Electricity Bill Savings from Residential Photovoltaic Systems: Sensitivities to Changes in Future Electricity Market Conditions

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January 2013

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Presentation Outline

- **LBNL's Related Previous Work**
- **Motivations and Overview**
- **Approach and Limitations**
- **Wholesale Market Scenarios**
- **Analysis Methods**
- **Results and Implications**

Berkeley Lab's PV Valuation Analysis

- **Incremental value of variable renewable energy (RE) changes with penetration, primarily driven by energy & capacity value**
- **Specific findings:**
  - Solar has high value at low penetrations
  - Value of PV and CSP without thermal storage drop with increasing penetration levels
  - At medium to high penetration, CSP with thermal storage is considerably more valuable than PV and CSP without thermal storage
  - Value of wind largely driven by energy value; lower than solar at low penetration, but higher at high penetration
- **Current study makes use of capacity expansion/dispatch model developed here**


LBNL-5445E

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Changes in the Economic Value of Variable Generation at High Penetration Levels: A Pilot Case Study of California

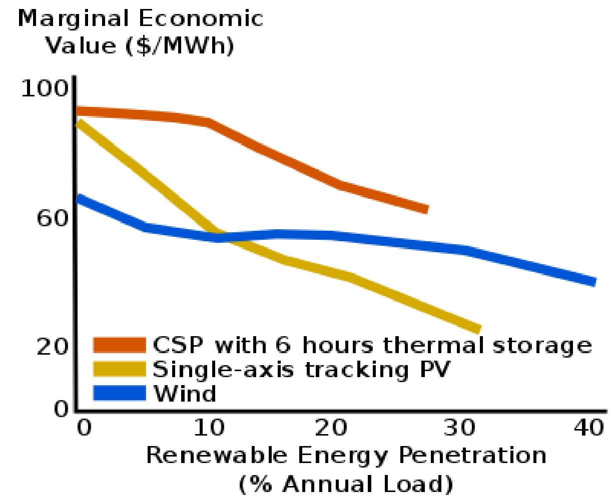
Andrew Mills and Ryan Wiser

Environmental Energy
Technologies Division

June 2012

Download from http://eetd.lbl.gov/EA/EMP

The work described in this paper was funded by the U.S. Department of Energy (Office of Energy Efficiency and Renewable Energy and Office of Electricity Delivery and Energy Reliability) under Contract No. DE-AC02-05CH11231.



Berkeley Lab's PV & Rate Design Analysis

- Examined how *current* rates can impact the bill savings under net metering and potential alternatives

- Findings have highlighted significance of rate design and net metering to the economics of PV for commercial and residential customers

- Related key previous work by NREL and others


LBNL-63019

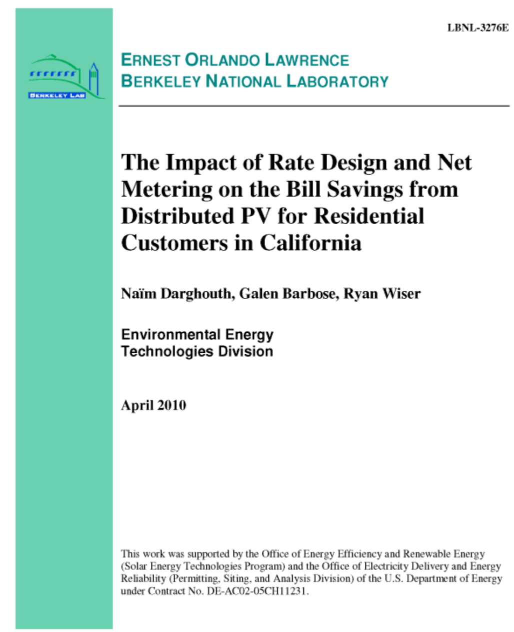
Ernest Orlando Lawrence Berkeley National Laboratory

The Impact of Retail Rate Structures on the Economics of Commercial Photovoltaic Systems in California

Ryan Wiser, Andrew Mills, Galen Barbose, and William Golove

Environmental Energy Technologies Division

July 2007


LBNL-3276E

Ernest Orlando Lawrence Berkeley National Laboratory

The Impact of Rate Design and Net Metering on the Bill Savings from Distributed PV for Residential Customers in California

Naïm Darghouth, Galen Barbose, Ryan Wiser

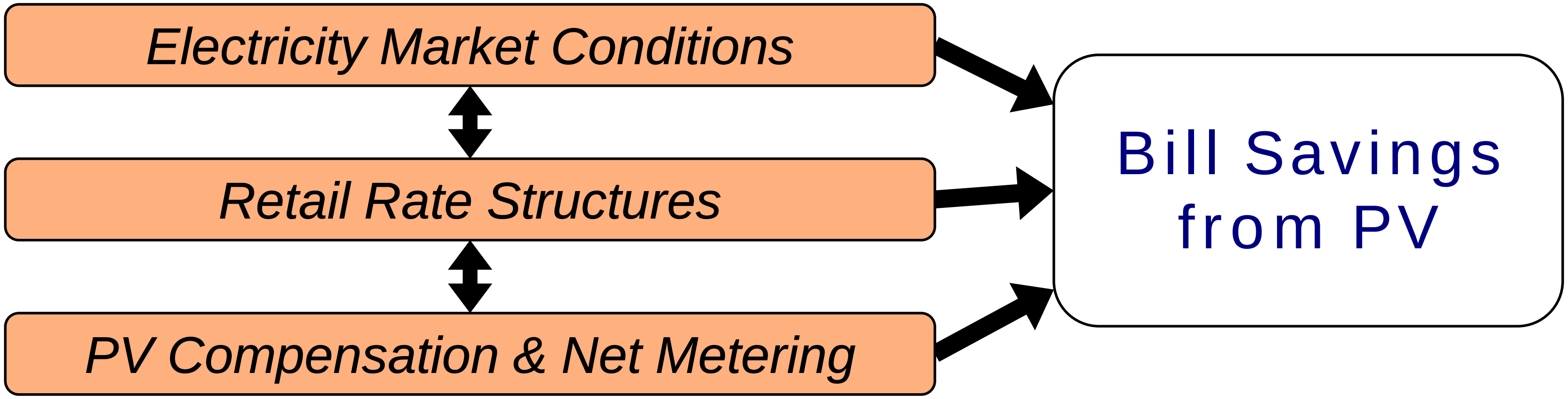
Environmental Energy Technologies Division

April 2010

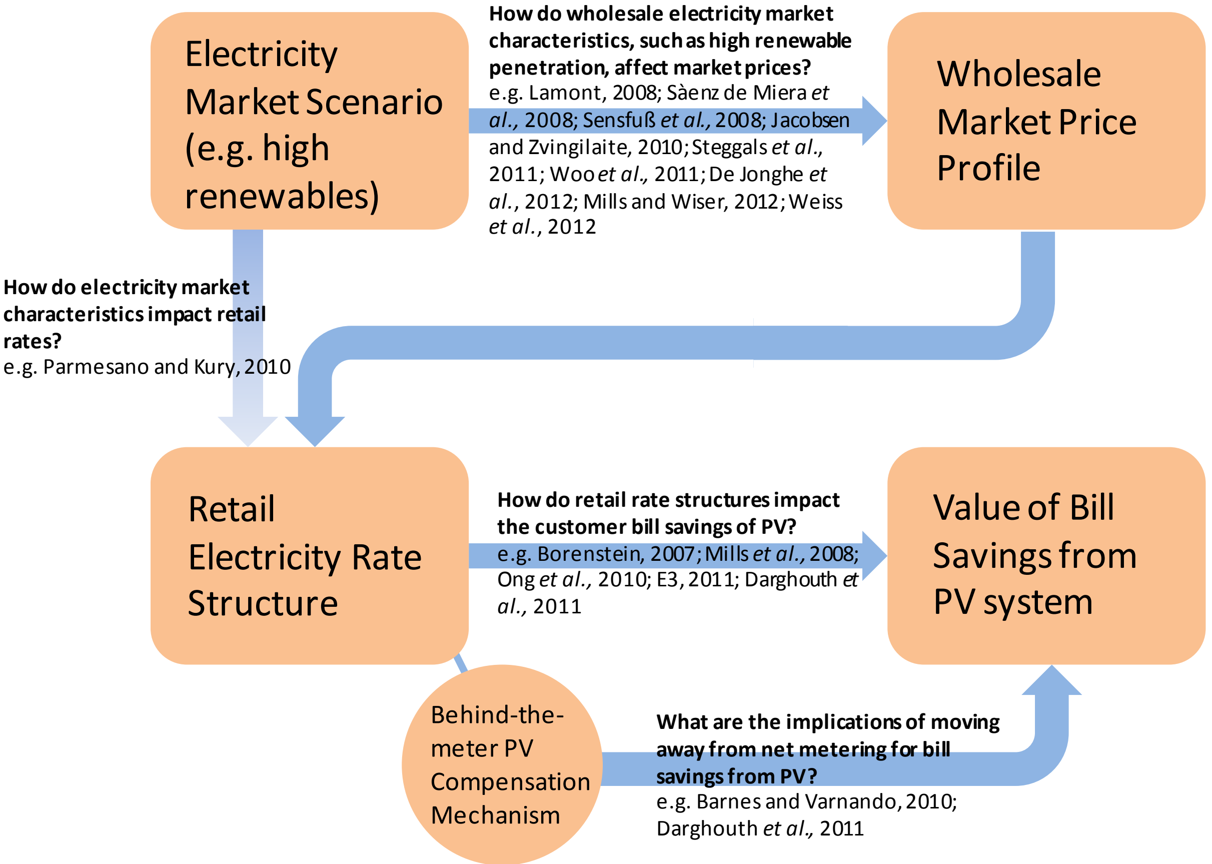
This work was supported by the Office of Energy Efficiency and Renewable Energy (Solar Energy Technologies Program) and the Office of Electricity Delivery and Energy Reliability (Permitting, Siting, and Analysis Division) of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Motivation and Overview

- *Today*, U.S. residential PV systems typically compensated via **net metering**, at customer's prevailing retail rate
- Often assumed that rate structures & PV compensation mechanisms will not change and that retail prices will increase (or be constant) over time → increasing (or keeping constant) bill savings from PV
- This study investigates the impact of three key sources of **uncertainty in the *future* value of bill savings** from residential PV, and the interactions among them



Existing Literature



Report builds on literature that has investigated different aspects of net metering, rate design and impacts of RE on wholesale prices

Study is first known effort to evaluate interactions

Note: Please see full report for literature review and complete bibliography

General Take-Away Messages of Study

- Future electricity market scenarios, retail rate structures, and the availability of net metering can interact to greatly impact the future value of bill savings from residential PV
- As policymakers / regulators / utilities / solar industry / potential PV owners consider the future economic attractiveness of PV, rate design and PV compensation methods, these interactions require further consideration and more detailed & location-specific analysis
- Assumption that bill savings from PV will increase (or remain constant) with time deserve investigation

Approach

- Simulate impacts of various future **electricity market scenarios** on hourly **wholesale market prices**, using simplified production cost and capacity expansion model
- Based on wholesale market price profiles, create **three potential retail rates** for each electricity market scenario: **flat**, **time-of-use (TOU)**, & **real-time pricing** (RTP)
  - Assuming full cost recovery and using standard rate design principles
  - Also develop flat rate with increasing-block pricing for reference scenario
- With two PV compensation mechanisms: **net metering** & **hourly netting**
- Calculate **bill savings from PV** for sample of 226 residential customers in California for each permutation of electricity market scenario, retail rate, and PV compensation mechanism

$$Bill\ savings\ \ from\ PV\left(\$/_{kWh}\right) = \frac{Bill\ without\ PV(\$) - Bill\ with\ PV(\$)}{PV\ \ generation\ (kWh)}$$

Boundaries and Limitations

Focuses on the private value of bill savings for residential PV

- Does not quantify broader social or economic cost or value of solar

Relies upon a variety of assumptions, including inherently uncertain future retail rate structures

- Loosely based on California's electricity market, though not intended to be forecast of California's electricity market in 2030
- Conclusions have broader implications, though some specific findings unique to assumptions applied: e.g. ,fixed costs are recovered through volumetric adder; considers only one potential alternative to net metering; uses summer peaking region

Makes use of an economic investment and dispatch model to simulate wholesale electricity prices in a future year 2030

- Model simulates energy-only market (no parallel capacity markets) → wholesale electricity prices allowed to climb to very high levels, potentially making results sensitive to relatively few hours in the year

Wholesale Market Scenarios

- **All scenarios based loosely on California electricity market in 2030**
  - Gross retail load scaled from 2010 levels assuming growth of 1.2%/yr
  - Residential load assumed to account for 32% of total retail load
  - All scenarios assume the same capacity of legacy generation
- **Reference Scenario**: Assumes 2011 levels of renewable energy (RE)
- **Isolation Scenarios**: Investigate impacts of changing a single characteristic of the electricity market relative to Reference Zcenario
- **33% Renewable Energy Mix Scenario**: 33% of retail load met by RE
- **Integration Scenarios**: Variants of 33% RE Scenario that include higher penetration of grid-level storage, demand response, or CSP with storage
- Simulate impacts of these scenarios on hourly **wholesale market prices**, using simplified production cost and capacity expansion model

Wholesale Market Scenarios: Key Characteristics

Scenarios vary in RE penetration and mix, natural gas prices, carbon price, pumped storage capacity, and price elasticity of demand

		2030 Renewable Penetration (energy)				Distributed PV	Natural Gas	Pumped Storage	Carbon Price	elasticity of load
	Scenario name	**PV**	**Wind**	**CSP w/ storage**	**Other RE**	**% of Total PV**	**Price ($/Mbtu)**	**GW**	**$/ton**	**-**
	Reference	0.3%	4.0%	0.0%	7.4%	50%	6.40	3.6	0	-0.001
Isolation scenarios	**high PV**	15.0%	4.0%	0.0%	7.4%	30%	6.40	3.6	0	-0.001
Isolation scenarios	**high wind**	0.3%	15.0%	0.0%	7.4%	50%	6.40	3.6	0	-0.001
Isolation scenarios	**high C price**	0.3%	4.0%	0.0%	7.4%	50%	6.40	3.6	50	-0.001
Isolation scenarios	**high NG price**	0.3%	4.0%	0.0%	7.4%	50%	7.97	3.6	0	-0.001
Isolation scenarios	**low NG price**	0.3%	4.0%	0.0%	7.4%	50%	4.95	3.6	0	-0.001
	33% RE mix	8.1%	11.5%	3.5%	10.0%	30%	6.40	3.6	0	-0.001
Integration scenarios	**High Storage**	8.1%	11.5%	3.5%	10.0%	30%	6.40	9.9	0	-0.001
Integration scenarios	**Demand Response**	8.1%	11.5%	3.5%	10.0%	30%	6.40	3.6	0	-0.1
Integration scenarios	**Increased CSP / decreased PV**	3.5%	11.5%	8.1%	10.0%	30%	6.40	3.6	0	-0.001

Notes: All currency figures are in real 2011 $US. Baseline, high, and low natural gas prices are from EIA's 2011 reference, high, and low shale gas cases, respectively (US EIA, 2011). The amount of pumped storage in the high storage scenarios is the sum of all current and proposed pumped hydro projects in California, as of November 2010, as per NHA (2010).

Retail Rates Designed to Recover Costs

- **Design three types of residential retail rates for each electricity market scenario**
  - Flat, time-of-use (TOU), and real-time pricing (RTP)
  - The rate levels and structures were created using standard rate design principles (see report for details)
  - Each of the rates assumes full cost recovery of variable and fixed costs (through volumetric charges)
- **Costs recovered through retail rates include:**

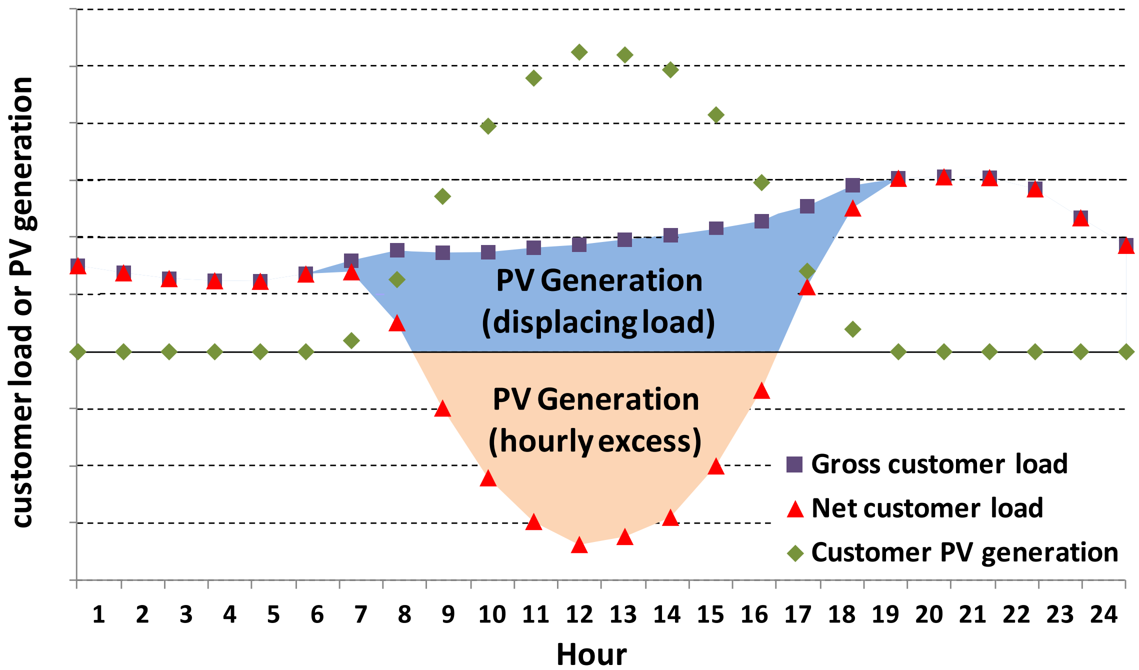
Generation purchased at wholesale price	Transmission and Distribution infrastructure	Utility-owned Generation (UOG)	Renewable Electricity Purchases

Generation purchased at wholesale price → **Recovered through R_{gen} (volumetric charge)**

Transmission and Distribution infrastructure, **Utility-owned Generation (UOG)**, **Renewable Electricity Purchases** → **Recovered through R_{adder} (volumetric charge)**

PV Compensation Mechanisms: Net Metering and Hourly Netting

Figure shows gross load, net load, and PV generation



Net metering (NM)

- Compensates all PV generation at retail rate

Hourly netting (HN)

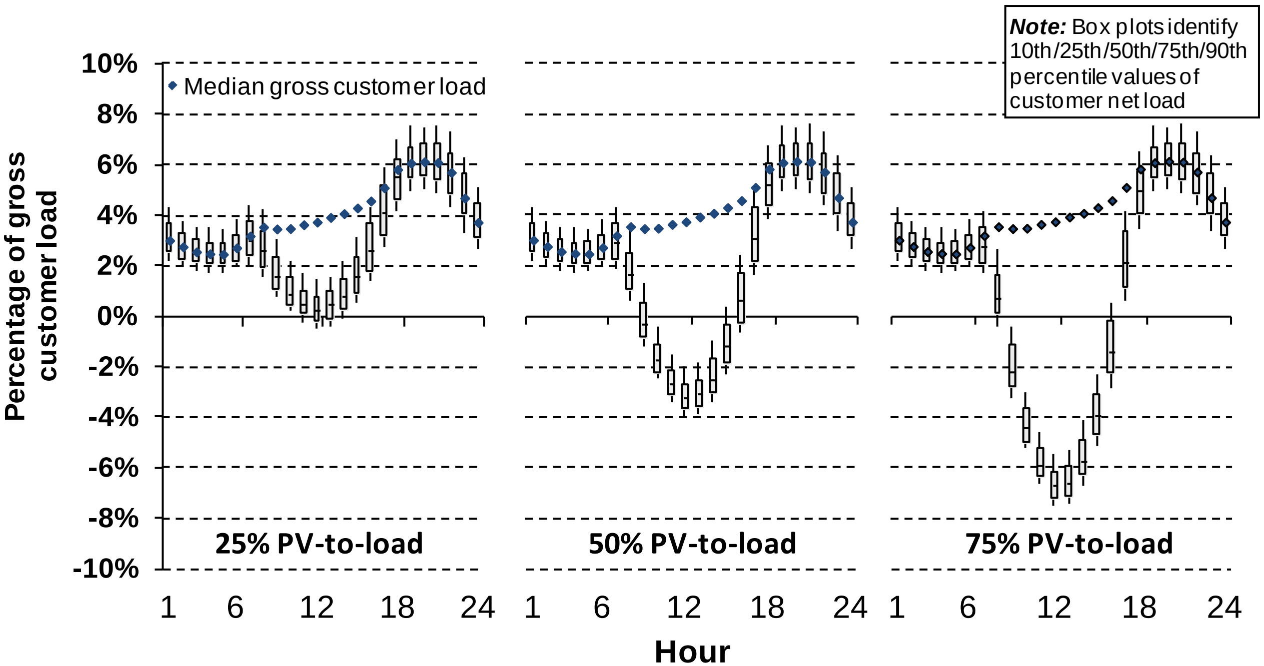
- Compensates PV generation that displaces hourly load at retail rate and that in excess of load at wholesale price

Compensation levels under net metering and hourly netting

	PV Generation (displacing load)	PV Generation (hourly excess)
Net metering	Retail rate	Retail rate
Hourly netting	Retail rate	Wholesale price

Net and Gross Customer Load Used in Bill Calculations

Figure shows net and gross hourly load for customers' mean day, as percentage of gross daily customer load

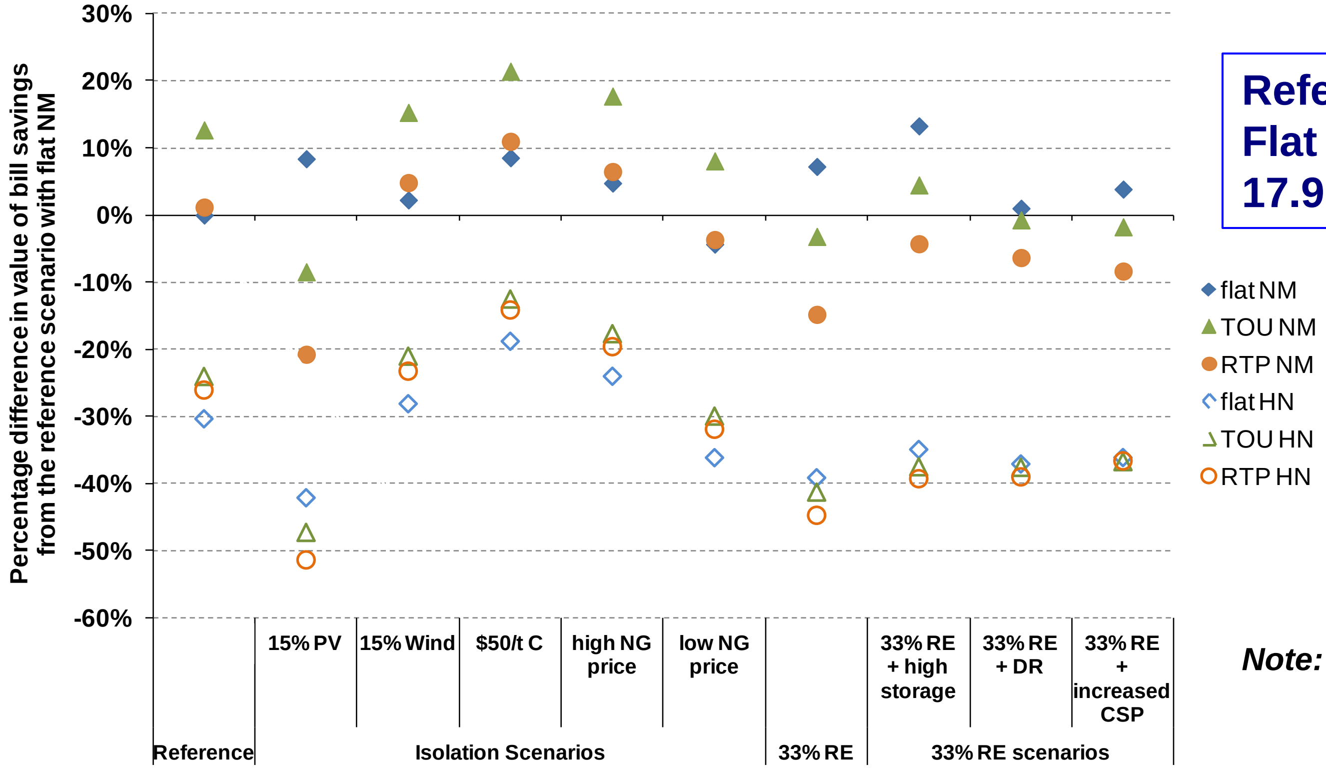


For most of our analysis, PV systems are sized to meet 75% of annual customer load; some results for 25% and 50% PV-to-load ratios are also presented

- Hourly load & simulated PV from 226 residential customers used to calculate customer bills with & without PV
- Gross load profiles peak in the evening hours
- Increasing PV-to-load ratio leads to increasing % of PV generation in excess of hourly load

  → an increasing % of PV compensated at wholesale price under hourly netting

Results Overview: *Change* in Bill Savings Relative to Reference Case w/ Flat Rate and Net Metering (NM)



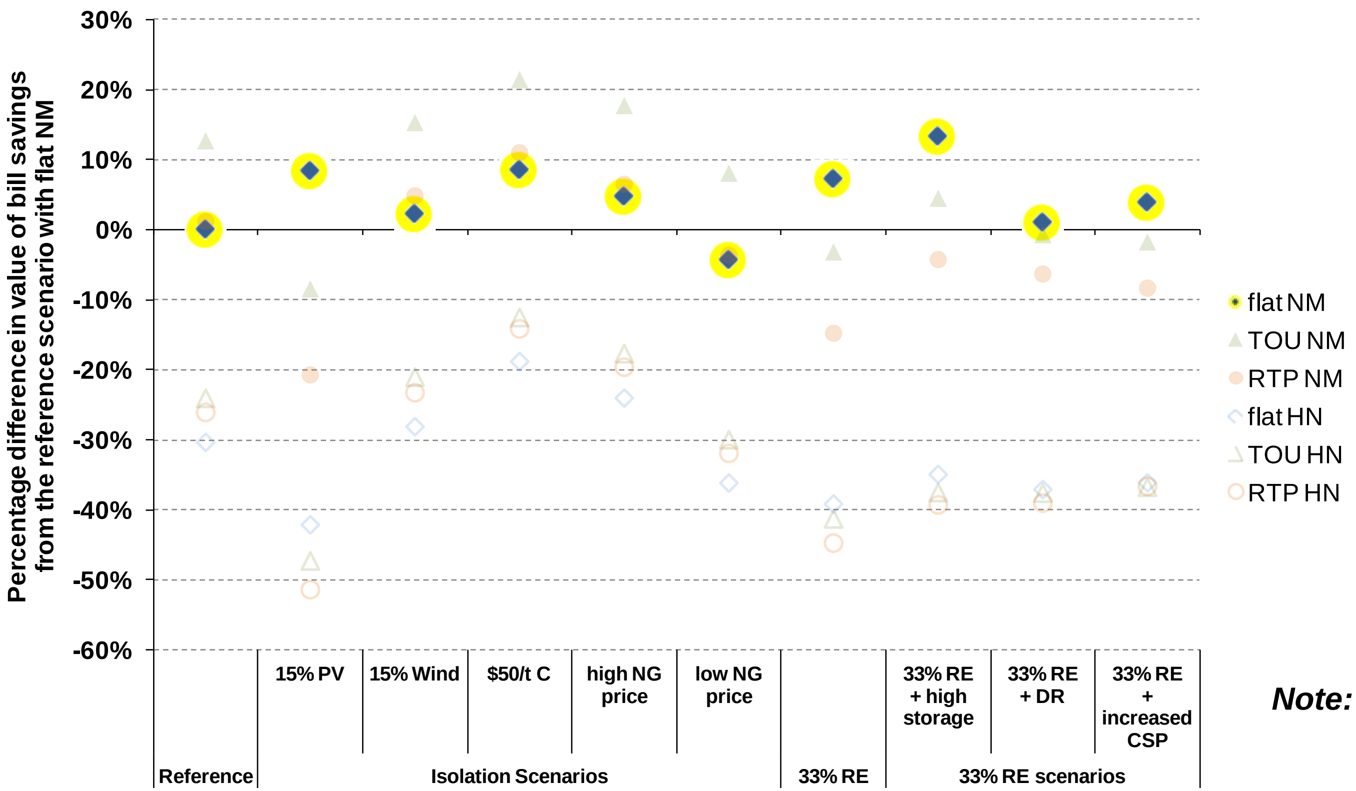
Reference Case, Flat Rate w/ NM = 17.9 cents/kWh

Note: NM = net metering; HN = hourly netting

Figure shows median value of bill savings for each combination of retail rate, PV compensation mechanism, and scenario, relative to the median bill savings under the reference case with a flat rate with net metering, assuming 75% PV-to-load ratio

- For full 226 residential customer sample, we calculate each customer's bill savings from PV for each electricity market scenario, rate option & PV compensation mechanism

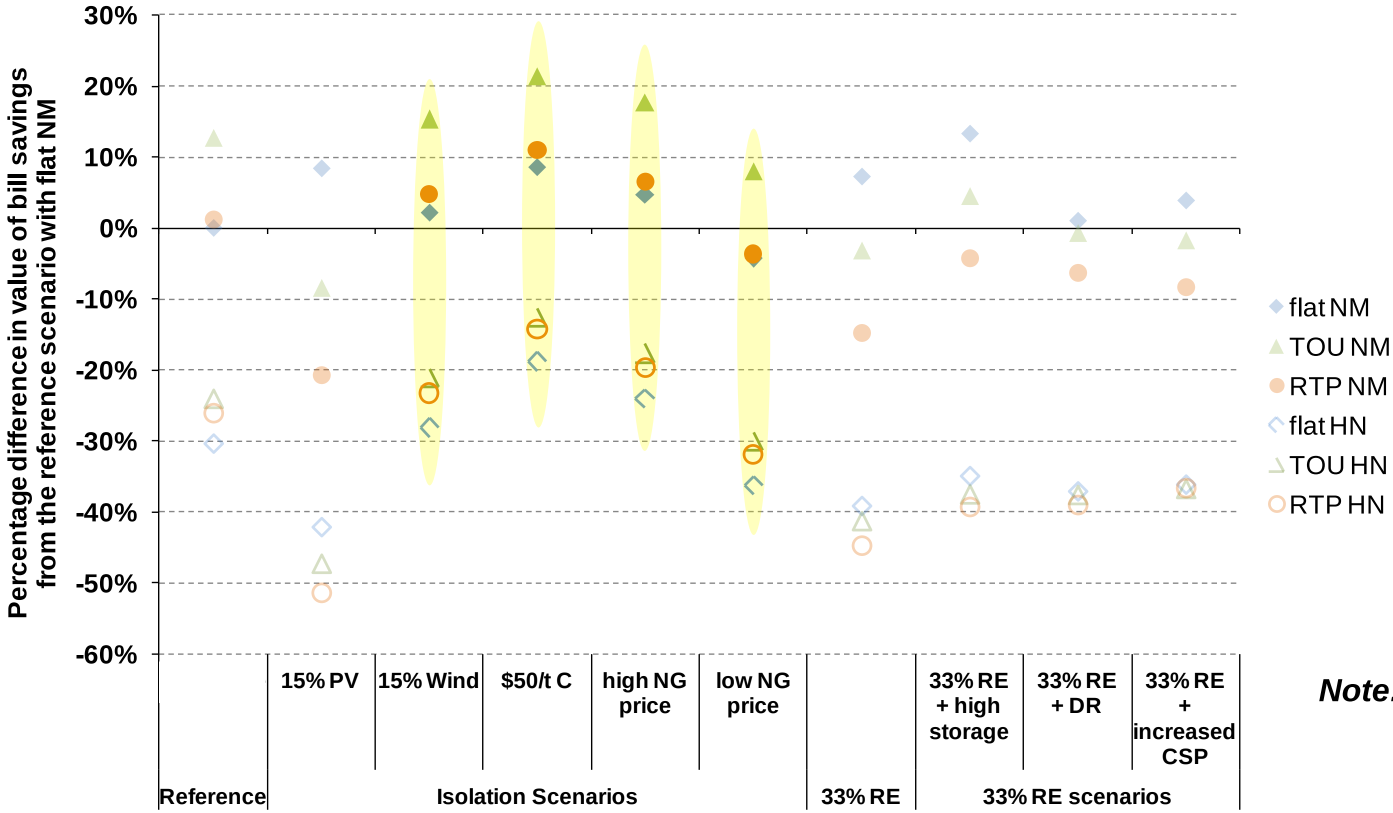
Under Scenarios with Increased Utility Costs, Bill Savings with Flat Rate & Net Metering Increase Relative to Reference Scenario



Note: Assumes 75% PV-to-load ratio

- **Most scenarios entail higher electricity costs than reference scenario due to higher assumed purchase costs of RE or increased costs for fossil generation**
  - → Increases flat rate needed to recover utility costs and thus also bill savings value of PV
- **Under scenarios considered, bill savings with flat rate & NM increased by 1%-13%, relative to reference case, except under lower natural gas price scenario**

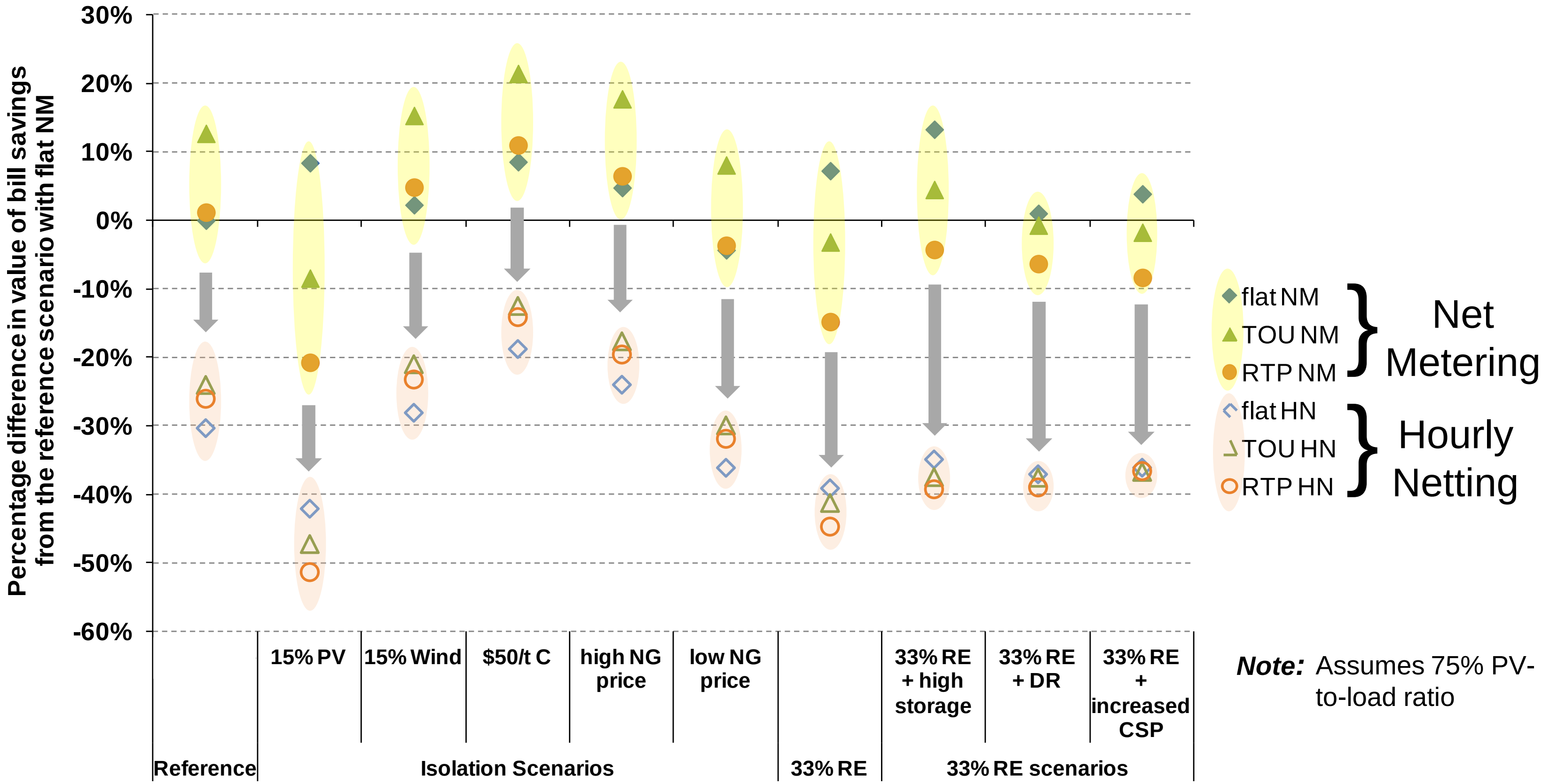
Impact of High Wind Penetration, Carbon Pricing & Changes in NG Prices on Bill Savings from PV Largely Independent of Rate Design



Note: Assumes 75% PV-to-load ratio

- **These scenarios lead to relatively uniform changes in wholesale electricity prices across all hours → relatively uniform changes to retail rates**
- **While bill savings from PV is impacted under these scenarios, the magnitude of the impact is largely independent of retail rate design**

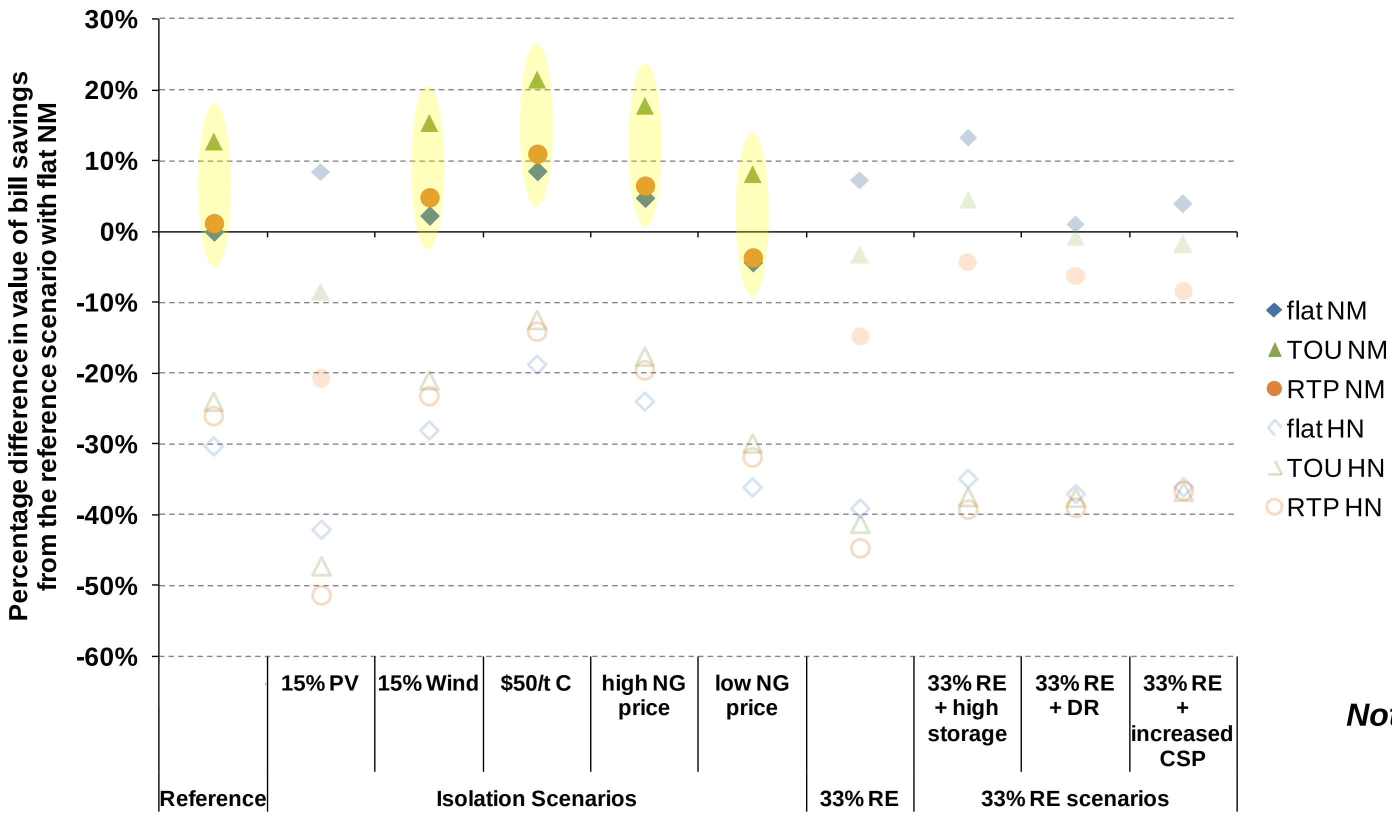
Hourly Netting Significantly Erodes Bill Savings from PV Relative to Net Metering



Note: Assumes 75% PV-to-load ratio

- **Under hourly netting, customers assumed to receive retail rate for PV that displaces hourly load but hourly wholesale price for excess hourly generation**
- **In most hours with net excess PV generation, wholesale prices are lower than retail rates → greater erosion in bill savings at high PV-to-load ratios with HN**

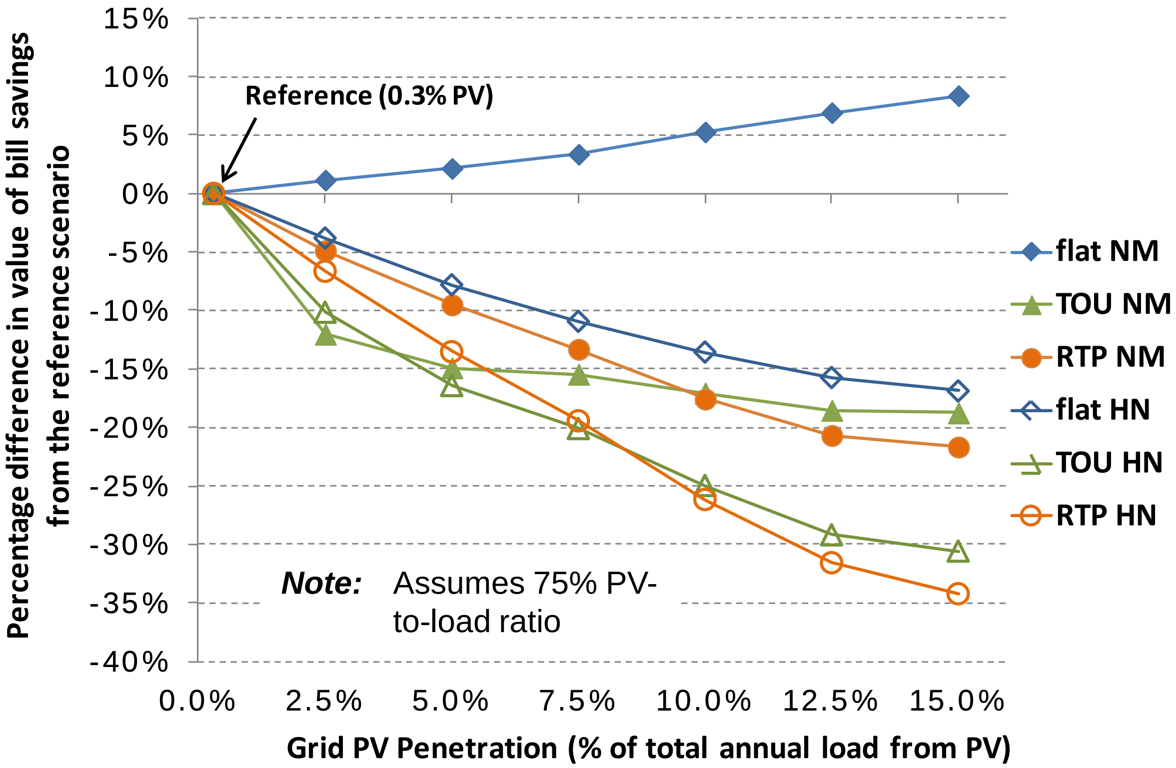
For Scenarios *without* an Increase in Solar Penetration, TOU Rates Provide the Greatest Bill Savings Value for PV



Note: Assumes 75% PV-to-load ratio

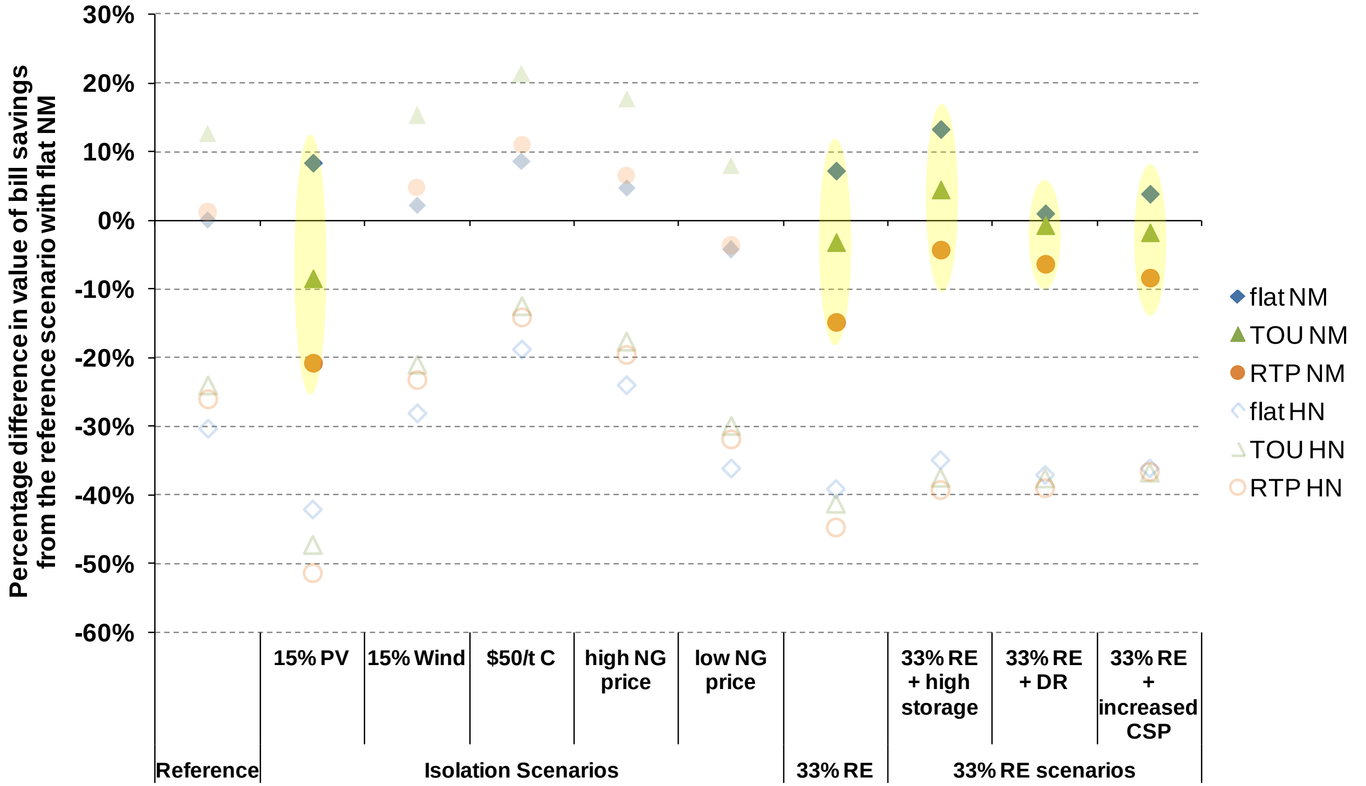
- **At low-solar-penetration, TOU and RTP yield higher bill savings than flat rate because PV output is positively correlated to summer peak load & prices**
  - → PV benefits from time-differentiated compensation; would differ for winter-peaking systems
- **Modeled TOU results in higher bill savings than RTP because PV customers benefit from averaging hourly wholesale prices over peak TOU period**

Sizable Declines in Estimated Bill Savings from PV Can Occur Even at Relatively Low PV Penetrations



- **All rates except for flat rate with net metering lead to continuous decline in value from bill savings with increasing PV penetration level**
- **Degree of decline depends on retail rate structure & compensation mechanism**
- **Reductions are due to time-varying component related to wholesale prices, which are lower than the reference scenario at times when PV generates**

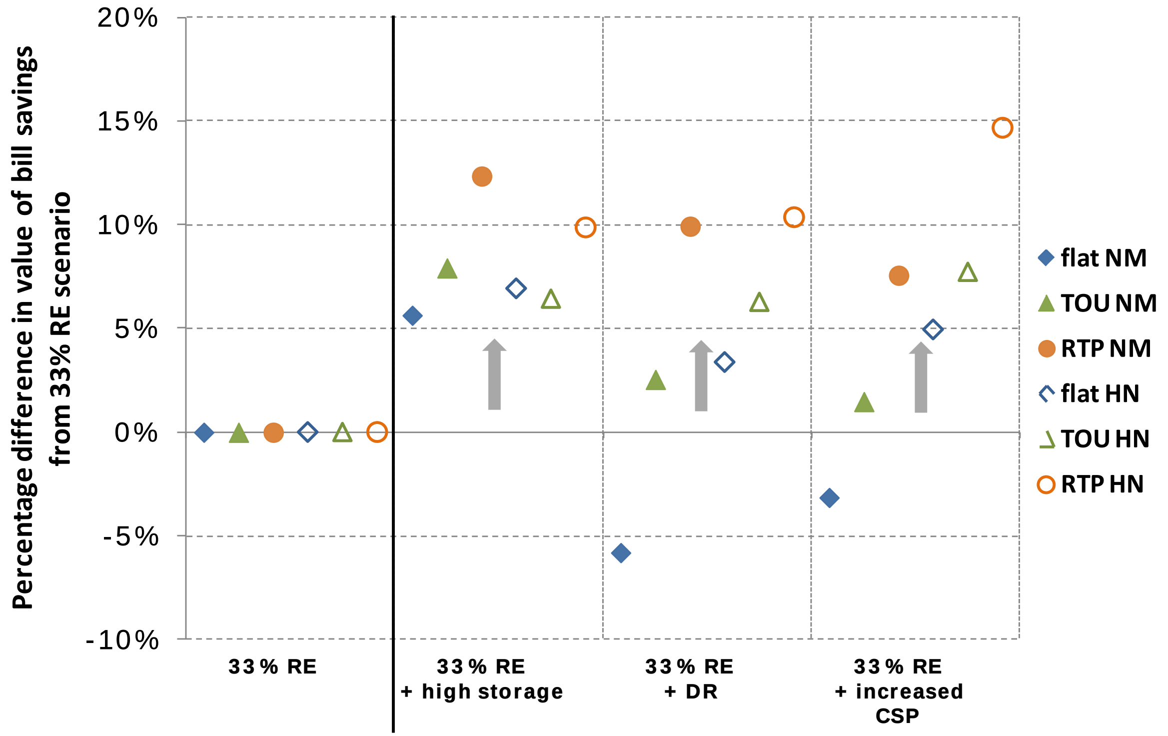
For Scenarios *with* High Solar Penetration, Flat Rates Provide the Greatest Bill Savings Value for PV



Assumes 75% PV-to-load ratio

- **With higher solar penetration, hourly wholesale prices are generally lower-than-average when PV generates electricity because PV generation during the afternoon shifts the time of peak "net" load into evening hours**
- **As a result, TOU and RTP rates, which are time-varying and directly related to wholesale prices, provide a lower value of bill savings from PV**

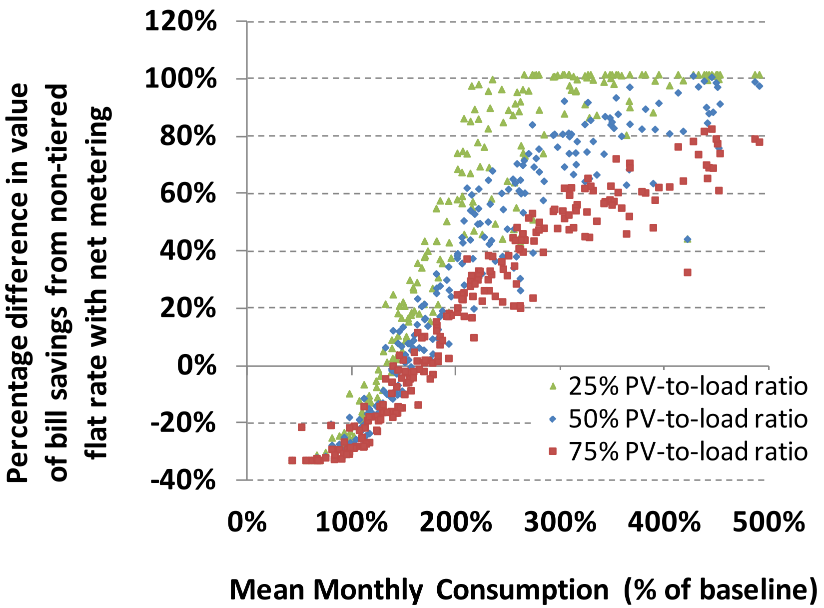
At High Renewables Penetrations, Bill Savings from PV Increase with more Grid Storage, Demand Response, or CSP with Storage

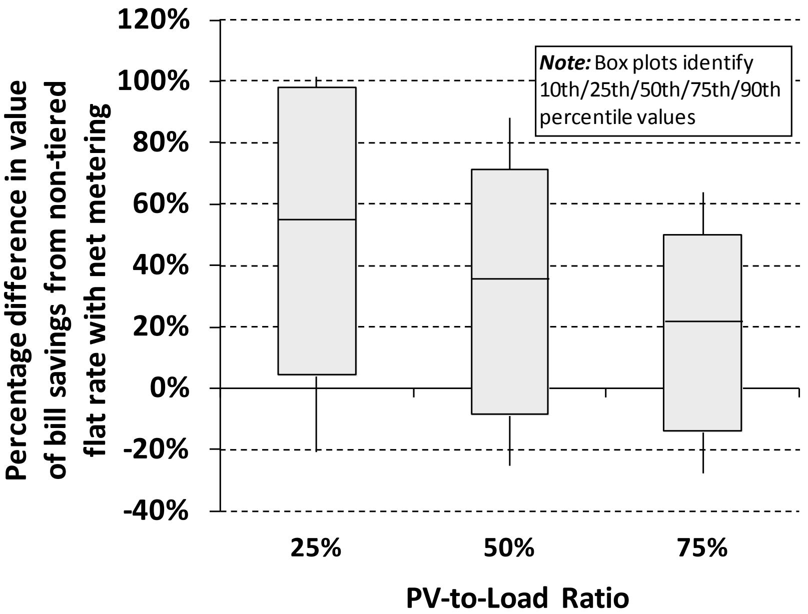


Note: Assumes 75% PV-to-load ratio

- **Other analyses highlight potential for storage & demand response to integrate renewables; our results show that these also enhance bill savings from PV**
- **These strategies increase average compensation rates for behind-the-meter PV compared to the price profile in the core 33% RE mix scenario from:**
  - Shift in price profiles such that peaks occur earlier than with 33% RE mix scenario
  - Increased retail rates resulting from the additional utility costs of CSP and storage

Increasing Block Pricing (IBP) Can Lead to Large Variations in Bill Savings From PV





- IBP is a rate structure with usage tiers and increasing volumetric charges for consumption within each successive tier
- IBP can lead to high value of bill savings from PV, especially for households with significant electricity load (and low value for households with low load)
- Introduction or revision of IBP may have an even greater impact on the value of bill savings from PV than the other uncertainties explored in this study

Conclusions

Future electricity market scenarios, retail rate structures, and the availability of net metering interact to impose substantial uncertainty on the future value of bill savings from PV: simple assumptions that lead to an estimate of an increase in the value of bill savings over time may, or may not, be accurate

- Under scenarios with increased utility costs, bill savings with flat rate and net metering increase relative to reference scenario
- Impact of high wind penetration, carbon pricing, and changes in natural gas prices on bill savings from PV is largely independent of retail rate design
- Hourly netting significantly erodes bill savings from PV relative to net metering
- For scenarios *without* an increase in solar penetration, TOU rates provides the greatest value of bill savings from PV
- Sizable declines in bill savings can occur even at relatively low PV penetrations
- For scenarios *with* high solar penetration, flat rates provide the greatest bill savings
- At high renewables penetrations, bill savings from PV increase with more grid storage, demand response, or CSP with storage
- Increasing block pricing can lead to large variations in bill savings from PV

Possibilities for Future Research

- **Consider scenarios, rate designs, and PV compensation mechanisms not explored in this study**
  - e.g., different generation mixes, winter-peaking system load profiles, retail rates that recover fixed costs through customer charges, etc.
- **Investigate potential impact of customer strategies and technologies to maximize bill savings from PV, such as customer-sited storage or adaptation of load patterns**
  - Particularly relevant under hourly netting arrangements, in order to minimize net excess hourly PV generation
- **Examine implication of changes to retail rate design and PV compensation for residential PV adoption**

For Further Information

Download the report:

http://emp.lbl.gov/sites/all/files/LBNL-6017E.pdf

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