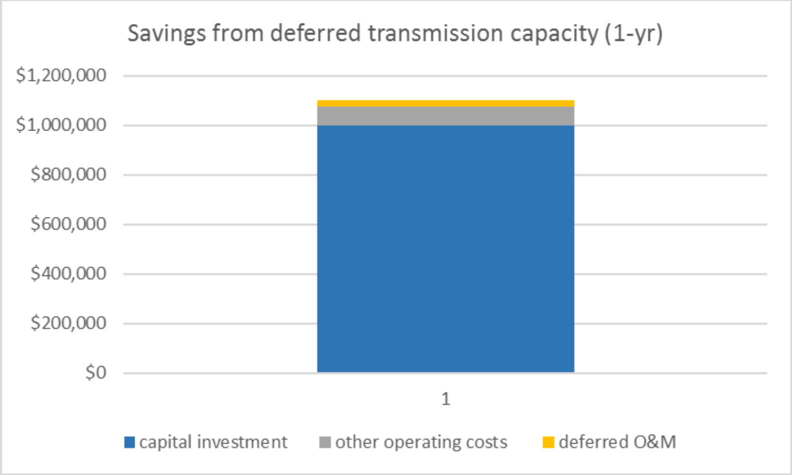
DPV Transmission Capacity Cost-Benefit Considerations

- Are there any transmission capacity benefits due to the large and step-wise nature of investments?
- APS: Need minimum level of capacity before any capacity savings begin to accrue. (R.W. Beck 2009)
- APS: Every unit of solar capacity creates transmission capacity benefits. (SAIC 2013)

Sources: R. W. Beck 2009, SAIC 2013

DPV Transmission Capacity: Financial Components

- Deferring T&D capital investments has three financial components, according to the Austin Energy study:
  1) Direct capital investment/cost deferral savings that result from waiting to invest until a later date.
  2) Indirect financial costs that are incurred when an investment is made, and continue as long as the investment exists (e.g., property taxes, insurance, etc.).
  3) O&M cost savings associated with the investment.



Source: Hoff et al. 2006

DPV Transmission Capacity Costs and Benefit Examples – 1

Oregon (PUC OR 2017)

- Actual, locational specific T&D that is avoided versus system-wide average of avoided or deferred T&D.

Maine (Norris et al. 2015)

- 2 of 3 utilities in Maine purchase transmission capacity from ISO.
  - This capacity is purchased monthly in $/kW.
  - A reduction in purchases from ISO translates into transmission capacity savings due to DPV.

Sources: PUC OR 2017; Norris et al. 2015

DPV Transmission Capacity Costs and Benefit Examples – 2

Utah (Norris 2014)

- Looked at existing loads and based calculation on a 1 kW system in Salt Lake City.
  - Assumed 1) perfect load match with no losses, 2) then adjusted for load match, and then 3) adjusted for lower line losses.
  - \$0.021/kWh X 53% X 1.25% = \$0.014/kWh savings.
- Large line loss savings of 16-25%.

Source: Norris 2014

DPV Transmission Capacity Costs and Benefit Examples – 3

Austin Energy (2018 Update)

- Peak coincident demand (i.e., ELCC) fell from 62% to 50%.
- But, avoided transmission costs increased from \$0.015/kWh to \$0.038/kWh.
  - According to AE, "cost of transmission service has gone up since 2014" and so deferring those costs have become more beneficial.
- Benefits increased by \$0.02/kWh even though ELCC fell to 50%.

Source: Austin Energy 2017

DPV Transmission Capacity: Summary of Key Concepts

- Extremely context- and location-specific.
- Limited/no short-term savings.
- Deferral of investment rather than avoidance of investment more likely.
- Dynamic calculation as costs and loads change over time.
- Offsetting investment in actual transmission or purchase of capacity (e.g. ISO, MISO, SPP).
- Targeted deployment of PV might be facilitated by locational pricing.

Source: Denholm et al., 2014

DPV Distribution Capacity Costs & Benefits

Defining the DPV Distribution Capacity Costs and Benefits – 1

- DPV supplies power close to loads and can yield distribution system benefits or costs, depending on a host of factors, particularly location.
- Distribution capacity is the extent to which DPV can defer or reduce distribution system investment or require additional ones to maintain a reliable, flexible grid.
- To calculate distribution capacity, calculate distribution capital investment costs with and without DPV. Calculations can be based on system-wide avoided costs or location-specific avoided costs.

Source: Denholm et al., 2014

Defining the DPV Distribution Capacity Costs and Benefits – 2

There are six methods for calculating distribution capacity of DPV:

1. PV capacity limited to current hosting capacity
2. Average deferred investment for peak reduction
3. Marginal analysis based on curve-fits
4. Least-cost adaptation for higher PV penetration
5. Deferred expansion value
6. Automated distribution scenario planning (ADSP)

Source: Denholm et al., 2014

DPV Distribution Key Cost-Benefit Considerations

- DG may or may not have a net distribution system savings.
  - DG distribution capacity benefits may be feeder-specific.
- Distribution capacity costs and benefits are highly dependent on location and time of use for power.
- DG might be able to *defer* distribution system investments.
  - Is not expected to eliminate them entirely.
- Load growth uncertainty can complicate calculating distribution capacity costs and benefits.
- Distribution capacity is included in most cost-benefit studies.
- Calculating distribution capacity costs and benefits is challenging "because the distribution grid has been built for all existing customers." (Denholm et al. 2014) Thus, there may only be value in areas of grid expansion.

Source: Denholm et al., 2014

DPV Distribution Capacity: Key Questions for Framing Analysis

- What are the current distribution capacity expansion plans and what may be able to be deferred by DG? For how long?
- Is load projected to be flat? If not, how certain are load growth estimates?
- Is there aging equipment that must be replaced and/or upgrades that need to be made?

DPV Ancillary Services Costs & Benefits

DPV Ancillary Services Costs and Benefits

Ancillary services: A broad array of services that help system operators maintain a reliable grid with sufficient power quality. Ancillary services are procured regardless of the existence of DPV, although DPG can influence the cost of having a particular service fulfilled.

Ancillary services are categorized differently across the various balancing authorities in the U.S. Below are some common broad categories of service:

- **Operating reserves**: Generators/loads capable of adjusting their electrical consumption or generation to respond to supply/demand imbalances over a range of timeframes:
  - **Regulation reserves**: Reserves held to respond to supply/demand imbalances over relatively short timeframes (i.e., several seconds).
  - **Flexibility reserves**: Reserves held to respond to supply/demand imbalances on timescales greater than regulation reserves, and to address imbalances from forecast error.
  - **Contingency reserves**: Reserves held to meet unplanned generation or transmission outages.
- **Frequency control**: Actions to ensure that the grid frequency stays within a nominal range.
- **Voltage control**: Actions to ensure that voltage levels on distribution networks stay within a nominal range. Often includes the provision of reactive power.
- **Black-start capability**: Actions to restart the electric grid after a complete loss of power.

Sources: Gagnon, 2018 and Denholm et al., 2014

DPV Environmental Costs & Benefits

Existing State Practices to Define DPV Environmental Costs-Benefits

- When DPV generation offsets fossil fuel generation it can provide certain environmental or health benefits.
- Environmental costs and benefits vary based upon the environmental factors considered and can include:
  - Criteria air pollutants (i.e., sulfur dioxide/SO_2 and nitrogen oxides/NO_X),
  - Water, land, and other impacts (i.e., avoided RPS costs), or
  - Carbon emissions.
- For states that have examined costs and benefits of DPV, it appears that some environmental component is typically included in all analyses;
  - The level of costs and benefits can vary significantly
  - Not all terms are included in all analyses.

Sources: (Denholm et al., 2014) (Hoff et al. 2006) (Norris, Putnam, and Hoff 2014) (Norris et al. 2015) (Perez, Norris, and Hoff 2012) (Norris 2014) (Whitehead et al. 2017) (Public Utility Commission of Oregon 2017).

DPV Environmental Cost and Benefit Considerations

- Some environmental considerations may be included in other categories including avoided energy costs (i.e., certain emission control costs).
  - What, if any, environmental factors are already included and how are these costs and benefits calculated?
  - How can double-counting be avoided?
- If additional environmental factors are to be included:
  - Which ones?
  - What methodology will reflect the costs and benefits?

Sources: (Hoff et al. 2006) (Norris, Putnam, and Hoff 2014) (Norris et al. 2015) (Perez, Norris, and Hoff 2012) (Norris 2014) (Whitehead et al. 2017) (Public Utility Commission of Oregon 2017).

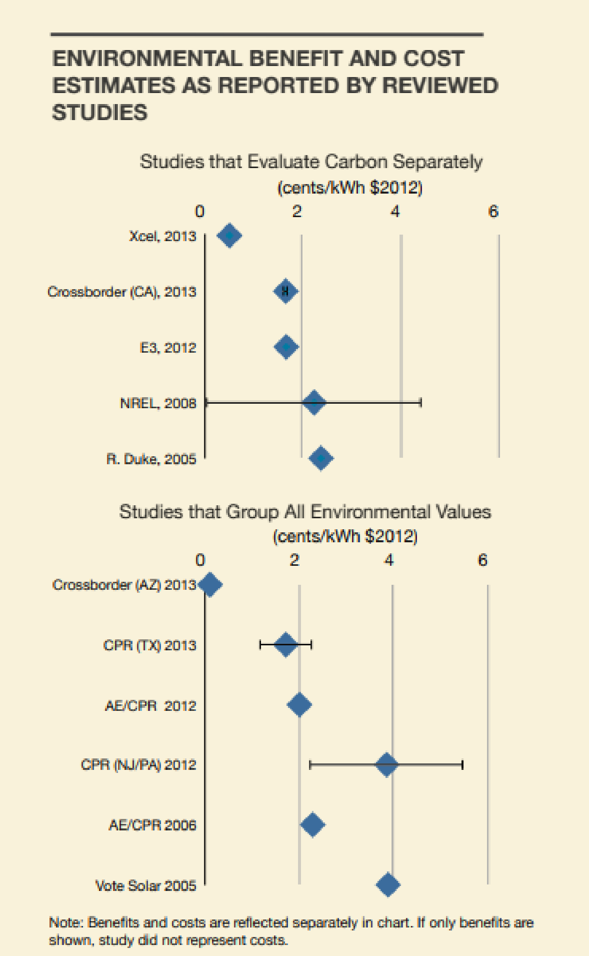
Methods to Quantify DPV Environmental Costs-Benefits

- Quantifying emission costs and benefits requires identifying the power plant type and power plant efficiency that reduces power output.
- Once emissions are determined, the methodology usually applies a monetary cost to avoided emissions to generate an environmental term.
  - This term can either be embedded within avoided energy costs or included as a stand-alone metric.
- Example: Quantifying SO_2 emission savings.
  - Confirm emissions are not already considered in avoided energy costs (i.e., markets that price SO_2).
  - Power plant type and heat rate directly impact potential emission savings.
    - AVERT is one tool to determine these inputs.
  - States who have used this method based the emission savings on reported prices in certain markets or on hypothetical prices.

Source: Denholm et al., 2014

Understanding Variation in DPV Environmental Costs-Benefits

- Environmental costs and benefits will vary based on the impacts included and how costs and benefits are monetized.
  - Not all methods include carbon emission savings and those that do adopt varying metrics for the benefits of those reductions.
- Emission savings will vary based upon the emission factors employed for certain offset generation.



Source: Hansen, L., Lacy, V., Glick, D. (2013)

Sources: (Hoff et al. 2006) (Norris, Putnam, and Hoff 2014) (Norris et al. 2015) (Perez, Norris, and Hoff 2012) (Norris 2014) (Whitehead et al. 2017) (Public Utility Commission of Oregon 2017).

DPV Other Services Costs & Benefits

DPV Other Services Costs and Benefits: Resilience

- Avoided outage costs/“value of lost load”:
  - Mentioned as consideration in Mississippi cost-benefit study, but not calculated (Stanton et al., 2014).
  - ERCOT study: value of lost load approx. $110/MWh for residential customers, between $125-$6,468/MWh for C&I customers (London Economics, 2013).
  - Caveat is that in assigning associated costs and benefits to DPV, one needs a reasonable assurance that DPV will offset risk. Key questions:
    - Will it operate during an outage?
    - All kinds of outages?
    - Is there only a benefit during the day when the sun is shining?
  - Note: DPV by itself does not necessarily provide resilience benefits.

Sources: Stanton et al. 2014; and London Economics 2013

DPV Other Services
Costs and Benefits: Battery Storage

- A report by the Interstate Renewable Energy Council, *Valuation of Solar + Storage in Hawaii: Methodology*, develops a methodology that could be used to estimate the benefits (and only the benefits) of solar energy coupled with battery storage.
  - The benefits of battery storage primarily provides peak load reduction.
  - This methodology determines a levelized capacity benefit of net generation (the per kWh benefit of energy storage to the utility).
  - The benefits of energy storage is added to the benefits of solar (which is separately calculated), to determine the benefits of solar + energy storage.
    - See pages 1-3 of report for an example calculation.
  - The cost of battery storage would also need to be considered, and would need to be added to the costs of DPV.

Source: Norris, 2015

DPV Other Services Costs and Benefits: Economic Development

- Siting, installation, maintenance of DPV as emerging industry.
- Associated job impacts.
- Mississippi VOS study mentions economic development benefits in literature review, but does not quantify.

Sources: Stanton et al. 2014; and Denholm et al. 2014

DPV Other Services Costs and Benefits: Other Potential Factors

- Impact on home value.
- Freedom of energy choice.
- Energy price hedging
  - From customer perspective
  - From utility perspective

Source: Denholm et al., 2014

References

- Austin Energy “2018 Value of Solar (VOS) Update.” 2017. Resource Management Commission. http://www.austintexas.gov/edims/document.cfm?id=277018
- California Public Utilities Commission (CPUC). 2014. “Effective Load Carrying Capacity and Qualifying Capacity Calculation for Wind and Solar Resources.” http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6555.
- Denholm, P., R. Margolis, B. Palmintier, C. Barrows, E. Ibanez, L. Bird, and J. Zuboy. 2014. “Methods for analyzing the benefits and costs of distributed photovoltaic generation to the U.S. electric utility system.” NREL/TP-6A20-62447. Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy14osti/62447.pdf.
- Gagnon, P. and A. Holm. 2018. *Review of Standby and Ancillary Services in the Context of Behind-the-Meter Photovoltaics*. NREL/PR-6A20-71165. https://www.nrel.gov/docs/fy18osti/71165.pdf.
- Hansen, L., V. Lacy, and D. Glick. 2013. “A Review of Solar PV Benefits & Cost Studies 2nd Edition.” *Rocky Mountain Institute*. https://rmi.org/wp-content/uploads/2017/05/RMI_Document_Repository_Public-Reprts_eLab-DER-Benefit-Cost-Deck_2nd_Edition131015.pdf
- Hoff, T.E., R. Perez, G. Braun, M. Kuhn, B. Norris. 2006. "The Value of Distributed Photovoltaics to Austin Energy and the City of Austin.” Prepared for Austin Energy by Clean Power Research. https://www.cleanpower.com/wp-content/uploads/034_PV_ValueReportAustinEnergy.pdf
- London Economics. 2013. “Estimating the Value of Lost Load.” Prepared for the Electric Reliability Council of Texas by London Economics International LLC. http://www.ercot.com/content/gridinfo/resource/2014/mktanalysis/ERCOT_ValueofLostLoad_LiteratureReviewandMacroeconomic.pdf
- Norris, B. 2014. “Value of Solar in Utah.” Prepared for Utah Clean Energy by Clean Power Research. https://pscdocs.utah.gov/electric/13docs/13035184/255147ExAWrightTest5-22-2014.pdf
- Norris, B. 2015. “Valuation of Solar + Storage in Hawaii: Methodology.” Prepared for the Interstate Renewable Energy Council by Clean Power Research. https://irecusa.org/wp-content/uploads/2015/06/IREC-Valuation-of-Solar-Storage-in-HI_Methodology_2015.pdf
- Norris, B., P. Gruenhagen, R. Grace, P. Yuen, R. Perez, and K. Rábago. 2015. “Maine Distributed Solar Valuation Study.” Prepared for the 127th Maine Legislature by Clean Power Research. https://www.nrcm.org/wp-content/uploads/2015/03/MPUCValueofSolarReport.pdf.

- 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. https://www.cleanpower.com/wp-content/uploads/MN-VOS-Methodology-2014-01-30-FINAL.pdf
- Ong, S. 2012. "White Paper: The Value of Grid-Connected Photovoltaics in Michigan," Michigan Review Draft, U.S. Department of Energy Solar Energy Technologies Program Public Utilities Commission Technical Assistance Program. https://www.michigan.gov/documents/mpsc/120123_PVvaluation_MI_394661_7.pdf
- Perez, R., Norris, B, and Hoff, T. 2012. "Value of Solar to New Jersey and Pennsylvania." Prepared for the Mid-Atlantic Solar Energy Industries Association by Clean Power Research. http://asrc.albany.edu/people/faculty/perez/2012b/MSEIA.pdf
- Public Utilities Commission of Oregon. 2014. Investigation into the Effectiveness of Solar Programs in Oregon. https://www.puc.state.or.us/electric_gas/Investigation%20into%20the%20Effectiveness%20of%20Solar%20Programs%20in%20Oregon%202014.pdf.
  - Idaho Power Final Briefing (Aug 9, 2018): https://edocs.puc.state.or.us/efdocs/HBC/um1911hbc12250.pdf
  - Portland General Electric Initial Filing (Dec 4, 2017): https://edocs.puc.state.or.us/efdocs/HAA/haa163313.pdf
  - PacifiCorp Opening Brief (July 26, 2018): https://edocs.puc.state.or.us/efdocs/HBC/um1910hbc124437.pdf
- R.W. Beck "Distributed Renewable Energy Operating Impacts and Valuation Study." Prepared for Arizona Public Service. http://files.meetup.com/1073632/RW-Beck-Report.pdf
- SAIC "2013 Updated Solar PV Value Report." Prepared for Arizona Public Service by SAIC (formerly R. W. Beck). https://www.azsolarcenter.org/images/docs/reports/SolarValueStudy-SAIC-2013-05.pdf
- Schneider Electric. 2013. "How big are Power line losses?" https://blog.schneider-electric.com/energy-management-energy-efficiency/2013/03/25/how-big-are-power-line-losses/.
- Stanton, E. A., Daniel, J., Vitolo, T., Knight, P, White, D., and Keith, G. 2014. "Net Metering in Mississippi." Prepared for the Public Service Commission of Mississippi by Synapse Energy Economics, Inc. http://www.synapse-energy.com/sites/default/files/Net%20Metering%20in%20Mississippi.pdf
- Whited, M., A. Horowitz, T. Vitolo, W. Ong, and T. Woolf. 2017. "Distributed Solar in the District of Columbia." Prepared for the Office of the People's Counsel for the District of Columbia by Synapse Energy Economics, Inc. http://www.synapse-energy.com/sites/default/files/Distributed-Solar-in-DC-16-041.pdf.

Thank you

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