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The Electricity Innovation Lab (e-Lab) brings together thought leaders and decision makers from across the U.S. electricity sector to address critical institutional, regulatory, business, economic, and technical barriers to the economic deployment of distributed resources. e-Lab members and advisors were invited to provide input on this report. The assessment is not a consensus organization, and the views expressed in this document do not necessarily represent those of any individual e-Lab member or supporting organization. Any errors are solely the responsibility of RMI.

About This Document

This report is a 2nd edition released in September 2013. This second edition updates the original with the inclusion of Xcel Energy’s May 2013 study, Costs and Benefits of Distributed Solar Generation on the Public Service Company of Colorado, as well as clarifies select descriptions and charts.

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WHAT IS e-LAB?
EXECUTIVE SUMMARY

THE NEED

The addition of distributed energy resources (DERs) onto the grid creates new opportunities and challenges because of their unique characteristics, including: (1) being connected to end-use loads, (2) being able to shave peaks and provide energy at times of peak demand, and (3) being able to provide energy at lower costs than conventional centralized resources.

Today, the increasing adoption of distributed solar resources creates new opportunities and challenges because of their unique characteristics. The need for advanced technologies and new business models have increased the need for new data-driven approaches to better understand the benefits and costs of DERs.

OBJECTIVE OF THIS DOCUMENT

The objective of this discussion document is to assess what is known and unknown about the categorization, methodological best practices, and gaps around the benefits and costs of DERs, and to begin to establish a clear foundation from which additional work on benefit/cost assessments and pricing methodologies can be built.

This discussion document reviews 16 DPV benefit/cost studies by utilities, national labs, and other organizations. Completed between 2005 and 2013, these studies reflect a significant range of estimated DPV value.

KEY INSIGHTS

No study comprehensively evaluated the benefits and costs of DPV, although many acknowledgment additional sources of benefit or cost and some recognize that some benefits and costs may be difficult or impossible to quantify, and some accrue to different stakeholders.

There is broad recognition that some benefits and costs may be difficult or impossible to quantify, and some accrue to different stakeholders. There is broad recognition that some benefits and costs may be difficult or impossible to quantify, and some accrue to different stakeholders.

Because of these differences, comparing results across studies can be varied widely.

There is significant variation across DPV value, driven primarily by differences in local context, input assumptions, and methodological approaches.

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Without increased understanding of the benefits and costs of DERs, there is little ability to make effective tradeoffs between investments.

There is significantly less agreement on overall approaches to estimating energy value.

There is significantly less agreement on overall approaches to estimating energy value.

There is a significant range of estimated value across studies, driven primarily by differences in local context, input assumptions, and methodological approaches.

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Because of these differences, comparing results across studies can be informative, but should be done with the understanding that results must be normalized for context, assumptions, or methodologies.

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While detailed methodological differences abound, there is general agreement on overall approach to estimating energy value, although there may be philosophical differences in how energy value is defined.

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EXECUTIVE SUMMARY (CONT’D)

IMPLICATIONS

Methods for identifying, assessing and quantifying the benefits and costs of DPV and other DERs are advancing rapidly, but important gaps remain to be filled before this type of analysis can provide an adequate foundation for policymakers and regulators engaged in determining levels of incentives, fees, and pricing structures for DPV and other DERs.

In any benefit-cost study, it is critical to be transparent about assumptions, perspectives, sources, and methodologies so that studies can be more readily compared, best practices developed, and drivers of results understood.

The most significant methodological gaps include:

- Distribution value: The benefits or costs that DPV creates in the distribution system are inherently local, so accurately estimating value requires much more analytical granularity and much greater difficulty.
- Grid support services value: There continues to be uncertainty around whether and how DPV can provide or require additional grid support services, but this could potentially become an increasingly important value.
- Financial, security, environmental, and social values: These values are largely (though not comprehensively) monetized.

Methods for identifying, assessing and quantifying the benefits and costs of DPV and other DERs are advancing rapidly, but important gaps remain to be filled before this type of analysis can provide an adequate foundation for policymakers and regulators engaged in determining levels of incentives, fees, and pricing structures for DPV and other DERs. Studies have largely focused on DPV by itself, but a confluence of factors is likely to drive increased adoption of DPV by itself. Thus far, studies have largely focused on DPV by itself, but a confluence of factors is likely to drive increased adoption of DPV by itself.

Looking Ahead

For repeaters:

- Development of these resources and lower overall system costs can be better aligned, enabling greater economic value.

- Studies have largely focused on DPV by itself. But a confluence of factors is likely to drive increased adoption of DPV by itself.

- Studies have largely focused on DPV by itself. But a confluence of factors is likely to drive increased adoption of DPV by itself.

Thus far, studies have made simplifying assumptions that:

- Quantify, analyze, and develop levels of incentivization, fees, and pricing structures for DPV and other DERs are advancing rapidly, and new methodologies for identifying, assessing and quantifying the benefits and costs of DPV and other DERs are advancing rapidly.

- Methods for identifying, assessing and quantifying the benefits and costs of DPV and other DERs are advancing rapidly, and new methodologies for identifying, assessing and quantifying the benefits and costs of DPV and other DERs are advancing rapidly.
FRAMING THE NEED

structural misalignments in practice
distributed energy resources
overview
Framing the Need

A confluence of factors including rapidly falling solar prices, supportive polices, and new approaches to finance are leading to a steadily increasing solar PV market. The addition of DPV onto the grid creates new challenges and opportunities because it is unique among conventional centralized resources. The value of DPV is temporally, operationally, and geographically specific and varies by distribution feeder, transmission network, and configuration of the generation fleet. Many instances pricing mechanisms are not in place to recognize or reward economic, social, and technical dimensions emerging. For example, in many instances pricing mechanisms are not in place to recognize or reward service that is being provided by either the utility or customer.

Under today’s regulatory and pricing structures, multiple misalignments along economic, social, and technical dimensions are emerging. For example, in many instances pricing mechanisms are not in place to recognize or reward service that is being provided by either the utility or customer. To enable better technical integration and economic optimization, it is critical to better understand the services that DPV can provide and realize, and the importance of properly valuing DPV and the current lack of clarity around the costs and benefits that define DPV’s value, as well as how to calculate them.

Electricity sector stakeholders around the country are recognizing the need for increased resource adequacy, resource options, and transparency in the configuration, and composition of the generation fleet. Arizona, Hawaii, and Massachusetts, for example, have especially solar-friendly policies. California, New Jersey, and, to a lesser extent, other states with large-scale solar projects, have solar penetrations in certain regions becoming significant. About 80% of customer-sited PV is concentrated in states with other ample solar. Solar penetrations in certain regions are becoming significant. About 80% of customer-sited PV is concentrated in states with other ample solar. In 2012, the US added 2 GW of solar PV to the nation’s generation mix, of which approximately 50% were customer-sited solar, not-metered solar, and new approaches to finance are leading to a steadily increasing solar market.

Distributed Energy Resources (DERs): demand- and supply-side resources that can be deployed through an electric distribution system to meet the needs of energy and reliability needs of the customers served by that system. DERs can be installed on either the customer side or the utility side of the meter.

Types of DERs:
- Distributed energy storage
- Smart inverters
- Microgrids
- Smart home networks
- Distributed intelligence
- Energy efficiency
- Distributed generation
- Distributed flexibility & storage
- Energy storage
- Combined heat & power (CHP)
- Solar PV
- Combined heat & power (CHP)
- Small-scale wind
- Others (i.e., fuel cells)

Future system/value constellation:
- Two-way power flow

Current system/value chain:
- One-way power flow

Efficiency:
- Smart inverters
- Microgrids
- Home-area networks
- Distributed intelligence

Siting:
- Energy storage
- Combined heat & power (CHP)
- Solar PV
- Small-scale wind
- Others (i.e., fuel cells)

Operations:
- Demand response
- Electric vehicles
- Thermal storage
- Battery storage

What makes DERs unique:
- Siting
- Ownership
- Operations
- Resource integration and planning
- Customer-first approach
- Coordination of a third party

DERs can be managed more efficiently and more effectively by breaking down the traditional grid into smaller, more modular energy resources that can be installed by any number of actors outside of the purview of centrally controlled dispatching mechanisms that control the real-time balance of generation and demand.

Distributed generation:
- Energy resources on the distribution network operate outside of centrally controlled dispatching mechanisms that control the real-time balance of generation and demand.

Distributed flexibility & storage:
- A collection of technologies that allows the overall system to use energy more efficiently and more effectively by storing it when supply exceeds demand and prioritizing need when demand exceeds supply.

Distributed intelligence:
- Technologies that combine sensory, communication, and control functions to support the electricity system and magnify the value of DER system integration. Examples include:
- Smart inverters
- Home-area networks
- Microgrids
- Distributed intelligence
- Energy efficiency
- Distributed generation
- Energy storage
- Combined heat & power (CHP)
- Solar PV
- Small-scale wind
- Others (i.e., fuel cells)
If costs are incurred by DER customers that are not paid for, those costs would be allocated to the rest of customers. Conversely, DER customers also provide benefits to other customers and to society.

Mechanisms are not in place to transparently recognize or compensate for the service (be it monetized grid services like energy, capacity or balancing supply and demand, or less consistently monetized values, such as carbon emissions, supply and demand, or less monetized services like energy efficiency, capacity or demand response) that DER customers provide. To the utility, revenue from DER customers may not match the cost to serve those customers, leading to a misalignment of costs and benefits.

Society values the environmental and social benefits that DERs could provide, but those benefits are often externalized and unmonetized.

Systemic misalignments are not well-adapted to the integration of DERs, causing friction and inefficiency. Today, operational and pricing mechanisms designed for an historically centralized electricity system are not well-adapted to the integration of DERs, causing friction and inefficiency.
What benefits can customers provide? Is the ability of customers to provide benefits contingent on anything? What costs are incurred to support DPV customer needs? What are the best practice methodologies to assess and monetize these values, such as externalized and unmonetized values? How should these be recognized and embedded into value propositions? What are the best practice methodologies to assess benefits and costs? How should externalized and unmonetized values, such as environmental and social benefits, be recognized and embedded into value propositions? What are the best practice methodologies to assess benefits and costs?

These structural misalignments are leading to important questions, debate, and conflict.
SETTING THE STAGE

defining value
categories of value
stakeholder implications
When considering the total value of DPy or any electricity resource, it is critical to consider the types of value, the stakeholder perspective and the flow of benefits and costs—i.e., who incurs the costs and who receives the benefits or avoids the costs. Setting the stage for calculating the value of DPy and other electricity resources requires understanding the basic framework of estimating cost effectiveness for energy efficiency. The primary stakeholders in calculating the value of DPy are the participants (the solar customer); the utility; other customers (also referred to as ratepayers); and society (taxpayers are a subset of society). For the purposes of this report, value is defined as net benefits, i.e., net value.
For the purposes of this report, value is defined as net value, i.e., benefits minus costs. Depending on the size of the benefit and the size of the cost, value can be positive or negative. A variety of categories of benefits or costs of DPV have been considered or acknowledged in evaluating the value of DPV. Broadly, these categories are:

- **Energy**
  - System losses
  - Energy

- **Capacity**
  - Generation capacity
  - Transmission & distribution capacity
  - Generation & distribution capacity

- **Grid Support Services**
  - Dynamic priority dispatch, forecasting, and system control & dispatch
  - Energy & generation imbalance
  - Regulation & frequency response
  - Reactive supply & voltage control

- **Security Risk**
  - Reliability & resilience

- **Environmental**
  - Carbon emissions (CO₂)
  - Criteria air pollutants (SO₂, NOₓ, PM)

- **Social**
  - Economic development (jobs and tax revenues)

- **Financial Risk**
  - Fuel price hedge
  - Market price response

- **Security**

- **Financial**

For the purposes of this report, value is defined as net value, i.e., benefits minus costs.
0.004
0.002

ENERGY

Energy value of DPV is positive when the solar energy generated displaces the need to produce energy from another resource at a net savings. There are two primary components:

- Avoided Energy - The cost and amount of energy that would have otherwise been generated from another resource at a net savings. There are two primary components:
- System Losses - The compounded value of the additional energy generated by central generation capacity that can be delivered or avoided due to the addition of DPV.

BENEFIT & COST CATEGORIES DEFINED

TRANSMISSION & DISTRIBUTION CAPACITY
- The value of the net change in T&D infrastructure capacity and (2) system capacity needs.

CAPACITY
- The cost of the amount of central generation capacity that can be deferred or avoided due to the addition of DPV. Key drivers of value include (1) DPV’s effective generation, transmission, and distribution assets that incur costs. There are two primary components:
- System Losses - The compounded value of the additional energy generated by central generation capacity that can be avoided or delivered at a net savings to the customer via the transmission and distribution system. Since DPV guarantees energy to the customer, they are able to avoid or defer transmission and distribution system upgrades.

GRID SERVICES
- Capacity value of DPV is positive when the addition of DPV defers or avoids more investment in capacity and lower emissions. Since avoided energy losses result in lower required maintenance costs, and (2) heat rate. Key drivers of avoided energy cost include (1) fuel price forecasts, (2) variable operation & maintenance costs.

ENERGY
- The value of the net change in energy value of DPV due to the coincidence of solar generation with demand and generation, key displaced in addition to the coincidence of solar generation with demand and generation. Key drivers include the avoided energy demand, the avoided energy demand, and the avoided energy demand. Key drivers include the avoided energy demand, the avoided energy demand, and the avoided energy demand.
Grid support value of DPV is positive when the net amount and cost of grid support services required to balance supply and demand is less than what would otherwise have been required.

Grid support services (or grid support value) is defined as:

- Reactive Supply and Voltage Control
  - Generation facilities used to supply reactive power and to regulate voltage
  - Includes:
    - Grid support services to enable the reliable operation of interconnected electric grid systems

- Frequency Regulation
  - Controlling and extra generating capacity (fuel-specific) necessary to (1) maintain frequency by following the moment-to-moment variations in electrical load and (2) respond immediately to frequency deviations in their network
  - Includes:
    - Frequency regulation services and frequency response services are different; they are complementarily supplied to meet any difference in actual and scheduled generation

- Energy Imbalance
  - Scheduling/Forecasting
  - Interchange schedule confirmation and implementation with other control areas

- Grid Services
  - Interchange schedule confirmation and implementation with other control areas
  - Grid support services, which encompass more narrowly defined ancillary services (AGS), are those services required to balance supply and demand in less than maximum output and should be located near the load, especially when the net amount and cost of grid support services required to balance the interchange are significant.

FINANCIAL RISK

Financial value of DPV is positive when financial risk or overall market price is reduced due to reductions in fuel costs.

Two components considered in the studies reviewed are:

- **Fuel Price Hedge**: The cost that a utility would otherwise incur to guarantee that a portion of electricity supply costs are fixed due to the addition of DPV. Two components considered in the studies reviewed are:
  - Market Price Response: The price impact as a result of DPV's reducing demand for centrally-supplied electricity and the fuel that powers those generators, thereby lowering electricity prices and potentially commodity prices.
  - Security Risk: The market price of DPV is positive when grid reliability and resiliency are increased by (1) reducing outages by reducing congestion along the T&D network, (2) reducing large-scale outages by increasing the diversity of the electricity system's generation portfolio with smaller generators that are geographically dispersed, and (3) providing backup power through the combination of PV, control technologies, inverters and storage.

SECURITY RISK

Security value of DPV is positive when grid reliability and resiliency are increased by (1) reducing outages by reducing congestion along the T&D network, (2) reducing large-scale outages by increasing the diversity of the electricity system's generation portfolio with smaller generators that are geographically dispersed, and (3) providing backup power through the combination of PV, control technologies, inverters and storage.
The studies reviewed in this report defined social value in economic terms. The social value of DPV was positive when DPV resulted in a net increase in jobs and local economic development. Key drivers include the number of jobs created or displaced, as measured by a job multiplier, as well as the value of each job, as measured by average salary and/or tax revenue. Key drivers include the number of jobs created or displaced, as measured by a job multiplier. Environmental value of DPV is positive when DPV results in a net increase in jobs and local economic development.

**Environmental Value**

- **Carbon**
  - The value from reducing carbon emissions is driven by the emission intensity of the displaced marginal resource and the price of emissions.
- **Criteria Air Pollutants**
  - The value from reducing criteria air pollutant emissions—NOx, SO2, and particulate matter—is driven by the cost of abatement technologies, the market value of the displaced marginal resource, and the price paid for water in competing sectors.
- **Water**
  - The value from reducing water use is driven by the differing water consumption patterns associated with different generation technologies, and is sometimes measured by the price paid for water in competing sectors.
- **Land**
  - The value associated with land is driven by the difference in the land footprint of displaced marginal resource or displaced marginal resource being displaced.

**Avoided Renewable Portfolio Standard costs (RPS)**

- The value derived from meeting electricity demand through DPV which reduces total demand that would otherwise have to be met and the associated renewable energy that would have to be procured as mandated by an RPS.

**Social Value**

- **Avoided Renewable Portfolio Standard costs (RPS)**
  - The value derived from meeting electricity demand through DPV which reduces total demand that would otherwise have to be met and the associated renewable energy that would have to be procured as mandated by an RPS.

**Social**

- **Land**
  - The value associated with land is driven by the difference in the land footprint of displaced marginal resource or displaced marginal resource being displaced.
- **Avoided Renewable Portfolio Standard costs (RPS)**
  - The value derived from meeting electricity demand through DPV which reduces total demand that would otherwise have to be met and the associated renewable energy that would have to be procured as mandated by an RPS.
- **Water**
  - The value from reducing water use is driven by the differing water consumption patterns associated with different generation technologies, and is sometimes measured by the price paid for water in competing sectors.
- **Land**
  - The value associated with land is driven by the difference in the land footprint of displaced marginal resource or displaced marginal resource being displaced.
The California Standard Practice Manual established the general standard for evaluating the flow of benefits and costs for solar PV projects. This framework was adapted to illustrate the flow of benefits and costs among stakeholders. The flow of benefits and costs of energy efficiency among stakeholders was adapted to illustrate the flow of benefits and costs among stakeholders.
<table>
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<tr>
<th>Stakeholder Perspective</th>
<th>Economy Perspective</th>
</tr>
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<tbody>
<tr>
<td>We want to have a predictable return on my investment, and I want to be compensated for benefits I provide.</td>
<td>We want improved air/water quality as well as an improved economy.</td>
</tr>
<tr>
<td>Benefits include the reduction in the customer’s utility bill, any incentive paid by the utility or other third parties, and any federal, state, or local tax credit received. Costs include the cost of the equipment and materials purchased (incl. tax &amp; installation), ongoing O&amp;M, removal costs, and the customer’s time in arranging the installation.</td>
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</tr>
<tr>
<td>Benefits include the reduction in the customer’s utility bill, any incentive paid by the utility or other third parties, and any federal, state, or local tax credit received. Costs include the cost of the equipment and materials purchased (incl. tax &amp; installation), ongoing O&amp;M, removal costs, and the customer’s time in arranging the installation.</td>
<td></td>
</tr>
<tr>
<td>Incentives, decreased revenue, integration &amp; interconnection costs. Benefits include the reduction in transmission, distribution, and generation, and grid support services.</td>
<td></td>
</tr>
<tr>
<td>Costs include administrative costs, rebates/incentives, and decreased revenue that is offset by increased rates.</td>
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</tr>
</tbody>
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Factors affecting value

STAKEHOLDER PERSPECTIVES
ANALYSIS OVERVIEW

summary of benefits and costs

detail categories of benefits and costs

ANALYSIS FINDINGS
This analysis includes 16 studies, reflecting diverse DPV penetration levels.
SUMMARY OF DPV BENEFITS AND COSTS

- **Monetized** benefits and costs include financial, energy, and social values.
- **Inconsistently Monetized** benefits and costs are not consistently included in studies.
- **Inconsistent Monetized** benefits and costs are inconsistently included in studies.

**BENEFITS AND COSTS OF DISTRIBUTED PV BY STUDY**

**INSIGHTS**

- No study comprehensively evaluated energy, social, and environmental benefits and costs.
- There is a significant range of estimated values.
- Results are sensitive to assumptions, methodologies, and local context.
- Studies often reported costs but not benefits.
- Costs are often more detailed than benefits in studies.
- There is a lack of consistency in monetization approaches.

**NOTE:** As of 2012, the study did not evaluate costs for cross-border operations.

- The LBNL study (2008) is a meta-analysis of previous studies.
- The NREL study (2008) is a meta-analysis of previous studies.
- The CPR study (NY) (2008) includes cost and revenue analysis.
- The CPR study (AZ) (2013) includes cost and revenue analysis.
- The CPR study (TX) (2013) includes cost and revenue analysis.
- The CPR study (NJ/PA) (2012) includes cost and revenue analysis.
- The CPR study (NY) (2013) includes cost and revenue analysis.
- The CPR study (CO) (2012) includes cost and revenue analysis.
- The CPR study (CA) (2013) includes cost and revenue analysis.
- The APS study (2013) includes cost and revenue analysis.
- The APS study (2009) includes cost and revenue analysis.

**REMARKS:**

- The power plant designs differ significantly.
- The cost estimates differ significantly.
- The benefit estimates differ significantly.
- The average local retail rate can vary significantly by location and time period.

Published Average Benefit Estimates

For a full range of values observed see the individual methodology slides.

The range in benefit estimates across studies is driven by variation in system context.

Energy range driven by fuel price volatility

Security range driven by assumptions of DPs’ ability to defer planned investment and support services (judged to be very low by most studies)

Market price response range driven by assumption of DPs’ ability to provide grid support services vs. requirement for additional grid support

Carbon range driven by value of carbon and assumed displaced fuel source (e.g., natural gas vs. coal)

Criteria pollutant range driven by methodology (mitigation cost vs. health damages for criteria air pollutants)

Environmental range based on what environmental values are included and on different approaches to estimating each value

Financial risk range driven by energy range assumptions

Social range driven by variability in job multipliers

System losses range driven by loading characteristics and granularity of marginal loss assumption (marginal vs. average)

Generation capacity range driven by timing of peak demand and the location of capacity needs

Transmission capacity range driven by assessment of DPV’s ability to defer planned investment and support services

Energy range driven by fuel price volatility

System losses range driven by loading characteristics and granularity of marginal loss assumption (marginal vs. average)

Energy range driven by fuel price volatility

System losses range driven by loading characteristics and granularity of marginal loss assumption (marginal vs. average)

Cost estimates associated with increased DPV deployment are not adequately assessed.

Costs, lost revenue to the utility, stranded assets, and costs and inefficiencies associated with throttling down existing plants.

Table: Average Cost Values for Reviewed Sources

- **Grid Support Services:** Ancillary services required by the system, such as operating reserves, voltage control, and frequency regulation, energy balancing, and scheduling / forecasting services.
- **Solar Technology:** DPV equipment (PV array, inverter, battery, etc.), engineering design, construction, as well as fixed O&M costs.
- **DPV Installed System:** Cost of land and permitting, the cost of land and interconnection cost, and the DPV installed system cost.

Other studies (for example E3 2011) include costs, but results are not presented individually in the studies and so not included.

<table>
<thead>
<tr>
<th>Source</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xcel 2013</td>
<td>CPR (NJ/PN) 2012</td>
</tr>
<tr>
<td>NREL 2008</td>
<td>LBNL 2012</td>
</tr>
<tr>
<td>Crossborder (AZ) 2013</td>
<td>E3 2012</td>
</tr>
</tbody>
</table>

Notes:
- Ancillary services required by the system.
- The power supply system adds to the overall cost of operating the power supply system.
- Lost retail rate revenues, DG incentives, and integration costs.
- All relevant costs, including infrastructure and operation.
- Ancillary services required by the system.
- Interconnection cost associated with increased deployment cost.
- Cost estimates not assessed.
Energy Value is created when DPV generates energy (kWh) that displaces the need to produce energy from another resource. There are two categories of energy value: the amount of energy that would have been generated equal to the DPV generation, and the additional energy that would have been generated but lost in delivery due to inherent inefficiencies in the transmission and distribution system.

**Approach Overview**

- Energy value is the most significant source of benefit to consumers and system operators. Energy value is frequently the most significant source of benefit.
- Energy value is the most significant source of benefit.

**Value Overview**

- Energy value is the most significant source of benefit.
- Energy value is the most significant source of benefit.

**Approach Overview**

- Energy value is the most significant source of benefit.
- Energy value is the most significant source of benefit.

**Value Overview**

- Energy value is the most significant source of benefit.
- Energy value is the most significant source of benefit.
As renewable and distributed resource (not just DPV) penetration increases, these resources will start to impact the underlying load shape differently, requiring more granular analysis to determine energy value.

### Looking Forward

With the NYMEX market ends, the regional trends reflect the greater integration of generation and demand. To accurately reflect weather drivers, demand, and generation and demand correlation, a more granular approach to determining energy value is required. Insights include:

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>More accurate daily peak value</td>
<td>More complex and less accurate resource in every hour</td>
</tr>
<tr>
<td>More accurate energy value when dispatched in operates</td>
<td>More accurate energy value when dispatched in operates</td>
</tr>
<tr>
<td>More accurate resource for on-peak</td>
<td>More accurate resource for off-peak</td>
</tr>
<tr>
<td>More accurate resource for on-peak</td>
<td>More accurate resource for off-peak</td>
</tr>
<tr>
<td>Single power plant assumed to be on the margin of dispatch</td>
<td>Single power plant assumed to be on the margin of dispatch</td>
</tr>
<tr>
<td>Simple generation, easy to determine</td>
<td>More accurate, complex analysis required</td>
</tr>
<tr>
<td>More complex analysis for solar and load profiles from the same year</td>
<td>More complex analysis for solar and load profiles from the same year</td>
</tr>
</tbody>
</table>

### Marginal Resource Characterization

The resources that DPV displaces depend on the dispatch order of other resources, when the solar is generated, and how much is generated. The resources that DPV displaces depend on the dispatch order of other resources, when the solar is generated, and how much is generated.

### Insights & Implications

- Accurately defining the marginal resource that DPV displaces requires an increasingly sophisticated approach as DPV penetration increases.
- Accurately defining the marginal resource that DPV displaces requires an increasingly sophisticated approach as DPV penetration increases.
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- Accurately defining the marginal resource that DPV displaces requires an increasingly sophisticated approach as DPV penetration increases.

### Sensitivities to Key Input Assumptions

- Natural Gas Cost for Power Plants (cents/Mbtu)
- Electric Generation:
- Natural Gas Cost Sensitivity
- Heat Rate:
- Value of Wholesale Energy (cents/kWh $2012)
- Energy (cents/kWh $2012)
Some studies also report geographic gradients of energy losses. Energy losses are generally reported as a value, although the value of energy losses is not transparent. System losses are generally recognized as a value, although the value of energy losses is not transparent. Some studies recognize energy losses, some recognize capacity, some recognize hedging values, and some recognize environmental benefits. Some studies report energy losses, some report capacity losses, and a few recognize environmental losses.

**Approach Overview**

The utilization of the transmission & distribution systems, the greater the energy losses. Because energy losses are proportional to the inverse of current squared, the higher the current, the higher the losses. Energy losses also represent a significant variable in determining the value of energy losses, the value of energy losses is not transparent. Energy losses are generally recognized as a value, although the value of energy losses is not transparent. System losses are generally recognized as a value, although the value of energy losses is not transparent. Some studies recognize energy losses, some recognize capacity, some recognize hedging values, and some recognize environmental benefits. Some studies report energy losses, some report capacity losses, and a few recognize environmental losses.

**System Context**

Congestion - Energy losses are proportional to the inverse of current squared, the higher the current, the higher the losses. Energy losses also represent a significant variable in determining the value of energy losses, the value of energy losses is not transparent. System losses are generally recognized as a value, although the value of energy losses is not transparent. Some studies recognize energy losses, some recognize capacity, some recognize hedging values, and some recognize environmental benefits. Some studies report energy losses, some report capacity losses, and a few recognize environmental losses.

**Methodologies**

- Some studies estimate losses by applying loss factors based on actual observation, others develop theoretical loss factors based on system modeling. Further, some utility systems have higher losses than others.
- Some studies apply an average loss factor to all energy generated by DPV, others apply peak/off-peak factors, and others conduct hourly analyses.
- Some studies recognize energy losses, some recognize capacity, some recognize hedging values, and some recognize environmental benefits. Some studies report energy losses, some report capacity losses, and a few recognize environmental losses.
WHAT ARE SYSTEM LOSSES?

In system losses, the square of the reduced load and associated capacity benefit is proportional to the power plant or customer equipment. Energy transmission and distribution system, not those in transmission, are energy intensive (electrical resistance) in the power plant or customers equipment. Energy losses are those driven by inherent inefficiencies (electrical resistance) in the system. For the purposes of this discussion document, relevant losses are those driven by inherent inefficiencies.

Some energy generated at a power plant is lost as energy or stored in reverse or energy. For every one unit of energy saved or generated close to where it is needed, 10 units of primary energy are saved. Losses will change over time due to changes in transmission and distribution infrastructure and customer behavior.

FOR THE PURPOSES OF THIS DISCUSSION DOCUMENT, RELEVANT LOSSES ARE THOSE DRIVEN BY INHERENT INEFFICIENCIES (ELECTRICAL RESISTANCE) IN THE POWER PLANT OR CUSTOMER EQUIPMENT. ENERGY LOSSES ARE PROPORTIONAL TO THE SQUARE OF CURRENT, AND ASSOCIATED CAPACITY BENEFIT IS PROPORTIONAL TO THE SQUARE OF CURRENT.

LOOKING FORWARD

Losses will change over time as the loading on transmission and distribution infrastructure changes due to changes in transmission and distribution infrastructure and customer behavior.

INSIGHTS & IMPLICATIONS

• All relevant system losses—energy, capacity, and environment—should be assessed.
• When calculating losses, it's critical to reflect marginal losses, not just average losses.
• Because losses are driven by the square of current, losses are significantly higher during peak periods.
• Whether or not losses are ultimately represented as an adder to an underlying value or as a stand-alone value, they are generally calculated separately. Studies should distinguish these values from the underlying value of a stand-alone system.

The combination of changing customer demand and DPV generation makes it difficult to drive consistency of methodology. Value for transparency and to drive consistency of methodology, relevant losses are those driven by inherent inefficiencies (electrical resistance) in transmission and distribution infrastructure, not those in the power plant or customer equipment. Energy losses are proportional to the square of current, and associated capacity benefit is proportional to the square of current.
**Generation Capacity Value**

Generation capacity value is the amount of central generation capacity that can be deferred or avoided due to the installation of DPV. Key drivers of value include:

1. **DPV's effective capacity**
2. **System capacity needs**

**Approach Overview**

Generation capacity value is the avoided cost of the marginal capacity resource, most frequently assumed to be a gas combustion turbine, and based on a calculation of DPV effective capacity (e.g., Crossborder (AZ), 2013).

**Inputs Assumptions**

- **Marginal resource**
- **Formulation of DPV effective capacity**
- **Minimum DPV required to defer capacity**
- **Inclusion of losses**

**Methodologies**

- **Value**
- **System Context**

**Why and How Values Differ**

- **Notation and terminology**
- **Value** includes capacity losses as well as capacity value rather than just the prevention of a capacity investment.

**Reviewed Studies**

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xcel</td>
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<td></td>
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<tr>
<td>APS</td>
<td>2013</td>
<td></td>
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<tr>
<td>Crossborder (AZ)</td>
<td>2013</td>
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<tr>
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<tr>
<td>NREL</td>
<td>2008</td>
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<tr>
<td>CPR (NY)</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td>AE/CPR</td>
<td>2006</td>
<td></td>
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<tr>
<td>Vote Solar</td>
<td>2005</td>
<td></td>
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<tr>
<td>R. Duke</td>
<td>2005</td>
<td></td>
</tr>
</tbody>
</table>

**Inception of DPV Required to defer capacity**

- Some studies include capacity losses as an order to capacity value rather than just the prevention of a capacity investment.

**Key Terms**

- Power flow: the flow of electric power from source to load.
- Capacity: the ability of a system to meet a demand.
- Tariff: a rate schedule for the sale of goods or services.
- Load: the total amount of power consumed by a system.
- Generation: the production of electric power from a primary energy source.

**Conclusion**

The ability to avoid or defer capacity depends on the interplay of several factors, including load growth, system capacity needs, and the characteristics of the DPV resource. Understanding these interactions is crucial for accurately estimating the value of DPV in deferment or avoidance scenarios.
Insights & Implications

Generaton capacity is one of the values most likely to change most quickly with increasing DPV power. Beyond DPV, it’s important to note that a shift towards more renewables could change the underlying economic landscape. Resources that are expensive when DPV is lower and (2) increasing DPV penetration could lower the peak to later in the day when DPV generation is lower and (2) increasing DPV penetration could have the effect of pushing the peak.

Therefore, the underlying load shape and therefore even the concept of a peak could begin to shift. Similarly, the underlying load shape, and therefore even the concept of a peak could begin to shift. Similarly, the underlying load shape, and therefore even the concept of a peak could begin to shift.

While effective load carrying capacity (ELCC) assesses DPV’s contribution to reliability, generation capacity value is key to changing significantly as more DPV and more renewables are expected.

Generation capacity value is key to changing significantly as more DPV and more renewables are expected. Or, planned DPV, or even DPV that has been added without any additional system demand.

Looking Forward

Generation capacity is one of the values most likely to change most quickly with increasing DPV penetration. Key reasons for this are (1) increasing DPV penetration could lower the peak to later in the day when DPV generation is lower and (2) increasing DPV penetration could have the effect of pushing the peak to later in the day when DPV generation is lower and (2) increasing DPV penetration could have the effect of pushing the peak.

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The value also depends on whether new capacity is needed on the system, and therefore whether DPV defers new capacity. It’s important to assess what capacity would have been needed without any additional system demand.

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VALUE OVERVIEW

The transmission and distribution (T&D) capacity value is a measure of the net change in T&D infrastructure as a result of the addition of DPV. Benefits occur when DPV is able to meet rising demand locally, relieving capacity constraints and deferring or avoiding transmission or distribution upgrades. Costs are incurred when additional transmission or distribution investment is necessary to support the addition of DPV, which could occur when the amount of solar energy exceeds the demand in the local area and increases the need for capacity.

APPROACH OVERVIEW

Some studies include the marginal benefit of deferred T&D capacity due to avoided losses, while others include the losses separately.

- **Benefits**
  - Increased value of capacity due to deferred T&D investments
  - Reduced peak demand
  - Improved system reliability
  - Decreased maintenance costs

- **Costs**
  - Increased capital costs of T&D infrastructure
  - Increased operational costs
  - Increased emissions

**Methodologies**

- Generalizations across service territories:
  - By level of granularity in which T&D investment plans were assessed—project by project or broader

**Input Assumptions**

- System context:
  - Locational characteristics
  - Projected load growth/T&D capacity investment plan

- Solar characteristics:
  - Timing of energy production from DPV and its coincidence with system peaks
  - The length of time that T&D can be deferred by the installation of DPV varies by the rate of load growth, the assumed effective capacity of the DPV, and its correlation with peak.

- The length of time the investment is deferred:
  - The cost of capital saved will increase with the length of deferment.

**Studies Estimates as Reported by Reviewed T&D Capacity Benefit and Cost**

<table>
<thead>
<tr>
<th>Study</th>
<th>T&amp;D Capacity Benefit and Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xcel, 2013</td>
<td>APS, 2013</td>
</tr>
<tr>
<td>APS, 2009</td>
<td>NREL, 2008</td>
</tr>
<tr>
<td>AE/CPR, 2006</td>
<td>Vote Solar, 2005</td>
</tr>
</tbody>
</table>

**Note:** Benefits and costs are reflected separately in the chart. If only benefits are shown, the study did not represent costs.

**Value Overview**

TRANSMISSION & DISTRIBUTION

**Approach Overview**

The transmission and distribution (T&D) capacity value is a measure of the net change in T&D infrastructure as a result of the addition of DPV. Benefits occur when DPV is able to meet rising demand locally, relieving capacity constraints and deferring or avoiding transmission or distribution upgrades. Costs are incurred when additional transmission or distribution investment is necessary to support the addition of DPV, which could occur when the amount of solar energy exceeds the demand in the local area and increases the need for capacity.
Strategically targeted DPV deployment can relieve T&D capacity constraints by providing power close to demand areas. This includes technologies that allow distribution planning that incorporates energy resources. Such DPV’s can defer or avoid transmission and distribution capacity investments, thus delaying the need for new infrastructure.

Insights & Implications (Cont’d)

Looking Forward

There are significantly differing approaches to the ability of DPV to allocate T&D capacity dependent on location, characteristics such as local hourly PV production and correlation with local load. The distribution system requires more geographic specificity due to the local distribution system. PV at the distribution level may provide less generation but may be more cost-effective compared to centralized generation at higher levels. While the ability to defer or avoid transmission is still location dependent, it is less so than distribution. The values of T&D of are often grouped together, but they are more complex.

Transmission & Distribution Capacity

Location Considerations at the Distribution Level

Adapted from Coddington, M. et al. Updating Interconnection Screens for PV System Integration

Feeder 1
Feeder 2
Feeder 3
Utility Substation

Penetration
40%
25%
15%
Up to
Up to
Up to
Locational Considerations for PV systems integration
First approval of PV allowance zones for fast approval of PV systems
Penetration
Location
Adapted from Coddington, M. et al. Updating Interconnection Screens for PV System Integration

The T&D network (especially during peak hours), the T&D network could potentially provide T&D value. This includes technologies that allow distribution planning that incorporates energy resources, such as DPV, into the education. Distribution planning that incorporates energy resources, such as DPV, into the education. Distribution planning that incorporates energy resources, such as DPV, into the education. Distribution planning that incorporates energy resources, such as DPV, into the education. Distribution planning that incorporates energy resources, such as DPV, into the education.
Grid support services, also commonly referred to as ancillary services (AS), are required to enable the reliable operation of interconnected electric grid systems, including operating reserves, reactive supply and voltage control; frequency regulation; energy imbalance; and scheduling.

APPROACH OVERVIEW

There is significant variation across studies in how the addition of PV will impact the need for grid support services and the associated costs. Differences in the methodologies utilized across studies are significant.

WHY AND HOW VALUES DIFFER

System Context:
- Reliability standards and market rules
- Market price of AS
- Performance characteristics of existing generation mix
- Local PV penetration
- System generation mix
- Supply and demand patterns

Methodologies:
- Effective capacity of PV
- Correlation of AS needs with reduced load and reduced operating reserves
- Market value of non-spinning reserves
- Meta-analysis

VALUE OVERVIEW

Grid support services are commonly referred to as ancillary services (AS) in wholesale energy markets, and are intended to support the grid by enabling the reliable operation of interconnected electric grid systems. Grid support services include providing regulation, frequency regulation, energy imbalance, and scheduling. Different methodologies are used across studies to estimate the impact of PV on grid support services and the associated costs.
Grid Support Services

The potential for DPV to provide grid support services is significant. However, it is likely that the net value of these services will increase with penetration levels of distributed energy resources and variable renewable generation. As with large scale renewable integration, there is still controversy over determining the net value of a grid resource without marked improvement in methodologies or quantification of the provision of grid services. The ability of DPV to provide grid support requires technological development or additions, such as advanced inverters, to meet the needs of the system.

Grid Support Services (cont’d)

INSGHTS & IMPLICATIONS

Looking Forward

Increasing levels of distributed energy resources and variable renewable generation will begin to shift the need for grid support services. The ability of DPV to provide these services increases with penetration level.

Insights & Implications

As with large scale renewable integration, there is still controversy over determining the net value of a grid resource without marked improvement in methodologies or quantification of the provision of grid services.

Operating Reserves

Additional balance and uncertainty from large penetrations of DPV may require additional reserves. However, these services will provide support for the grid at a reduced cost. As with large scale renewable integration, there is still controversy over determining the net value of a grid resource without marked improvement in methodologies or quantification of the provision of grid services.
FUEL PRICE HEDGE BENEFIT AND COST ESTIMATES AS REPORTED BY REVIEWED STUDIES

VALUE OVERVIEW

DPV produces roughly constant-cost power compared to fossil fuel generation, which is tied to potentially volatile fuel prices. DPV can provide a "hedge" against price volatility, reducing risk exposure to utilities.

APPROACH OVERVIEW

More than half the studies reviewed acknowledge DPV's fuel price hedge benefit, although fewer quantify it and those that do take different approaches. Although conceptually similar, approaches differ in how much and volatility are accounted. A study did not represent costs, therefore values reflect hedge only. Note: Benefits and costs are reflected separately in chart. If only benefits are shown, study did not represent costs.

INSIGHTS & IMPLICATIONS

NYMEX futures market prices are an adequate reflection of volatility in the years in which it operates.

WHY AND HOW VALUES DIFFER

System Context:
- Marginal resource characterization
  - What resource is on the margin, and therefore how much fuel is displaced varies.
- Exposure to fuel price volatility
  - Most utilities already hedge some portion of their natural gas purchases for some period of time in the future.

Methodologies:
- Approach to estimating value
  - While most studies agree that NYMEX futures prices are an adequate reflection of volatility, there is no largely agreed upon approach to estimating volatility beyond that NYMEX futures prices are an adequate reflection of volatility in the years in which it operates.
- Estimating volatility
  - While most studies agree that NYMEX futures prices are an adequate reflection of volatility, there is no largely agreed upon approach to estimating volatility beyond that NYMEX futures prices are an adequate reflection of volatility in the years in which it operates.
- Escalating NYMEX prices as a constant rate, under the assumption that doing so would continue to reflect hedge value (Crossborder (AZ) 2013); or
- Estimating volatility separately as the value or an option/swap, or as the actual price adder the utility is incurring now to hedge gas prices (CPR (NJ/PA) 2012), NREL 2008).

- Retaining hedge value (Crossborder (AZ) 2013); or
- Estimating volatility separately as the value or an option/swap, or as the actual price adder the utility is incurring now to hedge gas prices (CPR (NJ/PA) 2012), NREL 2008).

- Estimating volatility separately as the value or an option/swap, or as the actual price adder the utility is incurring now to hedge gas prices (CPR (NJ/PA) 2012), NREL 2008).

Note: Benefits and costs are reflected separately in chart. If only benefits are shown, study did not represent costs.

FINANCIAL: FUEL PRICE HEDGE
The addition of DPV, especially at higher penetrations, can affect the market price of electricity in a particular market or service territory. These market price effects span energy and capacity values in the short term and long term, all of which are interrelated. Benefits can occur as DPV provides electricity close to demand, reducing the demand for centrally-supplied electricity and the fuel powering those generators, thereby lowering electricity prices and potentially fuel commodity prices. A related benefit is derived from the effect of DPV’s contribution at higher penetrations to reshaping the load profile that central generators need to meet. Depending upon the correlation of DPV production and load, the peak demand could be reduced and the marginal generator could be more efficient and less costly, reducing overall electricity costs. These benefits could be monetized by adjusting downward the marginal value of energy that DPV would displace. However, for the purposes of the study, E3 2012 did not add this as a benefit to the avoided cost because they “assume the market price effect would also occur with alternative approaches to meeting [CA’s] RPS.”

While several studies evaluate a market price response of DPV, distinct approaches were employed by E3 2012, CPR (NJ/PA) 2012, and NREL 2008.

E3 2012 incorporated market price effects by adjusting market prices downward in its high penetration case. They note that the market price effect would also occur with alternative approaches to meeting CA’s RPS. E3 2012 incorporated potential feedback effects between the energy and capacity markets by assuming a market price calibration factor. That is, it assumes that, in the long run, the CCGT’s energy market revenues plus the capacity payment equal the fixed and variable costs of the CCGT. Therefore, a CCGT would collect more revenue through the energy market and capacity market than is needed to cover its costs.

CPR (NJ/PA) 2012 incorporates market price effect “by reducing demand during the high priced hours resulting in a cost savings realized by all consumers.” They note “that further investigation of the methods may be warranted in light of two arguments...that the methodology does not address induced increase in demand due to price reductions, and that it only addresses short-run effects (ignoring the feedback effects).”

Insights & Implications

• The market price reduction value only assesses the initial market reaction of reduced price, not subsequent market dynamics (e.g., increased demand in response to price reductions, or the impact on the capacity market), which has to be studied and considered, especially in light of higher penetrations of DPV.

• The market price reduction value only assesses the initial market reaction of reduced price, not the feedback effects. CPR (NJ/PA) 2012 incorporated market price effects by reducing demand during the high priced hours. E3 2012 incorporated market price effects in its high penetration case by adjusting downward the marginal value of energy that DPV would displace. However, for the purposes of the study, E3 2012 did not add this as a benefit to the avoided cost because they “assume the market price effect would also occur with alternative approaches to meeting CA’s RPS.”

• Considering market price effects is essential to determining the full cost of DPV. The market price response of DPV, distinct approaches were employed by E3 2012, CPR (NJ/PA) 2012, and NREL 2008.

Approach Overview

The energy market could have a feedback effect by raising capacity prices. The non-price effects of DPV, which could result in higher demand, also cause energy markets to respond to the higher penetration of DPV. These market price effects can impact energy and capacity values in the short term and long term. The addition of DPV especially at higher penetrations, can affect the market price of electricity in a particular market or service territory. These market price effects can impact energy and capacity values in the short term and long term. The addition of DPV especially at higher penetrations, can affect the market price of electricity in a particular market or service territory.
The grid could also play a role in
network (especially during peak hours). Any distributed technologies with the capability to be isolated from the grid would make them less vulnerable to the impacts of weather. Increasing electricity consumption.

Disruption value is a measure of the damages of outage and power- quality interruptions on the increased probability of these events occurring.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>0.028</td>
<td>0.41</td>
</tr>
<tr>
<td>Commercial</td>
<td>11.77</td>
<td>14.40</td>
</tr>
<tr>
<td>Industrial</td>
<td>0.4</td>
<td>1.99</td>
</tr>
</tbody>
</table>

Source: The National Research Council, 2010

Disruption Value Range by Sector

Insights & Implications

- The value of increased reliability is significant, but there is a need to quantify and demonstrate how much value can be provided by DPV.
- Opportunities to leverage combinations of distributed technologies to increase customer reliability and reduce the incidence of outages can only be realized if DPV is coupled with storage and equipped with the capability to island itself from the grid.

Looking Forward

Any distributed resource that can be isolated near the end user to reduce use of, and congestion along, the T&D network could potentially reduce transmission stress. This includes technologies that allow energy to be generated locally, with the potential to reduce demand and stress on the network. The value of DPV in increasing supply during outages can only be realized if DPV is coupled with storage and equipped with the capability to island itself from the grid.

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<td>Industrial</td>
<td>0.4</td>
<td>1.99</td>
</tr>
</tbody>
</table>

Source: The National Research Council, 2010

Disruption Value Range by Sector

Approach Overview

1. The potential to reduce damages by reducing congestion along the T&D network, power outages and storage.
2. The ability to reduce high- and peak-period demand by increasing the diversity of the energy system.
3. The potential for co-locating generation with other technologies to achieve the benefits.
The benefits of reducing carbon emissions include (1) reducing future compliance costs, carbon taxes, or other fees, and (2) mitigating the health and ecosystem damages potentially caused by climate change.

The approach overview

By and large, studies that addressed carbon focused on the compliance costs or fees associated with future carbon emissions, and conclude that carbon reduction can increase PV's value by more than two cents per kilowatt-hour, depending heavily on the price placed on carbon. While there is some agreement that carbon reduction provides value and on the general formulation of carbon value, there are widely varying assumptions, and not all studies include carbon value.

Carbon reduction benefit is the amount of carbon displaced times the price of reducing a ton of carbon. The amount of carbon displaced is directly linked to the amount of energy displaced, when it is displaced, and the carbon intensity of the resource being displaced.

Why and how values differ

Cultural, economic, and sociopolitical differences can significantly impact different regions.

Environmental Resource Characterization - Different resources may be on the margin in different regions.

Input Assumptions:

• The assumed efficiency of the marginal power plant is directly correlated to amount of carbon displaced by DPV.
• The assumed efficiency of the marginal power plant is directly correlated to amount of carbon displaced by DPV.
• The assumed efficiency of the marginal power plant is directly correlated to amount of carbon displaced by DPV.
• The assumed efficiency of the marginal power plant is directly correlated to amount of carbon displaced by DPV.

Methodologies:

• There is no common approach to whether carbon is represented as a stand-alone value (for example, NREL 2008 and E3 2012) or as an adder to energy value (for example, APC 2013).
• There is no common approach to whether carbon is represented as a stand-alone value (for example, NREL 2008 and E3 2012) or as an adder to energy value (for example, APC 2013).
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• There is no common approach to whether carbon is represented as a stand-alone value (for example, NREL 2008 and E3 2012) or as an adder to energy value (for example, APC 2013).

System Context:

• Cross-border (2012)egas combined cycle, or gas combustion turbines.
• Cross-border (2012)egas combined cycle, or gas combustion turbines.
• Cross-border (2012)egas combined cycle, or gas combustion turbines.
• Cross-border (2012)egas combined cycle, or gas combustion turbines.

Studies that Group All Environmental Values

• Cross-border (2012)egas combined cycle, or gas combustion turbines.
• Cross-border (2012)egas combined cycle, or gas combustion turbines.
• Cross-border (2012)egas combined cycle, or gas combustion turbines.
• Cross-border (2012)egas combined cycle, or gas combustion turbines.

Studies that Evaluate Carbon Separately

• Cross-border (2012)egas combined cycle, or gas combustion turbines.
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• Cross-border (2012)egas combined cycle, or gas combustion turbines.
• Cross-border (2012)egas combined cycle, or gas combustion turbines.

Environmental Benefit and Cost Estimates as Reported by Reviewed Studies

• Cross-border (2012)egas combined cycle, or gas combustion turbines.
• Cross-border (2012)egas combined cycle, or gas combustion turbines.
• Cross-border (2012)egas combined cycle, or gas combustion turbines.
• Cross-border (2012)egas combined cycle, or gas combustion turbines.
Looking Forward

While there has been no federal action on climate over the last few years, leading to greater uncertainty about potential future prices, many states and utilities continue to value carbon as a reflection of assumed environmental protection benefits. The amount of carbon displaced by solar depends on the dispatch order of other resources, when the solar is generated, and how much is generated.

Insights & Implications

Just as with energy value, carbon value depends heavily on what the marginal resource is that is being displaced. The same determination of the marginal resource should be used to drive both energy and carbon values.

While there is little agreement on what the $/ton price of carbon is or should be, it is likely non-zero.
ENVIRONMENT: OTHER FACTORS

In addition to carbon, DPV has several other environmental benefits (or potentially costs) that, while commonly acknowledged, are included in only a few of the studies reviewed here. That said, there is a significant body of thought for each outside the realm of DPV cost/benefit valuation, some of which is referenced below.

CRITERIA AIR POLLUTANTS

SUMMARY:

Criteria air pollutants (NOₓ, SO₂, and particulate matter) released from the burning of fossil fuels can produce both health and ecosystem damages. The economic cost of these pollutants is generally estimated as: 

1. The compliance costs of reducing pollutant emissions from power plants, or AVAIDED RENEWABLE PORTFOLIO STANDARD (RPS)

2. The estimated costs of damages, such as medical expenses for asthma.

VALUE:

Crossborder (CA) 2012 estimated the value of criteria air pollutant reductions, based on APS’s Integrated Resource Plan, to be $0.2-1.4/MWh (2012$). NREL 2008 estimated the value of criteria air pollutant reductions, based on APS’s Integrated Resource Plan, to be $0.365/MWh (2012$). CPR (NJ/PA) 2012 also acknowledged criteria air pollutants, but estimated cost based on a combined environmental value.

RESOURCES:

In addition to carbon, DPV has several other environmental benefits (or potentially costs) that, while commonly acknowledged, are included in only a few of the studies reviewed here. That said, there is a significant body of thought for each outside the realm of DPV cost/benefit valuation, some of which is referenced below.

**ENVIRONMENT: OTHER FACTORS**

In addition to pollution, DPV has several other environmental benefits (or potentially costs) that, while commonly acknowledged, are included in only a few of the studies reviewed here. That said, there is a significant body of thought for each outside the realm of DPV cost/benefit valuation, some of which is referenced below.

**WATER**

Coal and natural gas power plants withdraw and consume water primarily for cooling. Approaches to valuing reduced water usage have focused on the cost of water or water in competing sectors, potentially including municipal, agricultural, and environmental/ecological uses.

**LAND**

DPV can impact land in three ways:

1. Change in property value with the addition of DPV,
2. Land requirement for DPV installation, or
3. Ecosystem impacts of DPV installation.

**RESOURCES**

Tellinghulsen, S., *Every Drop Counts*. Western Resources Advocates, Jan 2011.


The assumed social value from DPV is based on any job and economic growth benefits that DPV brings to the economy, including jobs and higher tax revenue. The value of economic development depends on the economic growth benefits that DPV brings to the economy.

**Approach Overview**

Very few studies reviewed quantify employment and tax revenue value, although a number of them did not clearly distinguish social and local communities from economic and quaternary jobs. The latter is higher to society and local communities, from economic and quaternary jobs.

**Social: Economic Development**

**Economic Development Benefit**

<table>
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<tr>
<td>Small Hydro</td>
<td></td>
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</tbody>
</table>

**Implications and Insights**

- Employment and tax revenue may not generally be quantified in studies reviewed.
- Economic growth benefits, particularly those associated with job creation and/or tax revenue, should be included.
- Job multipliers may not reflect the range of job multipliers.
### Section Structure

#### Study Characteristics

**Study Objective**
- A brief overview of the stated purpose of the study

**Geographic Focus**
- Relevant characteristics of the electricity system analyzed

**System Context**
- Geographic region analyzed

**Stakeholder Perspective**
- Key stakeholder perspectives analyzed (e.g., participants, ratepayers)

**Granularity of Analysis**
- Level of granularity reflected in the analysis
- How the solar generation profile is established (e.g., actual insolation data vs. modeled)
- Whether the marginal resources and losses are calculated on a marginal or average basis
- How the marginal losses characterization - whether the method is based on a marginal or average basis

#### Tools Used

- Key modeling tools used in the analysis

#### Key Components Included in Each Study Overview

- **Overviews of Value Categories**
- **Keyholders' Perspectives**
- **Level of Solar Analyzed**
- **System Context**
- **Geographic Focus**

#### Highlights

The study's approach, key drivers of results, and findings.

<table>
<thead>
<tr>
<th>Key Modeling Tools Used in the Analysis</th>
<th>Tools Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Geographic granularity - Approach to estimating locationally dependent benefits or costs (e.g., distribution feeders)</td>
<td></td>
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<tr>
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<td></td>
</tr>
<tr>
<td>- Approach to estimating locationally dependent benefits or costs (e.g., distribution feeders)</td>
<td></td>
</tr>
</tbody>
</table>

The chart above depicts the average values by category explored in each study.
Energy:

Energy provides the largest source of value to the APS system. Value is calculated based on a PROMOD hourly commitment and dispatch simulation. DPV reduces fuel, purchased power requirements, line losses, and fixed O&M. The natural gas price forecast is based on NYMEX forward prices with adjustment for delivery to APS's system.

Generation Capacity:

There is little, but some, generation capacity value. Generation capacity value does not differ based on the geographic location of solar, but generation capacity investments are "lumpy," so a significant amount of solar is needed to displace it. Transmission capacity value includes benefits from reduced losses.

T&D Capacity:

There is very little distribution capacity value, and what value exists is very little (distribution capacity is determined as the ELCC). Since distribution capacity is often determined by geographical location of solar generation, the geographic location of solar is critical to the T&D capacity value. There is little, but some, transmission capacity value since value does not differ based on the geographic location of solar, but transmission investments are "lumpy," so a significant amount of solar is needed to displace it.

Tools Used:

SAM 2.0; ABB's Feeder-All; EPRI's Distribution System Simulator; PROMOD

Understand the key operating impacts:

- To determine the potential value of DPV for Arizona Public Service, and to understand the likely operating impacts.

Key Findings:

- Value was measured incrementally in 2010, 2015, and 2025. The study approach combined system modeling, empirical testing, and information review, and represents one of the more technically rigorous approaches of reviewed studies.

- The study determines that total value decreases over time, primarily driven by decreasing generation capacity value.

- The study acknowledges but does not quantify a number of other values including job creation, a more sustainable environment, carbon reduction, and increased worker productivity.

- The study acknowledges that the study is that generation, transmission, and distribution capacity value can only be given to DPV when it actually defers or avoids a planned investment.

- The implications are that a certain minimum amount of DPV must be installed in a certain time period (and in a certain location for distribution capacity) to create value.

- The study determined that total value decreases over time, primarily driven by decreasing capacity value. Increasing levels of DPV effectively push the system peak to later hours.

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Generation Capacity: Generation capacity value is highly dependent on DPV's dependable capacity during peak. Generation capacity value is based on PROMOD simulations, and results in the deferral of combustion turbines. Benefits from avoided energy losses are included as part of capacity value, and unlike the 2009 report, are based on a recorded peak demand loss. Like the 2009 study, generation capacity value is based on an ELCC calculation.

T&D Capacity: The study concludes that there are an insufficient number of feeders that can defer capacity upgrades based on non-targeted solar PV installations to determine measurable capacity savings. Distribution capacity savings can only be realized if distributed solar systems are installed at adequate penetration levels and located on specific feeders to relieve congestion or delay specific projects, but solar adoption has been geographically dispersed. Distribution value includes reduced losses, capacity, extended service life, and reduced equipment sizing.

Transmission capacity value is highly dependent on DPV's dependable capacity during peak. No transmission projects can be deferred more than one year, and none past the target years. As with the 2009 study, DPV dependable capacity for the purposes of T&D benefits is calculated based on a 90% confidence of generation during peak summer hours. Benefits from avoided energy losses are included.

**Tools Used**
- PVWatts
- EPRI's Distribution Feeder Model
- PROMOD

**Highlights**
- Value was measured incrementally in 2015, 2020, and 2025.
- 2009 study does not show significant clustering of generation.
- 2005 study shows growth in clustered PV systems.
- The study notes the potential for increased value (primarily in T&D capacity) if DPV can be geographically targeted.
- The study concludes that there are an insufficient number of feeders that can defer capacity upgrades based on non-targeted solar PV installations to determine measurable capacity savings.
- The study concludes that there are an insufficient number of feeders that can defer capacity upgrades based on non-targeted solar PV installations to determine measurable capacity savings.
- Like the 2009 study, capacity value is assumed to be based on DPV's ability to defer planned capacity investments. Rather than assuming every installed unit of DPV defers capacity.
Energy:
Avoided energy costs are the most significant source of value. APS’s long-term marginal resource is assumed to be a combustion turbine in peak months and a combined cycle in off-peak months, and avoided energy is based on these resources.

The natural gas price forecast is based on NYMEX forward market gas prices, and the study determines that it adequately captures the fuel price hedge benefit. Key assumptions: $15/ton carbon adder, 12.1% line losses included in the energy value.

Generation Capacity:
Generation capacity value is calculated as DPV dependable capacity (based on DPV’s near-term ELCC from APS’s 2012 IRP) times the fixed costs of a gas combustion turbine. Every installed unit of DPV receives that capacity value, based on the assumption that, when coupled with efficiency and demand response, capacity would have otherwise been needed before APS’s planned investment.

T&D Capacity:
T&D capacity value is calculated as DPV dependable capacity (ELCC) times APS’s reported costs of T&D investments. Like generation capacity, every installed unit is credited with T&D capacity, with the assumption that 50% of distribution feeders can see deferral benefit. The study notes that APS could take a proactive approach to targeting DPV deployment, thereby increasing distribution value.

Grid Support (Ancillary Services):
DPV in effect reduces load and therefore reduces the need for ancillary services that would otherwise be required, including spinning and non-spinning reserves.

Environmental:
DPV effectively reduces load and therefore reduces environmental impacts. Lower load means reduced criteria air pollutant emissions and lower water use (carbon is included as an adder to energy value).

Renewable Value:
DPV helps APS meet its Renewable Energy Standard, thereby lowering APS’s compliance costs.

Solar Cost:
Since the study takes a ratepayer perspective, costs included are lost retail revenues, impacting operating costs, and integration costs.

Highlight:
The study notes that DPV must be considered in the context of efficiency and demand response—

- Projecting on solar installed over next few years, rather than examining whether there is diminishing value with increasing penetration.
- Defining peak demand hours for T&D capacity.
- Using ELCC to determine dependable capacity for generation, transmission, and distribution and deferring capacity.
- Odd even credit for every unit of solar DG installed, rather than removing solar to be determined value leveraged over 20 years, and 2013 studies include:
- The benefits of DPV on the APS system exceed the cost by more than 50%.

### Overview of Value Categories

<table>
<thead>
<tr>
<th>Category</th>
<th>2012</th>
<th>2013</th>
<th>Net Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
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<td>Gen Cap</td>
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<td>T&amp;D Cap</td>
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<td>Grid Support</td>
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<td>Environmental</td>
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<td>Avoided RPS Solar Cost</td>
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<td>Total</td>
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</tbody>
</table>

### Study Objectives

- To determine how demand-side solar will impact APS’s ratepayers; a response to the APS 2013 study.
- Arizona Public Service territory
- Vertically integrated IOU, 15% RPS by 2025
- DPV likely to be installed between 2013-2015; estimated here to be approximately 1.5%
- Ratepayers
- Secondary analysis based on SAIC and APS detailed modeling
- The benefits of DPV on the APS system exceed the cost by more than 50%.
OVERVIEW OF VALUE CATEGORIES

Solar Cost:
- from 27%-32% for fixed installations and 40%-46% for tracking PV.
- DPV across the four solar zones uses a single TMY2 generation profile which was non-serially correlated with system peak demand.
- The capacity credits range from 27%-32% for fixed installations and 40%-46% for tracking PV.

Carbon:
- The avoided emissions are calculated by using the ProSym model and using an estimated value for the remainder.
- The study concludes that the most significant avoided emissions (>90%) is due to the use of DPV.

Fuel Price Hedge Value:
- The avoided fuel price hedge was estimated using actual hourly feeder load data for the 58 feeders that represent 55% of the system.
- The avoided fuel price hedge is credited to DPV based on a 4% economic carrying charge of a generic CT's fuel price.

Carbon:
- The avoided emissions are calculated by using the ProSym model and using an estimated value for the remainder.
- The study concludes that the most significant avoided emissions (>90%) is due to the use of DPV.

Energy:
- The avoided energy costs are based on losses incurred across top 50 load hours.
- The avoided energy costs are calculated by comparing ProSym simulations with and without DPV, and on a peak basis for generation capacity.

Emissions:
- The avoided emissions are calculated by using the ProSym model and using an estimated value for the remainder.
- The study concludes that the most significant avoided emissions (>90%) is due to the use of DPV.

Avoided T&D lines losses were assumed to achieve savings in energy, emissions, and fuel hedge value.

Highlights

- Energy value was calculated by comparing ProSym simulations with and without DPV.
- For the study, Xcel updated its ELCC calculations that are used to estimate capacity credit.
- Change in marginal emissions over time driven by planned changes in generation fleet (primarily retirement of 1,300 MW coal in 2017).
- The capacity credits range from 27%-32% for fixed installations and 40%-46% for tracking PV.
- The study concludes that the most significant avoided emissions (>90%) is due to the use of DPV.
This study assesses overall cost-effectiveness based on five cost tests (participant cost test, ratepayer impact measure, program administrator cost, total resource cost, and societal cost) as defined in the California Standard Practices Manual, and presents total rather than itemized results. Therefore, individual results are not shown.

**Energy:** Hourly avoided value of energy measured at the point of interconnection.

**System Losses:** Losses between the delivery location and the point of wholesale energy transaction. Losses scale with energy value, and reflect changing losses at peak periods.

**Generation Capacity:** Value of avoided generation capacity to meet system peak loads, including additional capacity avoided due to decreased energy losses. DPV receives the full value of avoided capacity after the resource balance year. Value is less in the short-run (before the resource balance year) because of CAISO’s substantial planning reserve margin.

**T&D Capacity:** Value of deferring T&D capacity to meet peak loads.

**Grid Support Services (Ancillary Services):** Value based on historical ancillary services market prices, scaled with the price of natural gas. Individual ancillary services included are regulation up, regulation down, spinning reserves, and non-spinning reserves, and the procurement of each AS is affected by load reduction.

**Avoided RPS:** Value is the incremental avoided cost of purchasing renewable resources to meet California’s RPS.

**Environmental:** Value of CO₂ reduction, with $/ton price based on a meta-analysis of forecasts. Unpriced externalities (primarily health effects) were valued at $0.01-0.03/kWh based on secondary sources.

**Social:** The study acknowledges that customers who install DPV may also install more energy efficiency, but does not attempt to quantify that value. The study also acknowledges potential benefits associated with employment and tax revenues and suggests that an input-output model would be an appropriate approach, although these benefits are not quantified in this study.

The study concludes that DPV is not expected to be cost-effective for most residential customers without program incentives by 2017. The study suggests that the value of non-economic benefits of DPV should be explored to determine if and how they provide value to California.

**Tools Used**

- E3 Avoided Cost Calculator (2011)

**Trends Continued in This Study:**

- Hourly avoided value of energy measured at the point of wholesale energy transaction.
- System Losses: Losses between the delivery location and the point of wholesale energy transaction.
- Generation Capacity: Value of avoiding new generation capacity to meet system peak loads, including additional capacity avoided due to decreased energy losses.
- T&D Capacity: Value of deferring T&D capacity to meet peak loads.
- Grid Support Services (Ancillary Services): Value based on historical ancillary services market prices, scaled with the price of natural gas.
- Avoided RPS: Value is the incremental avoided cost of purchasing renewable resources to meet California’s RPS.
- Environmental: Value of CO₂ reduction, with $/ton price based on a meta-analysis of forecasts. Unpriced externalities (primarily health effects) were valued at $0.01-0.03/kWh based on secondary sources.
- Social: The study acknowledges that customers who install DPV may also install more energy efficiency, but does not attempt to quantify that value. The study also acknowledges potential benefits associated with employment and tax revenues and suggests that an input-output model would be an appropriate approach, although these benefits are not quantified in this study.

**Highlights**

- The study assesses hourly avoided costs in each of California's 16 climate zones to reflect varying climate conditions.
- The study focuses on a fuel source inclusion of DPV should be explored to determine if and how they provide value to California.
- The study focuses on seven benefits including energy, line losses, generation capacity, T&D capacity, emissions, ancillary services, and avoided RPS purchases. It focuses on costs including net energy metering bill credits, rebates/incentives, utility interconnection, costs of the DG system, net metering costs, and program administration.
- The study assesses overall cost-effectiveness based on the cost-effectiveness of the California Solar Initiative.
The estimated hourly wholesale value of energy adjusted for losses between the point of wholesale transaction and delivery. Annual forecast based on market forwards that transition to annual average market price needed to cover the fixed and operating costs of a new CCGT, less net revenue from day-ahead energy, ancillary service, and capacity markets. Hourly forecast derived based on historical hourly day-ahead market price shapes from CAISO’s MRTU system.

System losses: Losses between the delivery location and the point of wholesale transmission. Losses scale with energy value, and reflect changing losses at energy transaction. Local DPV is defined as PV sized such that its output will be consumed by load on the feeder or substation where it is interconnected. Specifically, the generation cannot backflow from the distribution system onto the transmission system.

The process for identifying sites included using GIS data to identify sites surrounding each of approximately 1,800 substations in PG&E, SDG&E and SCE. The study compared hourly load that the individual substation level to potential DPV generation at the same location. The study compared hourly load in 2012 to current system load. The avoided cost of a new CCGT less net energy, AS revenues (see Overview box) is based on the fixed cost of a new CCGT, less net energy, AS revenues.

The avoided cost of a new CCGT less net energy, AS revenues (see Overview box) is based on the fixed cost of a new CCGT, less net energy, AS revenues.

- **Average Values from Study**
  - **Solar Cost**
    - Installed system cost, the cost of land and permitting, and the interconnection cost.
  - **Total Cost**
    - The installed system cost, the cost of land and permitting, and the interconnection cost.

**Table:**

<table>
<thead>
<tr>
<th>Category</th>
<th>Average Values from Study</th>
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<td>T&amp;D</td>
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</tr>
<tr>
<td>Total</td>
<td>0</td>
</tr>
</tbody>
</table>

**Highlights**

- Local DPV is defined as PV sized such that its output will be consumed by load on the feeder or substation where it is interconnected. Specifically, the generation cannot backflow from the distribution system onto the transmission system.
- The process for identifying sites included using GIS data to identify sites surrounding each of approximately 1,800 substations in PG&E, SDG&E and SCE. The study compared hourly load that the individual substation level to potential DPV generation at the same location.
- The study compared hourly load in 2012 to current system load. The avoided cost of a new CCGT less net energy, AS revenues (see Overview box) is based on the fixed cost of a new CCGT, less net energy, AS revenues.

**T&D Capacity Value**: Value is based on the “present worth” approach to calculate deferment value, incorporating investment plans as reported by utilities.

**Grid Support Services (Ancillary Services)**: Value based on the value of avoided reserves, scaling with energy.

**Generation Capacity**: In the long-run (after the resource balance year), generation capacity value is based on the fixed cost of a new CCGT less expected revenues from real-time energy and ancillary services markets. Prior to resource balance, value is based on a resource adequacy value.
The study bases its DPV value assessment on E3's avoided cost model and approach. It updates key assumptions including updated natural gas price forecasts, greenhouse gas allowance prices, and ancillary services revenues, and excludes the resource balance year approach (the year in which avoided costs change from short-run to long-run). The study views the resource balance year as the year in which avoided costs change from short-run to long-run (from 2010 to 2012).

The study bases its DPV value assessment on E3's avoided cost model and approach. It updates key assumptions including updated natural gas price forecasts, greenhouse gas allowance prices, and ancillary services revenues, and excludes the resource balance year approach (the year in which avoided costs change from short-run to long-run). The study views the resource balance year as the year in which avoided costs change from short-run to long-run (from 2010 to 2012).

The study focuses on seven benefits: avoided energy, avoided generation capacity, avoided carbon, avoided grid support services, reduced line losses, reduced T&D investments, and avoided RPS purchases. The study's analysis reflects costs to other customers (ratepayers) from "bill credits that the utility provides to solar customers as compensation for DPV exports, plus any incremental utility costs to meter and bill DPV customers." These costs are not quantified and levelized individually in the report, so they are not reflected in the chart to the right.

The study considers that "on average over the residential markets of the state's three big IOUs, NEM does not impose costs on non-participating ratepayers, and instead creates a small net benefit." This conclusion is driven by "recent significant changes that the CPUC has adopted in IOUs' residential rate designs" plus "recognition that DPV...avoid other purchases or renewable power, resulting in a significant improvement in the economics of NEM compared to the CPUC's 2009 E3 NEM Study."}

**STUDY OBJECTIVE**
"To explore recent claims from California's investor-owner utilities that the state's NEM policy causes substantial cost shifts between energy customers with Solar PV systems and non-solar customers, particularly in the residential market." Crossborder Energy for Vote Solar Initiative, 2013
Energy: Avoided fuel and variable O&M. Natural gas fuel price multiplied by assumed heat rate of peaking power plant (9360 MMBtu/kWh). Assumed value of consumables such as water and ammonia to be approximately 0.5 cents/kWh. For non-peak, average heat rates of existing fleet of natural gas plants were used for each electric utility’s service area. Assumed heat rates: PG&E: 8740 MMBtu/kWh, SCE – 9690 MMBtu/kWh, SDG&E – 9720 BBtu/kWh.

System Losses: Solar assumed to be delivered at secondary voltage. The summer peak and the summer shoulder loss factors are used to calculate the additional benefit derived from solar power systems because of feeders and substations. The losses at peak and non-peak periods are used to calculate the avoided fuel and variable O&M. Natural gas fuel price multiplied by assumed heat rate of peaking power plant (9360 MMBtu/kWh). The summer peak and the summer shoulder loss factors are used to calculate the avoided fuel and variable O&M. Natural gas fuel price multiplied by assumed heat rate of peaking power plant (9360 MMBtu/kWh).

Highlights

• The study concluded that the value of on-peak solar energy in 2005 ranged from $0.23 - 0.35 /kWh.

• The analysis looks at avoided costs under two alternative scenarios for the year 2005. The two scenarios vary the cost of developing new power plants and the price of natural gas.

• Scenario 1 assumed new peaking generation will be built by the electric utility at a cost of capital of 9.5% with cost recovery over a 20 year period; the price of natural gas is based on the 2005 summer market price (average gas price)

• Scenario 2 assumed new peaking generation will be built by a merchant power plant developer at a cost of capital of 15% with cost recovery over a 10 year period; the price of natural gas is based on the average gas price in California for the period of May 2000 through June 2001 (high gas price – 24% higher)

• While numerous unquantifiable benefits were noted, five benefits were quantified:
  1) Deferral of investments in new peaking power capacity
  2) Avoided purchase of natural gas used to produce electricity
  3) Avoided emissions of CO₂ and NOₓ that impact global climate and local air quality
  4) Reduction in transmission and distribution system power losses
  5) Deferral of investments in new peaking power capacity

The study assumed that, “in California, natural gas is the fuel used by power plants on the margin both for peak demand periods and non-peak periods. Therefore it is reasonable to assume the solar electric peaking power plants will displace the burning of natural gas in all hours that they produce electricity.”
Energy:
Energy value is based on the marginal resource on-peak (gas combustion turbine) and off-peak (inefficient gas in California, and coal in Illinois). Fuel prices are based on Energy Information Administration projections, and levelized.

System Losses:
Energy losses are assumed to be additive since the gas focus was used rather than NYMEX. There is an REC advantage to be added since gas prices were used rather than NYMEX. The utility of a fixed marginal gas price for up to 10 years based on a market swap deal. The utility of a fixed marginal gas price for up to 10 years based on the market value to the fuel price hedge value. Hedge value is estimated based on the average price of a fuel at the time.

Generation Capacity:
Generation capacity value is based on the assumption that the marginal resource is always a gas combustion turbine. Effective capacity is based on an ELCC estimate from secondary sources.

Fuel Price Hedge Value:
Hedge value is estimated based on the market value to utilities of a fixed natural gas price for up to 10 years based on market swap data. The hedge is assumed to be additive since EIA gas prices were used rather than NYMEX. The utility of a fixed marginal gas price for up to 10 years based on the market value to the fuel price hedge value. Hedge value is estimated based on the average price of a fuel at the time.

Criteria Air Pollutants:
Criteria air pollutant reduction value is based on avoided costs of health impacts, estimated by secondary sources.

Carbon:
Carbon value is the price of carbon (estimated based on European market projections) times the amount of carbon displaced.

The study notes that true value varies dramatically with local conditions, so precise calculations at a high level are impossible. As such, transmission and distribution impacts were acknowledged but not included.

Highlights:

<table>
<thead>
<tr>
<th>Tools Used</th>
<th>Granularity of Analysis</th>
<th>Stakeholder Perspective</th>
<th>Level of Solar Analysis</th>
<th>Geographical Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>High level, largely based on secondary analysis</td>
<td>Geographic granularity - transmission and distribution system impacts</td>
<td>Environmentally aware, including grid location and efficiency</td>
<td>Low, assuming low California: 33% RPS, mostly gas generation; Illinois: mostly coal generation</td>
<td>Integrate into new houses built in the US</td>
</tr>
<tr>
<td></td>
<td>Geographical parity - solar resource characterization for energy margin resource</td>
<td>Socioeconomic impact as context for grid parity</td>
<td>Low</td>
<td>Study objective</td>
</tr>
<tr>
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<td>Solar characterization - single estimate based on two sites</td>
<td>System context</td>
<td>Low</td>
<td>Study objectives</td>
</tr>
<tr>
<td></td>
<td>Energy</td>
<td>System perspective</td>
<td>Low</td>
<td>Study characteristics</td>
</tr>
<tr>
<td></td>
<td>Fuel</td>
<td>High level</td>
<td>Low</td>
<td>Study characteristics</td>
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<td>Gen</td>
<td>Assessment of two categories</td>
<td>High level, largely based on secondary analysis</td>
<td>Study characteristics</td>
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<td>Assessment of two categories</td>
<td>High level, largely based on secondary analysis</td>
<td>Study characteristics</td>
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<td>Total</td>
<td>Assessment of two categories</td>
<td>High level, largely based on secondary analysis</td>
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<td></td>
<td>Total</td>
<td>Assessment of two categories</td>
<td>High level, largely based on secondary analysis</td>
<td>Study characteristics</td>
</tr>
</tbody>
</table>

Average Values From Study

<table>
<thead>
<tr>
<th>(cents/kWh $2012)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.96</td>
</tr>
</tbody>
</table>

Overview of Value Categories
Energy: Energy value decreases at high penetrations because the marginal resource that DPV displaces changes as the system moves down the dispatch stack to a lower cost generator. Energy value is based on the short-run profit earned in non-scarcity hours (those hours where market prices are under $500/MWh), and generally displaces energy from a gas combined cycle. Fuel costs are based on Energy Information Administration projections.

Generation Capacity: Generation capacity value is based on the portion of short-run profit earned during hours with scarcity prices (those hours where market prices equal or exceed $500/MWh). Effective DPV capacity is based on an implied capacity credit as a result of the model's investment decisions, rather than a detailed reliability or EDC analysis.

Grid Support (Ancillary Services): Ancillary services value is the net earnings from selling reliability services in the market. Ancillary services are defined as the short-term services used to adjust the system frequency and other utility services.

Averagcal Characteristics:

<table>
<thead>
<tr>
<th>Energy</th>
<th>Gen Cap</th>
<th>Grid Support</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.91</td>
<td>3.15</td>
<td>2.5</td>
<td>11.55</td>
</tr>
</tbody>
</table>

- **Overview of Value Categories**
  - Energy
  - Generation Capacity
  - Grid Support (Ancillary Services)
  - Total

**Highlights**

- The marginal economic value of solar exceeds the value of grid power at low penetration levels, largely attributable to generation capacity value and solar coincidence with peak demand.
- The marginal value of DPV drops considerably as the penetration of solar increases, initially, driven by a decrease in capacity value with increasing generation. At the highest renewable penetration levels, the marginal value of DPV drops considerably as the penetration of solar increases, initially, driven by a decrease in capacity value with increasing generation. At the highest renewable penetration levels, the marginal value of DPV drops considerably as the penetration of solar increases, initially, driven by a decrease in capacity value with increasing generation.
- The study notes that it is critical to use an analytical framework that addresses long-term investment decisions, uncertainty, and reversibility of investment decisions. Uncertainty in future fuel and investment capital costs, and DPV's capital cost, are not considered in this study. The study also notes the importance of considering the impact of DPV on the energy market, including environmental impacts.

**Tools Used**

- Customized model that evaluates long-run investment decisions and short-term dispatch and operational constraints.
- Geographic characterization: Hourly satellite derived insolation data from the National Solar Research Database, 10 km x 10 km geographic resolution.
- Marginal revenue from load and capacity: Hourly satellite derived load and capacity data from 10 km x 10 km geographic resolution.
- System context: Market rules, ISO participation levels, and transmission and distribution costs of DPV.

**Granularity of Analysis**

- System level: 33% RPS, ISO market
- Level of solar analyzed: Up to 40% (by energy)

**Stakeholder Perspective**

- To quantify the change in value for a subset of economic benefits, including environmental impacts.

**Study Objective**

To quantify the change in value for a subset of economic benefits.
Methodology. Rather, the loss savings effect is included separately for each value component.

Loss savings were not treated as a stand-alone benefit under the convention used in this study, with the assumed PJM value of 35% for solar resources.

Social (Economic Development Value): The market price reduction (avg $55/MWh) and economic development value (avg $44/MWh).

The total value ranged from $256 to $318/MWh. Of this, the highest value components were:

- Capital.
- Capital cost of displaced generation times PV’s effective load carrying capability of 15%.

The analysis represents the value of PV for a “fleet” of PV systems, evaluated in 4 orientations, each at 7 locations (Pittsburgh, PA; Harrisburg, PA; Scranton, PA; Philadelphia, PA; Jamesburg, NJ; Newark, NJ; and Atlantic City, NJ), spanning 6 utility service territories, each at 7 locations. The study evaluated 10 benefits and 1 cost. Evaluated benefits included: Fuel cost savings, O&M cost savings, security enhancement, long term societal benefit, fuel price hedge, O&M cost of the generator most likely operating on the margin (assumed to be a combined cycle gas turbine). Assumed natural gas price forecast: NYMEX futures years 0-12; NYMEX futures price for year 13 is 12 x 2.33% escalation factor. Escalation rate assumed to be the same as the rate of wellhead price escalation from 1981-2011.

OVERVIEW OF VALUE CATEGORIES

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Cost</th>
<th>Social</th>
<th>Environmental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel and O&amp;M cost savings</td>
<td>24.9</td>
<td>-10</td>
<td>0</td>
</tr>
<tr>
<td>Security Enhancement Value</td>
<td>12.5</td>
<td>-15</td>
<td>10</td>
</tr>
<tr>
<td>Market Price Reduction</td>
<td>22.9</td>
<td>-20</td>
<td>5</td>
</tr>
<tr>
<td>Economic Development Value</td>
<td>15.5</td>
<td>-25</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>$76.8</td>
<td>-$60</td>
<td>$15</td>
</tr>
</tbody>
</table>

The value of PV for a “fleet” of PV systems, evaluated in 4 orientations, each at 7 locations. The study evaluated 10 benefits and 1 cost. Evaluated benefits included: Fuel cost savings, O&M cost savings, security enhancement, long term societal benefit, fuel price hedge, O&M cost of the generator most likely operating on the margin (assumed to be a combined cycle gas turbine). Assumed natural gas price forecast: NYMEX futures years 0-12; NYMEX futures price for year 13 is 12 x 2.33% escalation factor. Escalation rate assumed to be the same as the rate of wellhead price escalation from 1981-2011.

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Energy:
The study shows high energy value compared to other studies, driven by using EIA’s “advanced gas turbine” with a high heat rate as the marginal resource. Financial incentives, risk-free zero-coupon bonds and a set of natural gas futures contracts to represent the avoided cost of reducing fuel price volatility.

Fuel Price Hedge:
The study estimates hedge value as a combination of two locations: natural gas price forecast is based on NYMEX forward market gas prices, then escalated at a constant rate. Energy losses are included in energy value, and are calculated on a hourly marginal basis.

Generation Capacity:
Generation capacity value is DPV’s effective capacity times the fixed costs of an “advanced gas turbine”, assumed to be the marginal resource. Effective capacity based on ELCC; the reported ELCC is significantly higher than other studies. Every installed unit of DPV is given generation capacity value.

T&D Capacity:
The study takes a two step approach: first, economic screening to determine expansion plan costs and load growth expectations by geographic area, and second, an assessment of the correlation of DPV and load in the most promising operating data. Values are levelized over 30 years.

Environmental:
The study quantified environmental value, as shown in the chart above, but did not include it in the final assessment of benefit since the study was from the utility perspective.

The study acknowledges that not quantifying a number of other values including climate change mitigation, environmental migration, and economic development was a limitation.

The study notes that likelihood decreases with increasing penetration, although higher penetration levels were not analyzed.

The study notes that value likely decreases with increasing penetration, although higher penetration levels were not analyzed.

The study acknowledges but did not quantify a number of other values including climate change mitigation, environmental migration, and economic development.

The study is based solely on publicly-available data; it notes that results would be more representative with actual financial and operating data. Value is a levelized over 30 years.
The value of distributed photovoltaics in Austin Energy and the City of Austin.

**The Value of Distributed Photovoltaics in Austin Energy and the City of Austin**

*The study evaluated 7 benefits—energy production, line losses, generation capacity, T&D capacity, reactive power control (*grid support*), environment, natural gas price hedge (*financial*), and disaster recovery (*security*).*

- Avoided energy costs are the most significant source of value (about two-thirds of the total value), which is highly sensitive to the price of natural gas.
- Distribution capacity deferral value was relatively minimal. AE personnel estimated that 15% of the distribution capacity expansion plans have the potential to be deferred after the first ten years (assuming growth rates remain constant). Therefore, the study assumed that currently budgeted distribution projects were not deferrable, but the addition of PV could possibly deferral distribution projects in the 11th year of the study period.

**Highlights**

- Estimated savings are the most significant source of value (about two-thirds of the total value), which is highly sensitive to the price of natural gas.
- Distribution capacity deferral value was relatively minimal. AE personnel estimated that 15% of the distribution capacity expansion plans have the potential to be deferred after the first ten years (assuming growth rates remain constant). Therefore, the study assumed that currently budgeted distribution projects were not deferrable, but the addition of PV could possibly deferral distribution projects in the 11th year of the study period.

**Tools Used**

- Clean Power Research internal analysis; satellite solar data; PVFORM 4.0 for solar simulation; AE's load flow analysis for T&D losses

**Granularity of Analysis**

- Energy: PV output plus losses minus marginal energy cost, Marginal energy cost calculated differently depending on benefit category, For all scenarios, loss savings are calculated hourly on the margin.
- Generation capacity: Cost of capacity times PV's effective load carrying capability (ELCC), Taking into account loss savings.
- System losses: Computed differently depending on benefit category.

**Utility Perspective**

- Level of Solar Analyzed: <1% - 2% system peak load

**System Context**

- Municipal Utility
- Austin, TX

**Geographic Focus**

- Study area: Municipal utility service area; Study is limited to DFPL to Austin Energy (AE) in 2006

**Study Objective**

- To quantify the comprehensive value of DPV to Austin Energy (AE) in 2006 and compare methods to other methodologies to assist AE in performing analyses as conditions explicity captured.
To design the DPV tariffs, the Distributed PV Value Calculator method was used. The levelized value of solar systems—the typical value calculation—was used. The focus was on designing the DPV tariffs based on the value of energy generated by the system, considering the marginal fuel price for the power plant on the margin and the system and network losses.

### Study Objective
To design a residential solar tariff based on the value of solar energy in Austin, TX.

### Tools Used
- Distributed PV Value Calculator
- SolarAnywhere,
- Clean Power Research's Distributed PV Value Calculator; Solar Anywhere, 2012

### Key Findings
1. The levelized value of solar was calculated to total $12/kWh.
2. The fixed, south-facing PV system with a 30-degree tilt, the most common configuration and orientation in AE’s service territory of approximately 1,500 DPV systems, was used as the reference system.
3. As with the AE/CPR 2006 study, avoided energy costs are the most significant source of value, which is very sensitive to natural gas price assumptions.
4. The levelized value of solar was calculated to total $12/kWh.
Energy: Energy value is fuel cost times the heat rate plus O&M costs for the marginal power plant, generally assumed to be natural gas.

System Losses: Avoided loss value is the amount of loss associated with energy, generation capacity, T&D capacity, and environmental impact times the cost of that loss.

Generation Capacity: Generation capacity value is the capital cost of the marginal power plant times the effective capacity (ELCC) of DPV.

T&D Capacity: T&D capacity value is T&D investment plan costs times the cost of money times effective capacity divided by load growth, levelized.

Grid Support Services (Ancillary Services): Ancillary services include VAR support, load following, operating reserves, and dispatch and scheduling. DPV is unlikely to be able to provide all of these.

Financial (Fuel Price Hedge, Market Price Response): Hedge value is the cost to guarantee a portion of electricity costs are fixed. Reduced demand for electricity decreases the price of electricity for all customers and creates a customer surplus.

Security: Customer reliability in the form of increased outage support can be realized. Customer value is the implicit value of PV.

Environmental (Criteria Air Pollutants, Carbon): Value is either the market value of emissions or the emission intensity of the marginal resource times the value of emissions.

Customer: Value to customer of having green option, as indicated by their willingness to pay.

Solar Cost: Costs include capital cost of equipment plus fixed operating and maintenance costs.

Net Present Value: NPV is a method of calculating the present value of the future cash flows generated by a distributed PV system.
<table>
<thead>
<tr>
<th>Study</th>
<th>Funded / Commissioned by</th>
<th>Prepped by</th>
<th>Published</th>
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