# No Time to Lose: Recent research on the time-sensitive value of efficiency

David Nemtzow, Building Technologies Office
Natalie Mims Frick, Berkeley Lab
Judd Boomhower, University of California San Diego
Edward Burgess, Strategen Consulting
Snuller Price, Energy and Environmental Economics (E3)

This presentation was supported by the U.S. Department of Energy's Building Technologies Office under Lawrence Berkeley National Laboratory Contract No. DE-AC02-05CH11231

# Agenda

- Time-sensitive value of efficiency – why do we care?
- Webinar housekeeping items
- Five perspectives on time-sensitive value of efficiency
  - U.S. Department of Energy Building Technologies Office – David Nemtzow (10 minutes)
  - Research from Berkeley Lab – Natalie Mims Frick (15 minutes)
  - Research from University of California San Diego - Judd Boomhower (15 minutes)
  - Time-sensitive valuation in DSM planning in Arizona – Edward Burgess (15 minutes)
  - Time-sensitive valuation in California – Snuller Price (15 minutes)
- Q&A – 15 minutes

# Why do we care about TSV?

- Electric energy efficiency resources save energy and may reduce peak demand.
- Historically, quantification of energy efficiency benefits has largely focused on the economic value of energy savings during the first year and lifetime of the installed measures. Less emphasis has been placed on the larger grid system.
- There are many applications for time-sensitive energy efficiency data (e.g., energy efficiency planning, distribution system planning, integrated resource planning).
- Today we will discuss why we study and implement time-varying efficiency values and how to operationalize time-varying efficiency values.

# Webinar housekeeping items

- We're recording the webinar and will post it on our web site.
- Because of the large number of participants, everyone is in *listen* mode only.
- **Please use the chat box** to send us your questions and comments any time during the webinar. You may want to direct your question to a specific author.
- The speakers will each have 10 or 15 minutes to present.
- Moderated Q&A will follow, with the report authors responding to questions typed in the chat box.
- The recording and webinar slides will be posted at https://emp.lbl.gov/projects/time-value-efficiency

# Today's Speakers (1)

- **David Nemtzow** As Director of the US Department of Energy's Building Technologies Office (BTO), David is responsible for leading this $200+ million per year office that helps develop innovative, cost-effective energy efficiency R&D and other solutions for U.S. building technologies, equipment, systems and whole buildings. During his time as BTO Director David has made an office priority to promote not only "traditional" energy efficiency, but dynamic, flexible and time-sensitive efficiency, load management and buildings-to-grid technologies. Previously, he was an executive at Ice Energy (the distributed thermal energy storage company), Director-General of the Department of Energy, Utilities & Sustainability for New South Wales (Australia's most populous state) and served as President of the Alliance to Save Energy (a Washington, D.C.-based association that promotes investment in energy efficiency. He earned a master's degree from Harvard University in public policy and a bachelor's from Brown University in environmental policy.
- **Natalie Mims Frick** is an Energy Efficiency Program Manager in the Electricity Markets and Policy Group at Lawrence Berkeley National Laboratory. Natalie conducts research and manages projects on energy efficiency technical assistance, policy, program design, implementation and evaluation. Prior to joining LBNL, Natalie was the principal at Mims Consulting, LLC, where she served as an expert witness in demand-side management regulatory proceedings across the country. Before starting her company, Ms. Frick was the Energy Efficiency Director at the Southern Alliance for Clean Energy (SACE) and, prior to that, a Senior Consultant at Rocky Mountain Institute. During her work at both of these non-profit organizations she focused on regulatory issues pertaining to clean energy adoption, most recently on planning, portfolio design and integrated resource planning for utility energy efficiency programs.

# Today's Speakers (2)

- **Judson Boomhower** is an applied microeconomist who studies environmental and energy economics and policy. He is currently an assistant professor in the Department of Economics at the University of California, San Diego. His research covers a range of topics and industries including electricity markets, oil and gas, energy efficiency, and the economics of climate change. He received a PhD in Agricultural and Resource Economics from the University of California, Berkeley. He earned his bachelor's and master's degrees from Stanford.
- **Edward Burgess** Ed helps to lead Strategen's utility and government consulting practices. He specializes in evaluation and design of policies and programs to advance deployment distributed energy resources, demand-side management programs, energy storage and grid integration of renewable energy. Ed has served clients in the renewable energy, energy efficiency, and energy storage industries, including consumer advocates, public interest organizations, Fortune 500 companies, energy project developers, trade associations, utilities, government agencies, universities and foundations. His analysis has given companies strategic insight into clean energy investment opportunities and has helped to guide regulations and policies in many states across the country.
- **Snuller (Snu) Price** has more than 20 years of experience supporting utilities and state and federal government clients with energy policy and resource planning. He has pursued a broad array of topics across the electricity sector, seeking large-scale, cost-effective opportunities and contributing insights, methods, and tools to the field throughout his career. Snu has helped develop standard methods that regulators widely use to assess the cost-effectiveness of cogeneration, demand response, electric vehicles, energy efficiency, and building standards. He has also managed economic evaluations of net energy metering for behind-the-meter solar in many states.

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The recording and webinar slides will be posted at https://emp.lbl.gov/projects/time-value-efficiency

U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

# Time-Sensitive Valuation and Buildings

## *Is Time on My Side?*

**David Nemtzow**

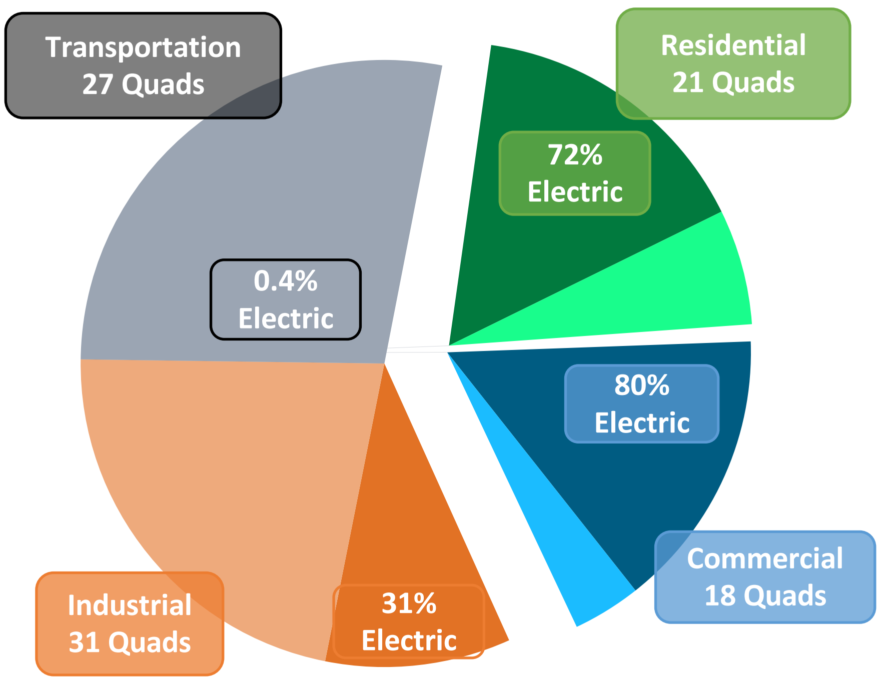
Director, Building Technologies Office

LBNL *No Time to Lose* Webinar 11/1/18

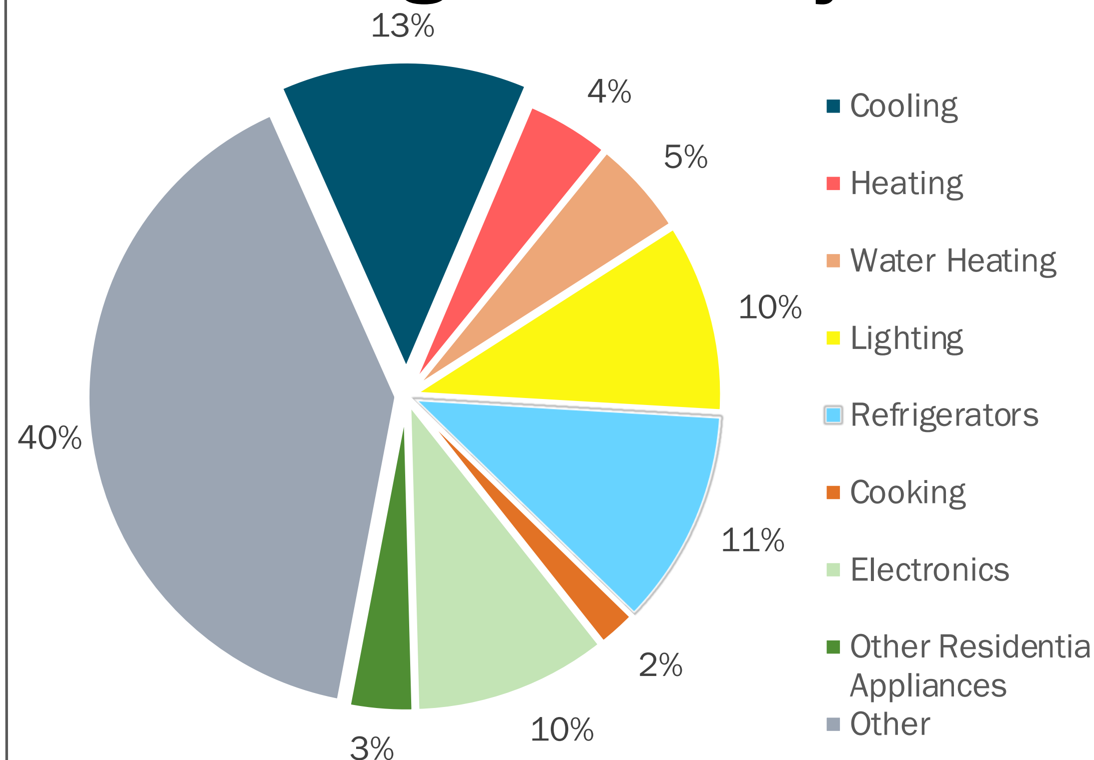
https://www.energy.gov/eere/buildings/geb

# Energy use in the U.S. building sector

## Energy Use




## Building Electricity Use




**Buildings Energy Use: 40% of U.S. total**

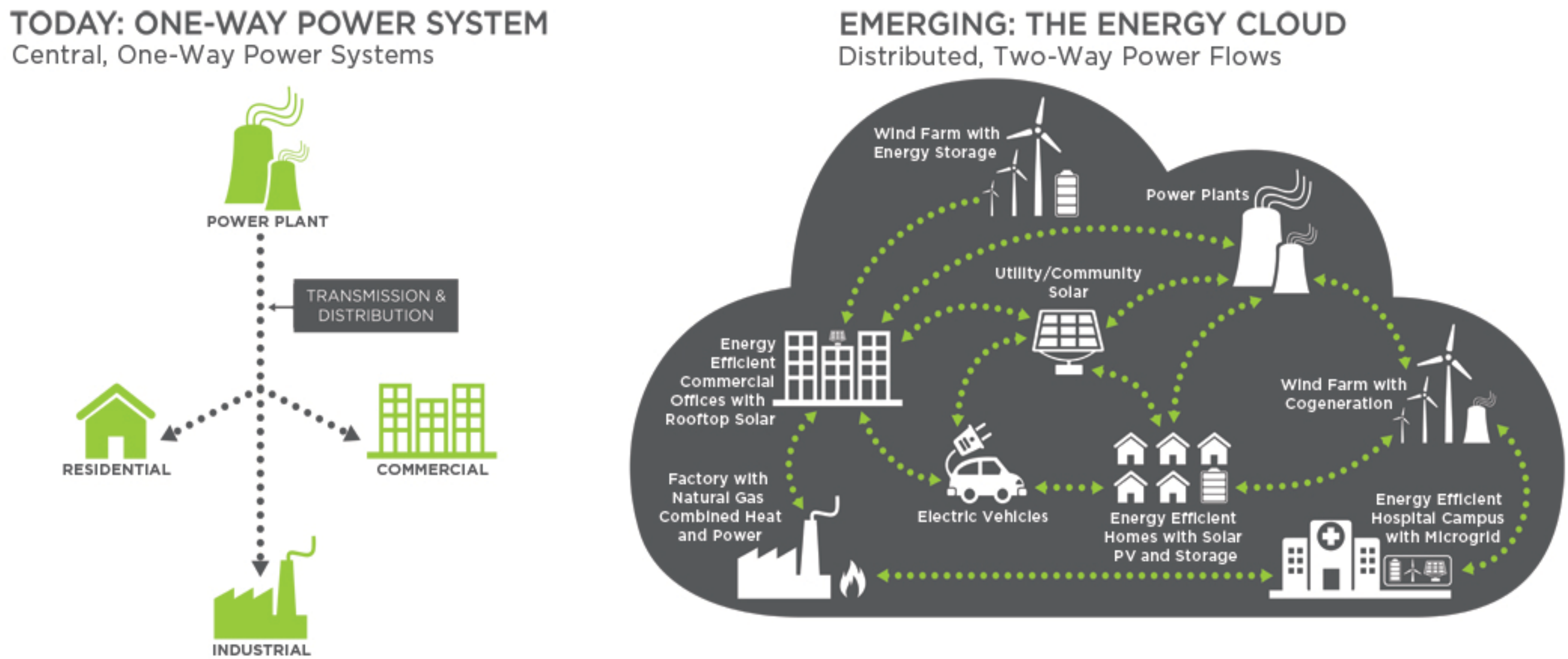
**Buildings Electricity Consumption: 75% of U.S. total**

**Buildings Peak Electricity Demand: ~80% of regional total**

**U.S. Building Energy Bill: $380 billion per year**

*Source: EIA 2017 Annual Energy Outlook*

# Moving Towards the Grid of the Future






*(Source: Navigant)*

# Flexible Building Loads

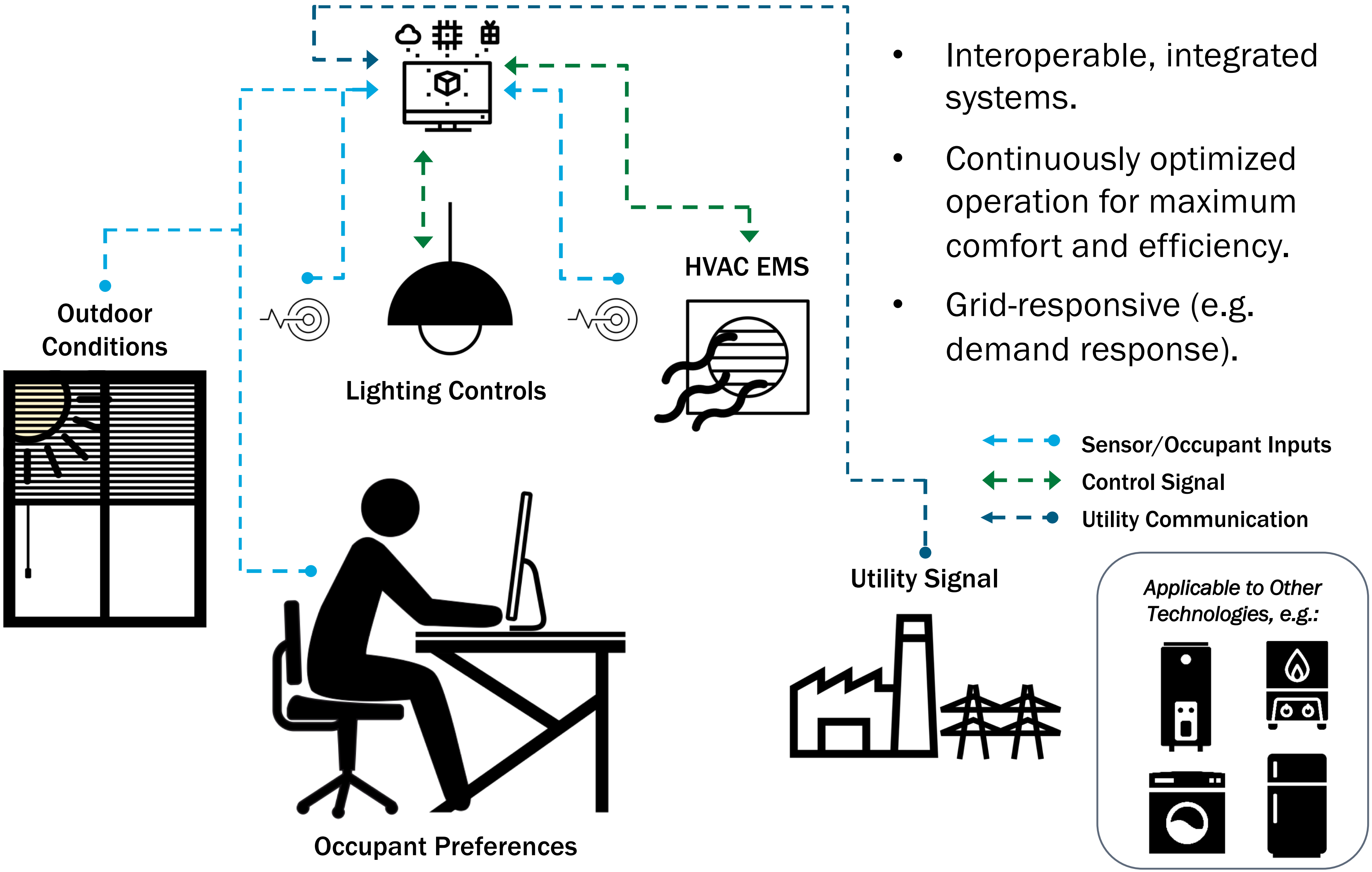
Provide options to increase electricity system reliability & energy affordability

Support all generation options resulting from grid modernization

Optimize energy use based on customer preferences

Respond to innovations in the energy economy

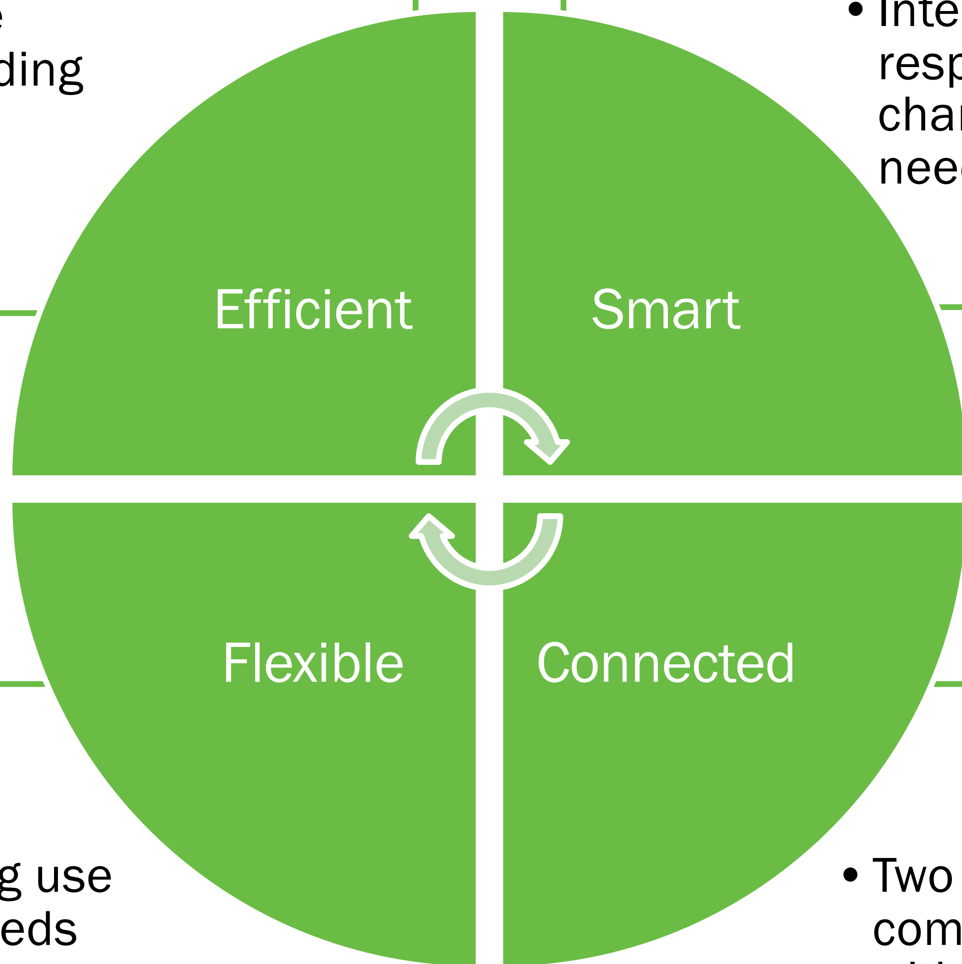
# Interactions with Building Occupants




- Interoperable, integrated systems.
- Continuously optimized operation for maximum comfort and efficiency.
- Grid-responsive (e.g. demand response).

# Grid-interactive Efficient Buildings

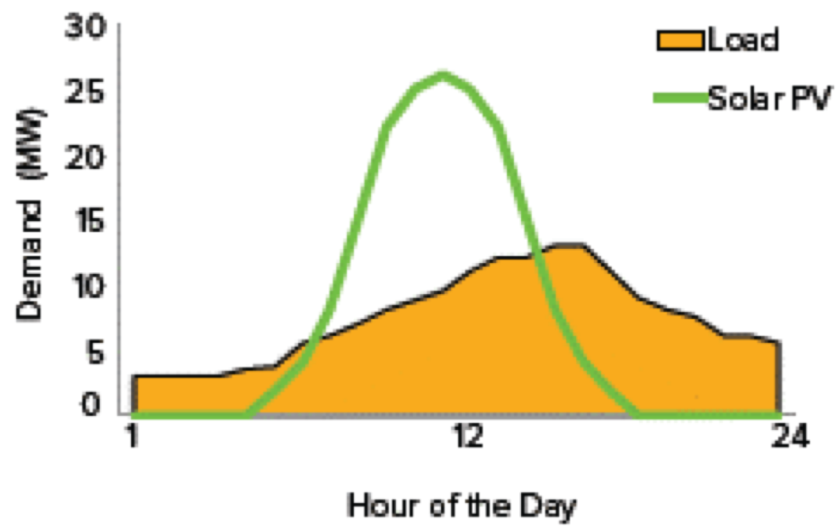
- Efficient end use devices and building design
- Intelligent responsiveness to changes in value and needs



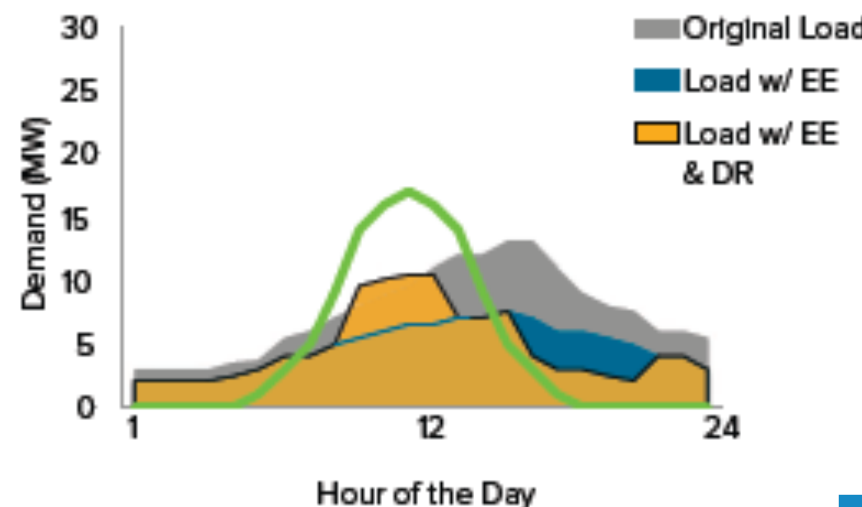

- Optimize building use per occupant needs and grid signals
- Two way communication flow with grid signals

# Impact on a Building's Energy Use

### Solar PV




### Energy Efficiency, Demand Response, then Solar PV




*Images and data courtesy of PG&E*

# BTO's Grid-interactive Buildings portfolio

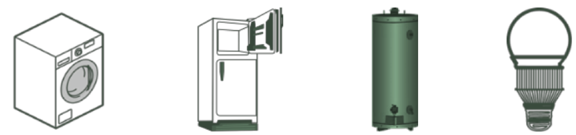
## VALUE OF GEB

**Key Question:** *How do time & the interaction of flexibility options impact value / improve affordability?*

**Outcome:** *Identify values to stakeholders, quantification of national value.*

## TECHNOLOGY OPTIONS

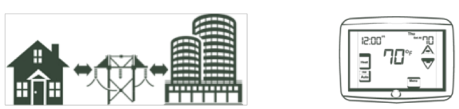
**Key Question:** *Which end use technologies provide solutions to specific grid needs?*



**Outcome:** *Prioritize technologies / solutions based on grid services.*

## OPTIMIZATION FOR GEB

**Key Question:** *How to optimize for flexibility while maintaining or improving building operation /occupant comfort / productivity?*



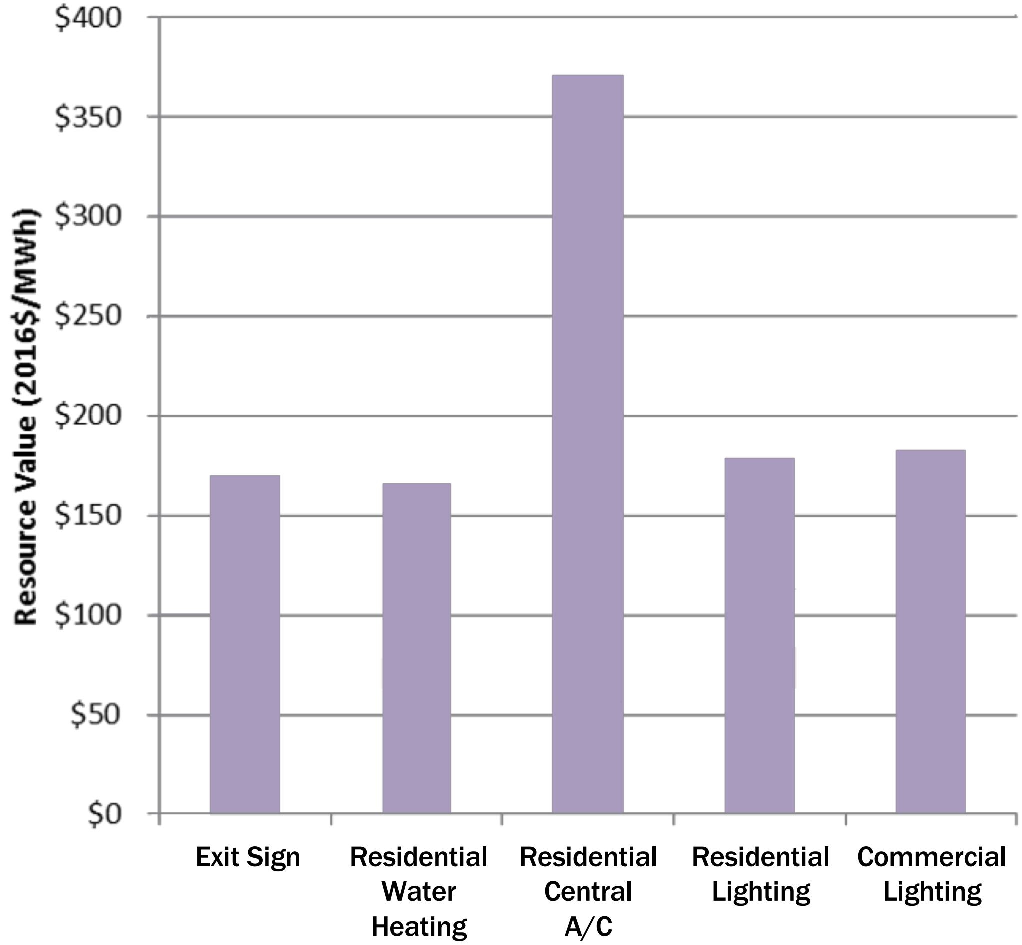
**Outcome:** *Solutions that meet grid operator & building occupant needs.*

## VALIDATION

**Key Question:** *Do technologies perform as predicted / meet grid operator & building occupant needs?*

**Outcome:** *Verification of technologies / strategies, increasing confidence in the value of energy flexibility.*

# Not All Energy Efficiency is Equally Valuable



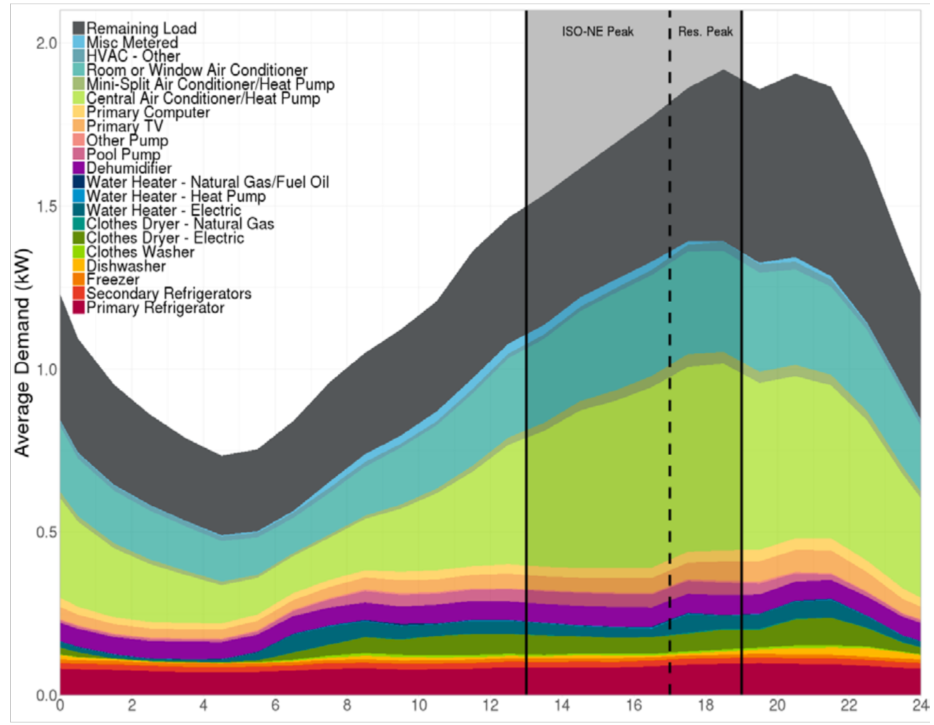

Time-varying value of energy efficiency savings by load shape

*(Massachusetts case study, reflects publicly available data only)*

Source: ***Time-Varying Value of Electric Energy Efficiency*** *June 2017* N.Mims, T.Eckman & C.Goldman, LBNL, for BTO

# End use load profile modeling for US building stock
## (BTO project w/NREL & LBNL, NEEA)

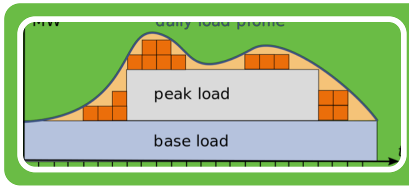
- End-use load/savings profiles are needed for:
  - ✓ TSV-EE analysis & implementation
  - ✓ R&D prioritization, utility resource & distribution system planning, state & local planning & regulation
  - ✓ widespread adoption of grid-interactive efficient buildings
- Existing profiles are often outdated, regionally limited, based on small sample size, & limited to subset of building stock
- Project will result in
  - ✓ validated end-use load profiles for U.S. building stock at both aggregate & individual building scales
  - ✓ calibrated building stock end use models with ability to estimate EE/DR savings profiles for existing & emerging technologies
  - ✓ published load profile use cases, critical gaps, model methodology, user guide




Source: Navigant Massachusetts RES 1 Baseline Load Shape Study

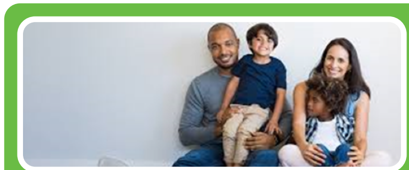
# Potential Benefits of Flexible Building Loads

✓ Energy Affordability




✓ Improved reliability

✓ Reduced grid congestion



✓ Enhanced services

✓ Environmental benefits

✓ Customer choice

# Questions ?

USDOE Buildings team includes:

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# Time-varying value of efficiency

Natalie Mims Frick, Berkeley Lab

# Recent Time-Varying Value Publications by LBNL

## Time-varying value of electric energy efficiency

Authors:

**Natalie Mims, Tom Eckman,[1] and Charles Goldman**

[1]Consultant and Senior Advisor, Northwest Power and Conservation Council

**Energy Analysis and Environmental Impacts Division**

**Lawrence Berkeley National Laboratory**

Electricity Markets and Policy Group

**June 2017**

This work was supported by the DOE Office of Energy Efficiency & Renewable Energy Building Technologies Office under Lawrence Berkeley National Laboratory Contract No. DE-AC02-05CH11231.



APRIL 2, 2018

### TIME-VARYING VALUE OF ENERGY EFFICIENCY IN MICHIGAN[1]

NATALIE MIMS, TOM ECKMAN AND LISA SCHWARTZ,[2] LAWRENCE BERKELEY NATIONAL LABORATORY

In December 2016, the Michigan Legislature passed new laws (SB 341 and 342) that require the Public Service Commission (PSC) to create regulations for integrated resource planning (IRP) and determine the potential of energy waste reduction resources to meet electricity needs. Following stakeholder engagement meetings, the PSC requested technical assistance from Berkeley Lab to better understand how to account for the time-varying value of electricity savings in IRP and demand-side management (DSM) planning in Michigan. Working collaboratively with the PSC, Consumers Energy and DTE Energy, Berkeley Lab calculated the time-varying value of electricity savings for five energy efficiency measures in the utilities' service areas.

Quantifying the time-varying value of energy efficiency is necessary to properly account for all of its benefits and costs and to identify and implement efficiency resources that contribute to a low-cost, reliable electric system (Mims et al. 2017; Boomhower and Davis 2016). Historically, most quantification of the benefits of efficiency have focused largely on the economic value of annual reductions in energy use. Due to the lack of statistically representative, metered data on end-use load shapes in Michigan (i.e., the hourly or seasonal timing of electricity savings), the ability to confidently characterize the time-varying value of energy efficiency savings in the state, especially for weather-sensitive measures such as central air conditioning, is limited.

Based on our analysis of data from Consumers Energy and DTE Energy, we conclude that: (1) overall, the ratio of the total utility system value of energy savings to their energy-related value in Michigan aligns with other states with similar system load shapes; (2) end-use load shape research that is specific to Michigan would enable more accurate analysis of the time-varying value of efficiency; (3) until such time that statistically representative, metered data on end-use load shapes in Michigan are available, data from regions with similar energy consumption characteristics should be considered for adoption (e.g., we used Pacific Northwest end-use load shapes in our analysis because they are based on metered data and are very similar to the end-use load shapes for some measures from the Electric Power Research Institute (EPRI) End Use Load Shape Library that are applicable to Michigan); and (4) an investigation of all value streams for energy efficiency (e.g., avoided risk and air emissions values) in Michigan will help avoid undervaluing this resource.

Still, electric utilities in Michigan can take advantage of opportunities to incorporate the time-varying value of efficiency into their planning. For example, end-use load research and hourly valuation of efficiency savings can be used for a variety of electricity planning functions, including load forecasting, DSM, demand-side evaluation, capacity planning, long-term resource planning, renewable energy integration, assessing potential grid modernization investments, establishing rates and pricing, and customer service (KEMA 2012). In addition, accurately calculating the time-varying value of efficiency may help energy efficiency program administrators prioritize existing offerings, set incentive or rebate levels that reflect the full value of efficiency, and design new programs.

June 2017 technical report supported by DOE's Office of Energy Efficiency and Renewable Energy - Building Technologies Office

April 2018 technical brief supported by DOE's Office of Electricity – Transmission Permitting and Technical Assistance

# Why study the time-varying value of efficiency savings?

- Motivations
  - Advance consideration of the value of efficiency measures during times of peak electricity demand and high electricity prices
  - Increase awareness of:
    - Available end-use load research and its application to time-varying valuation of energy efficiency
    - Gaps in (and need for) research on energy savings shapes
- Goals
  - Calculate the time-varying value of efficiency for 5 regions
  - Recommend methodology(ies) to appropriately value efficiency for meeting peak demand
  - Consider changes to efficiency valuation methodologies to address the changing shape of net load (total electric demand in the system minus wind and solar)

# Approach (1)

- Provide background for the studies by summarizing existing analyses that quantify benefits of electric efficiency measures and programs during peak demand and high electricity prices.
- Use publicly available avoided costs and end-use load shapes from state or regional sources.
- Document time-varying energy and demand impacts of 5 measures in 5 locations:

| *Measures* | *State/Region* |
| --- | --- |
| Exit sign (flat load shape) | Pacific Northwest |
| Commercial lighting | California |
| Residential lighting | Massachusetts |
| Residential water heater | Georgia |
| Residential air conditioning | Michigan |

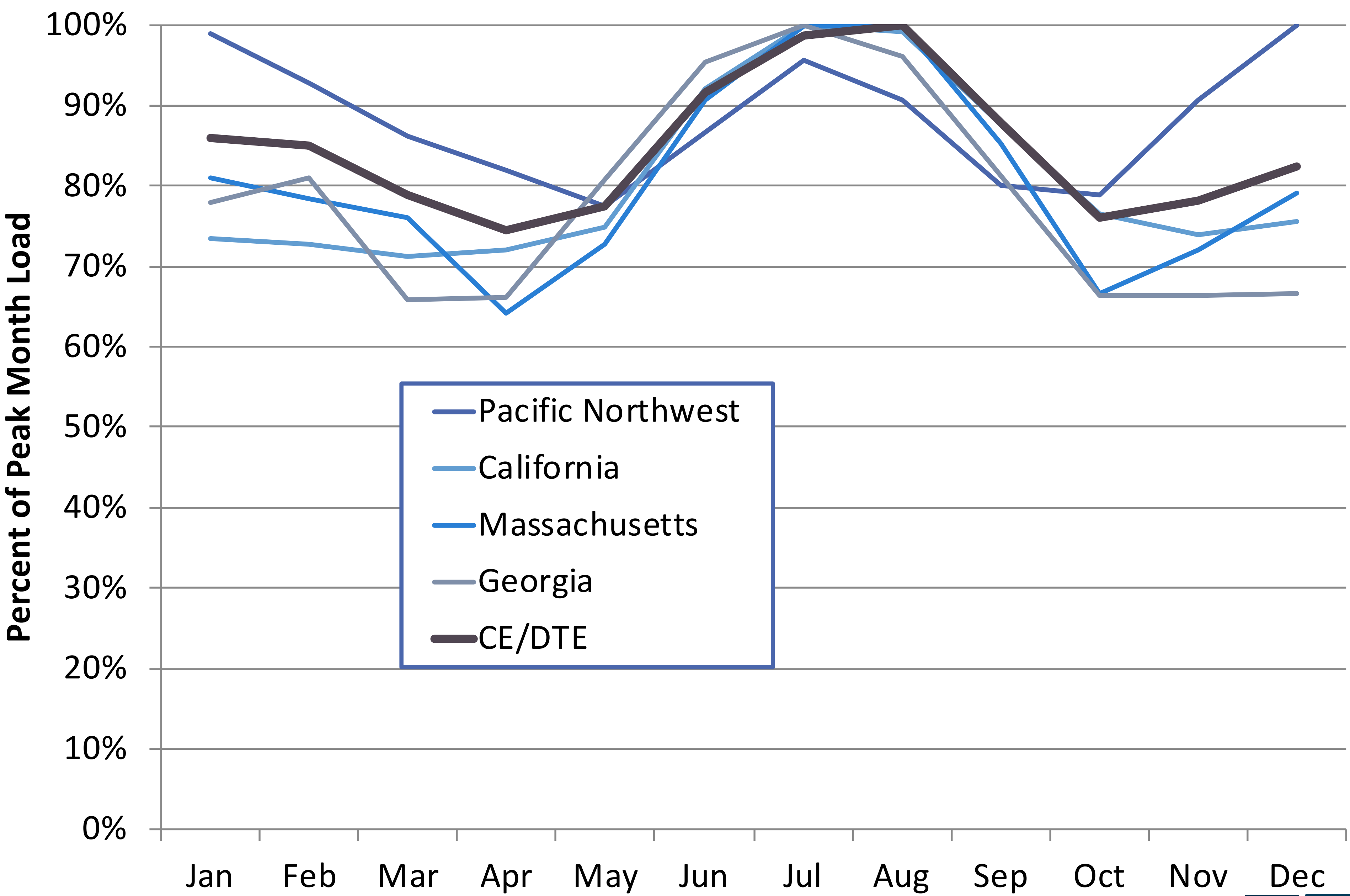
# Approach (2)

- One of the following methodologies was used for each region:

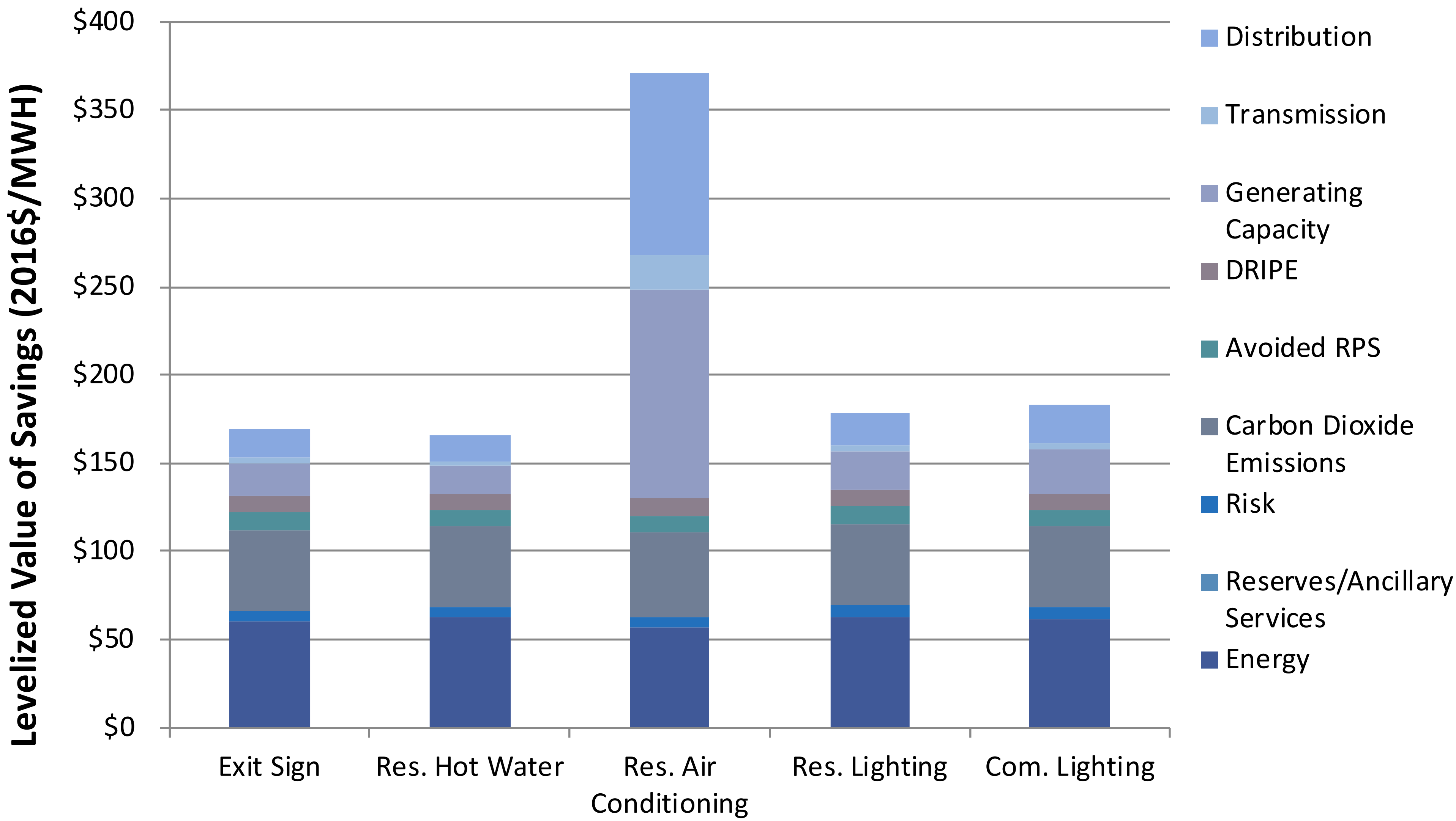
1. Apply hourly avoided costs to each measure load shape to calculate the time-varying value of measure, *or*
2. Use seasonal system peaks, coincidence factors and diversity factors to determine peak/off-peak savings and apply seasonal avoided costs to savings.

- If hourly avoided costs and end-use load shapes were available, LBNL used that data. Often, that data was not available and the second methodology was used.

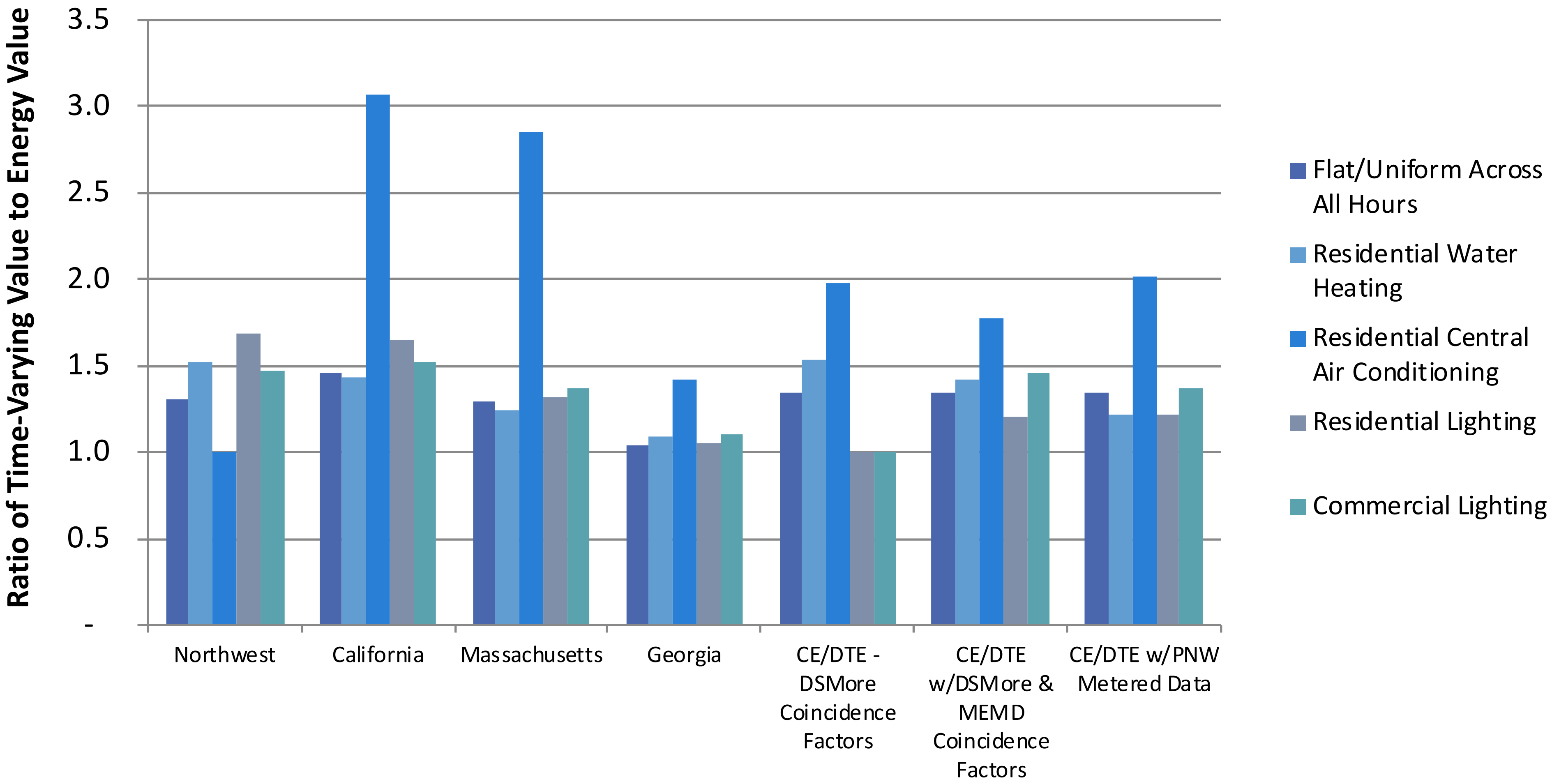
# Annual System Load Shapes



# Massachusetts Time-Varying Value by Load Shape



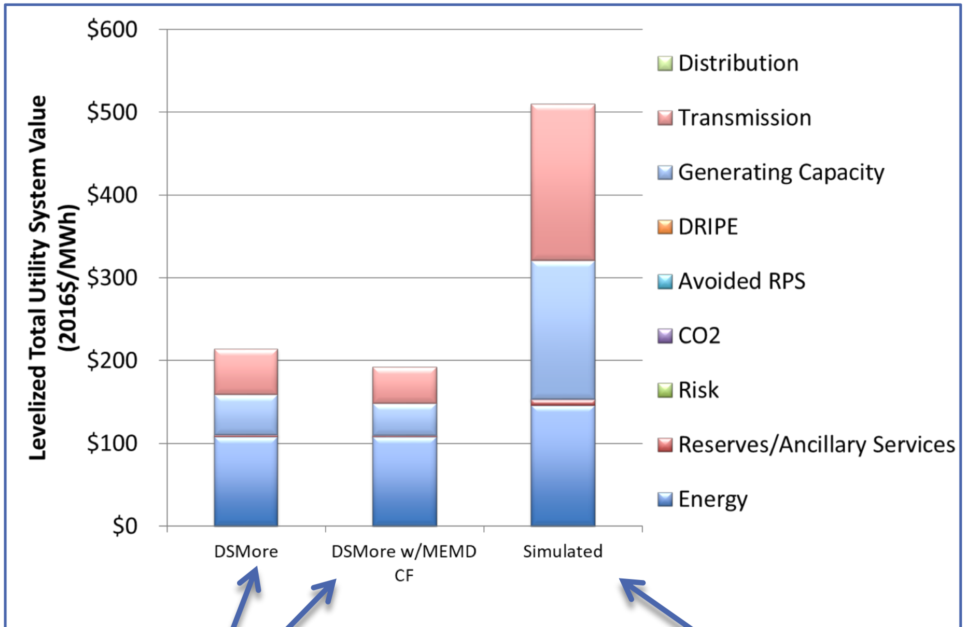
# Results: Total Utility System Value of Savings Compared to Only Their Energy Value



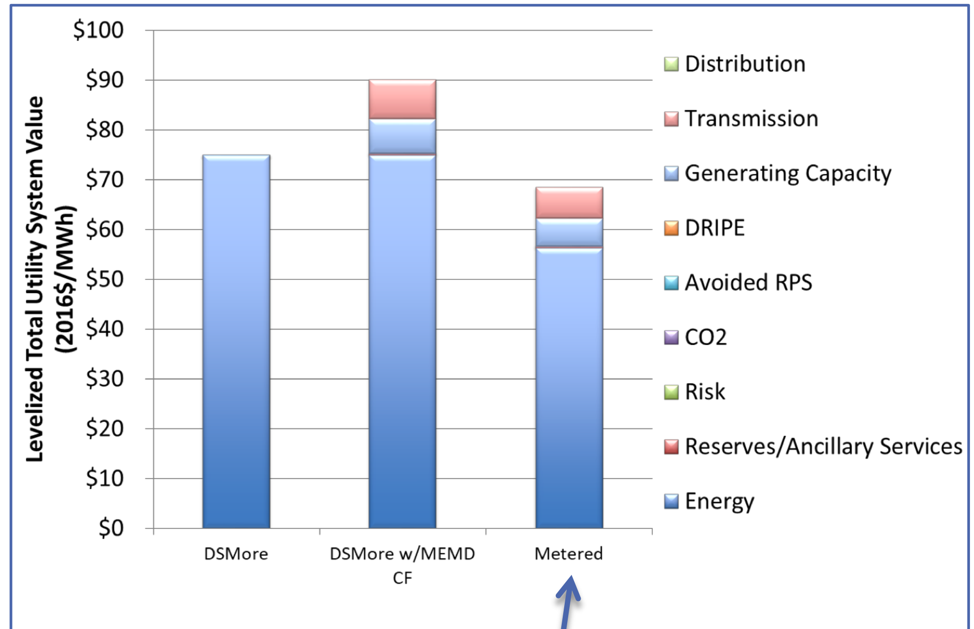

Notes: The flat load shape is an exit sign. Energy value includes: energy, risk, carbon dioxide emissions, avoided RPS and DRIPE, as applicable if reported. Total time-varying value includes all energy values and capacity, transmission, distribution and spinning reserves. Ratios are calculated by dividing total time-varying values by energy-only values.

# Why Accurate Load Shapes Matter (1)

## Residential Central Air Conditioning - MI




## Residential Lighting - MI



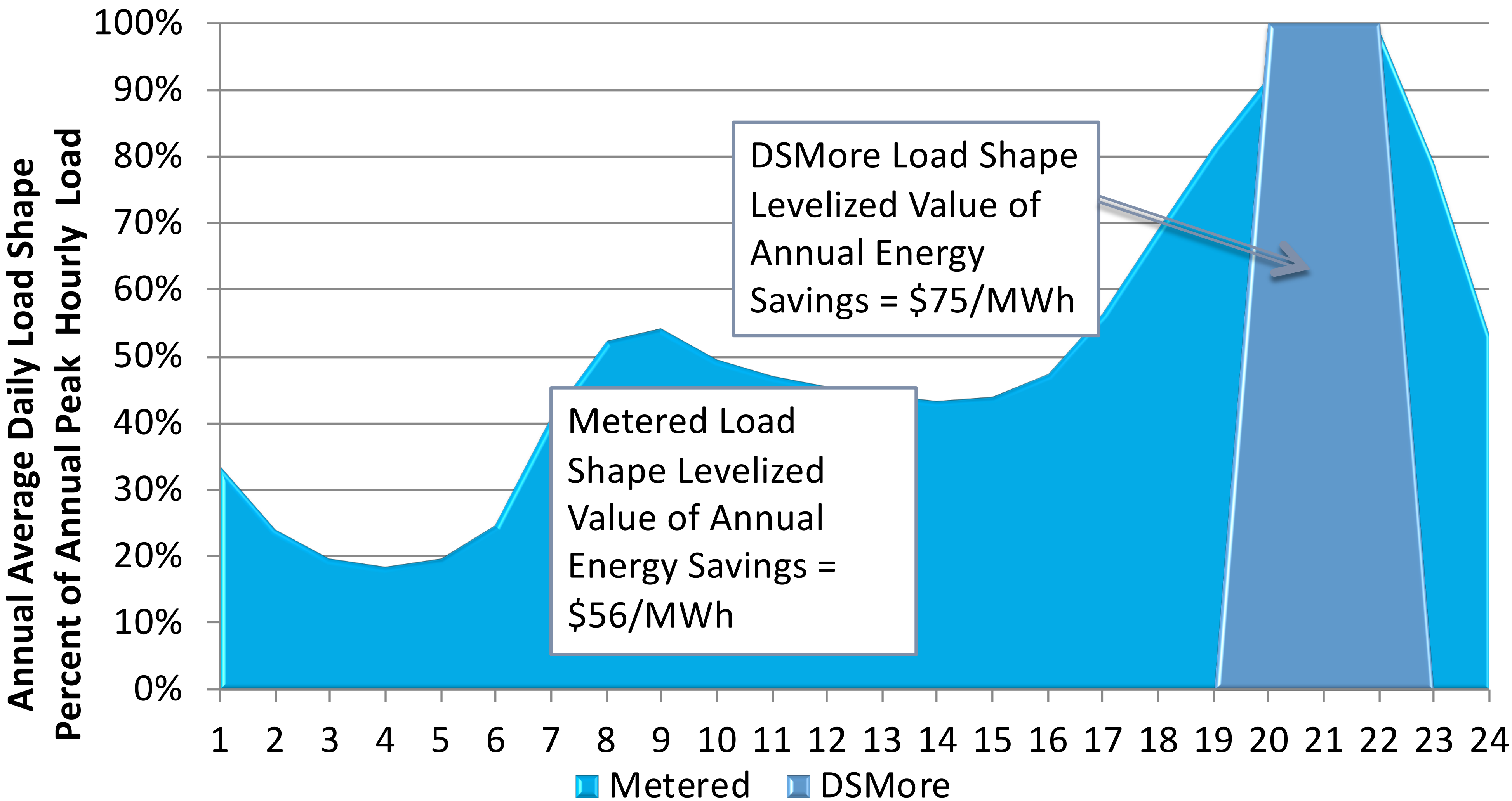

Load Shapes Not Based on Metered Data

Simulated Load Shapes May Not Represent “Diversified Loads”

Statistically Representative Metered Data Provides More Accurate Representation

# Why Accurate Load Shapes Matter (2)

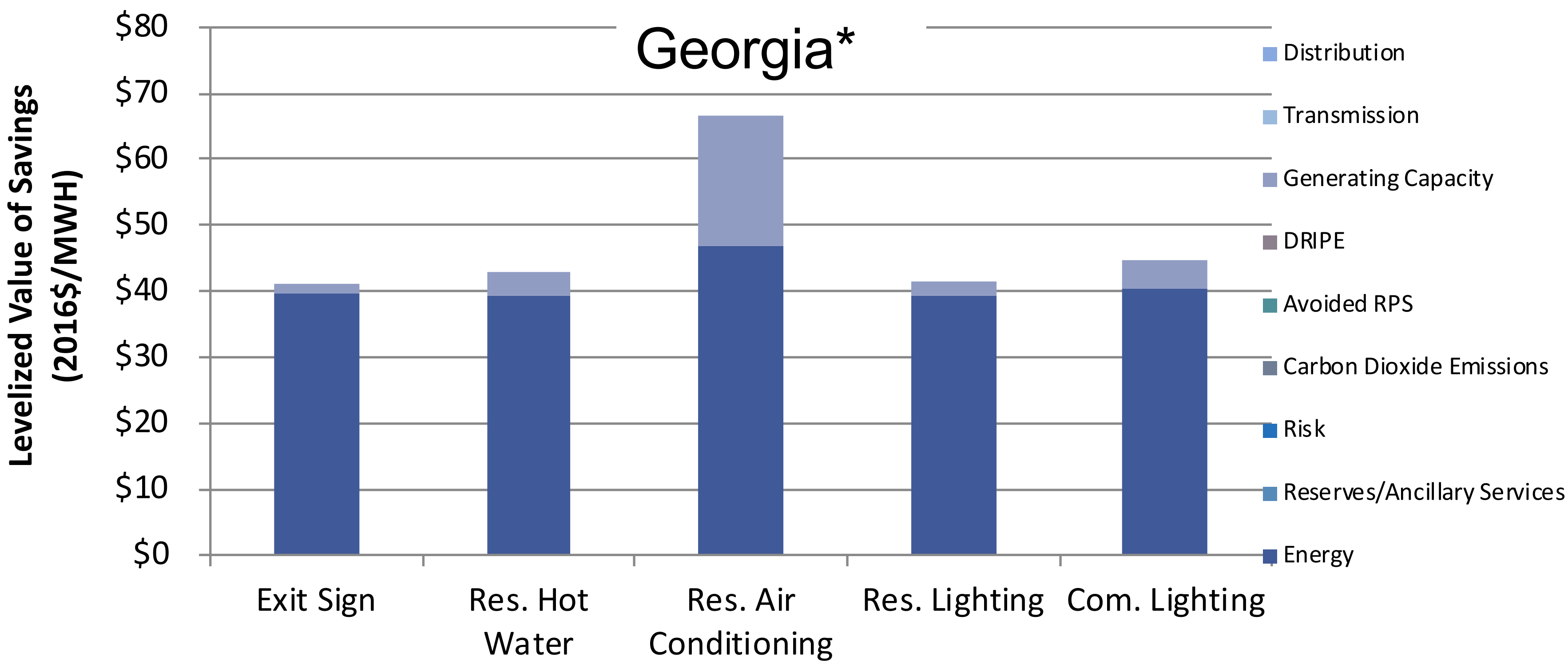
DSMore* (modeled) and metered load shapes produce significantly different values for annual energy savings.




*DSMore is a commercially available model that determines the hourly value of energy savings for their demand-side management plans. See http://www.integralanalytics.com/products-and-services/dsm-planning-and-evaluation/dsmore.aspx.

# Why All Avoided Cost Values Matter

- The time-varying value of energy efficiency measures varies across the locations studied because of physical and operational characteristics of the utility system, the time periods that savings occur and differences in the value and components of avoided cost considered.
- Publicly available components of electric system costs avoided through energy efficiency are not uniform across states and utilities. Inclusion or exclusion of these components and differences in their value affect estimates of the time-varying value of efficiency.

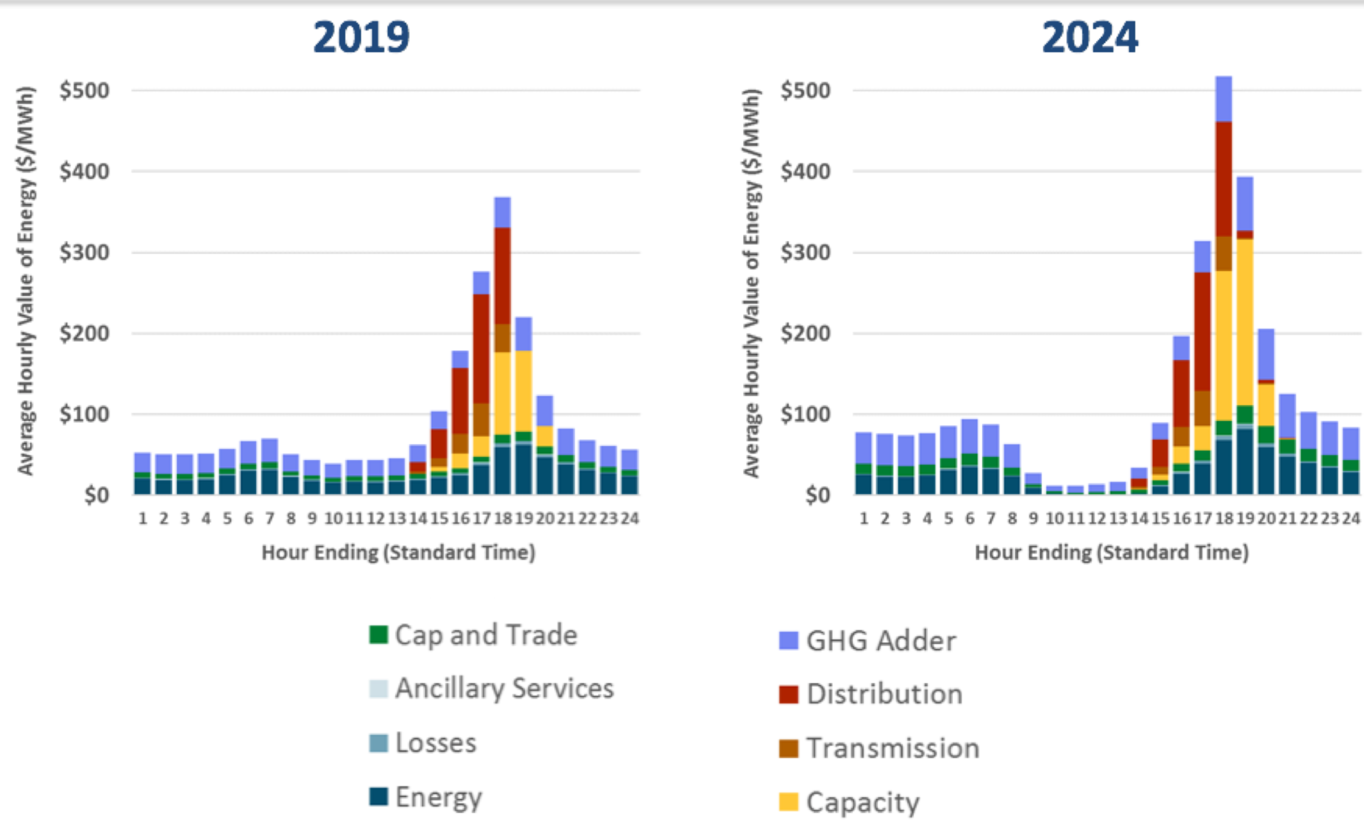



* In Georgia, where publicly available data did not include avoided transmission and distribution system values, the time-varying value of efficiency appears much lower for all measures evaluated. Avoided transmission and distribution costs are included in Georgia Power's energy efficiency planning, but are not a part of the publicly available PURPA avoided cost filing and therefore are not included here.

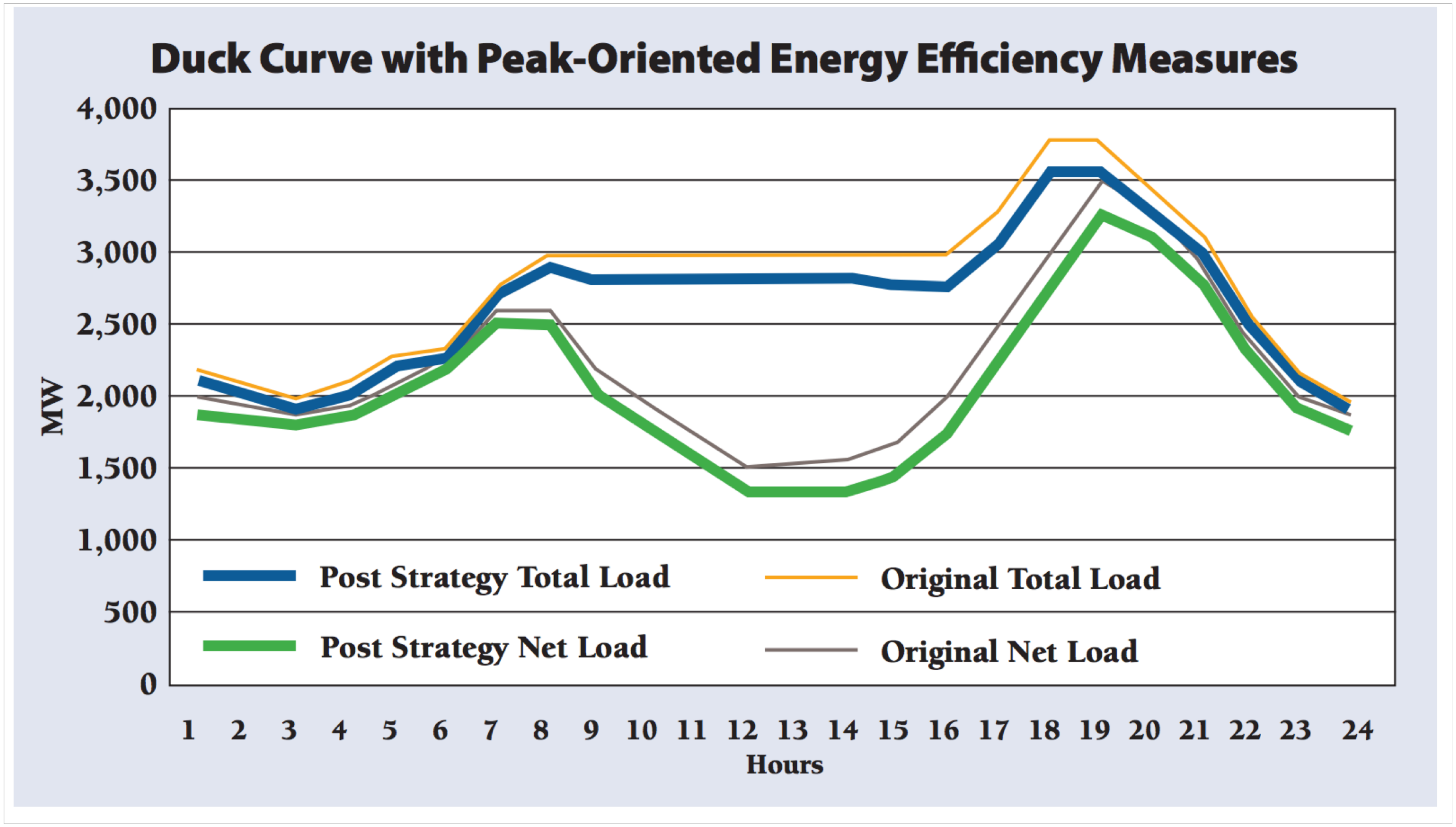
# Why Changing *System* Shapes Matter (1)

- The increased use of distributed energy resources and the addition of major new electricity-consuming end-uses are anticipated to significantly alter the load shape of many utility systems in the future.
- Data used to estimate the impact of energy efficiency measures on electric system peak demands will need to be updated periodically to accurately reflect the value of savings as system load shapes change.

Components of Electric Avoided Cost for climate zone 4 in 2019 and 2024



# Why Changing *System* Shapes Matter (2)



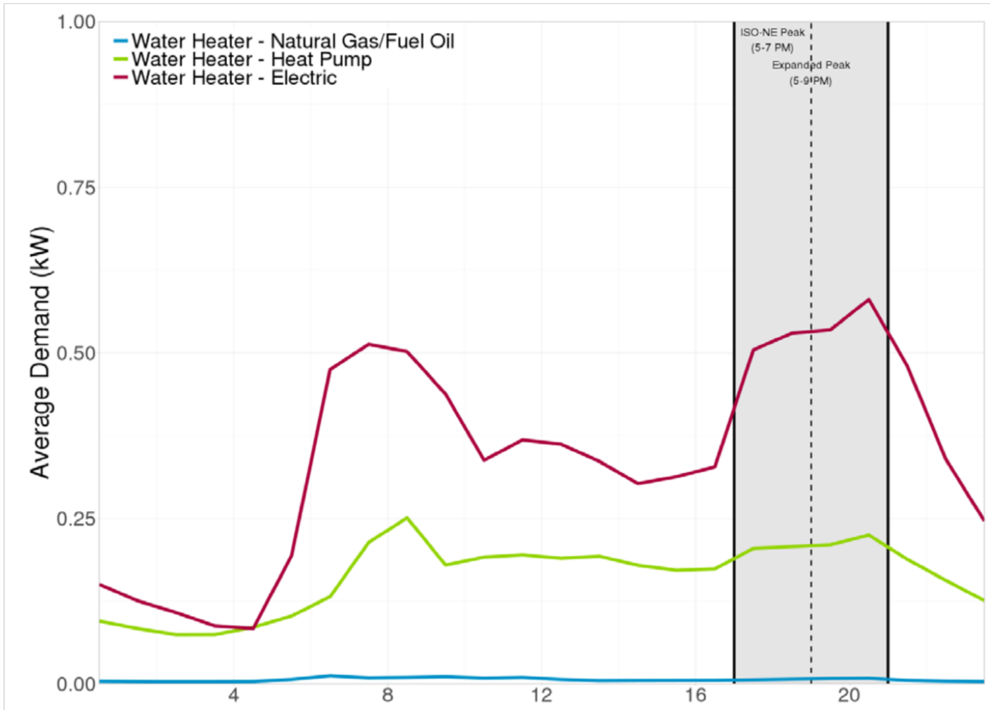

Target efficiency for steep ramping period — for example, LEDs

Source: Teaching the Duck to Fly (2016)

# Why *Savings* Shapes Matter (1)

- Definitions:
  - **End-use load shape:** Hourly consumption of an end-use (e.g., residential lighting, commercial HVAC) over the course of one year
  - **Energy savings shape:** The difference between the hourly use of electricity in the baseline condition and the hourly use after installing the energy efficiency measure (e.g., the difference between the hourly consumption of an electric resistance water heater and a heat pump water heater) over the course of one year
- The time pattern of savings from the substitution of a more efficient technology does not always mimic the underlying end-use.

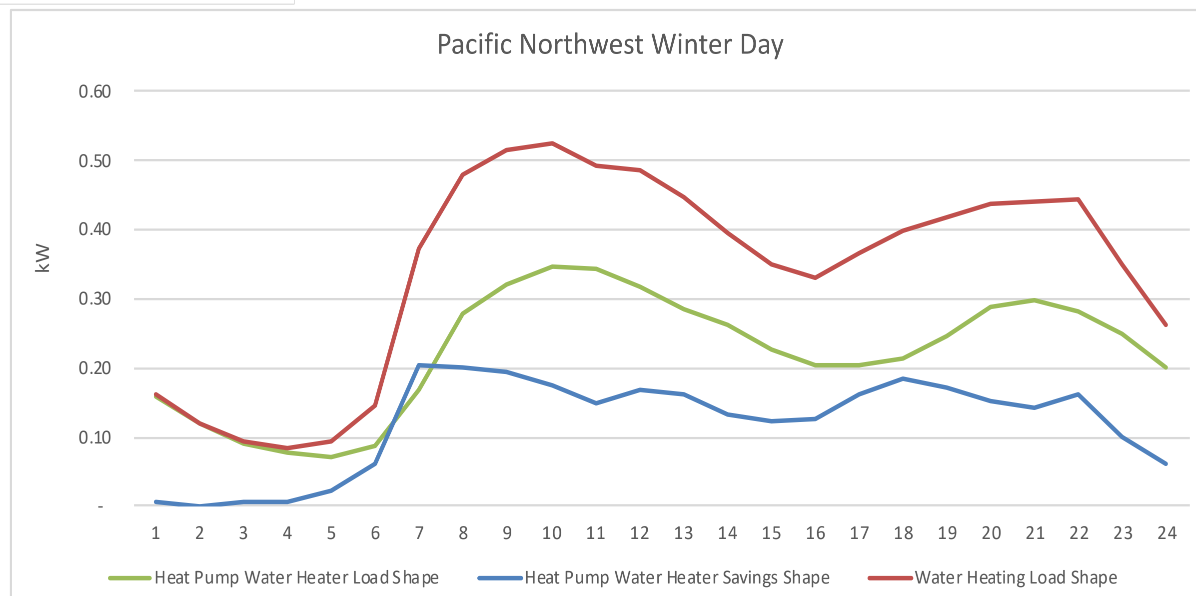
# Why Savings Shapes Matter (3)




Winter peak day water heating load shapes in Massachusetts

Source: Navigant Massachusetts Residential Baseline Study (2018)

Winter peak day water heating <u>load and savings shapes</u> in the Pacific Northwest



# Do Energy Efficiency Investments Deliver at the Right Time?

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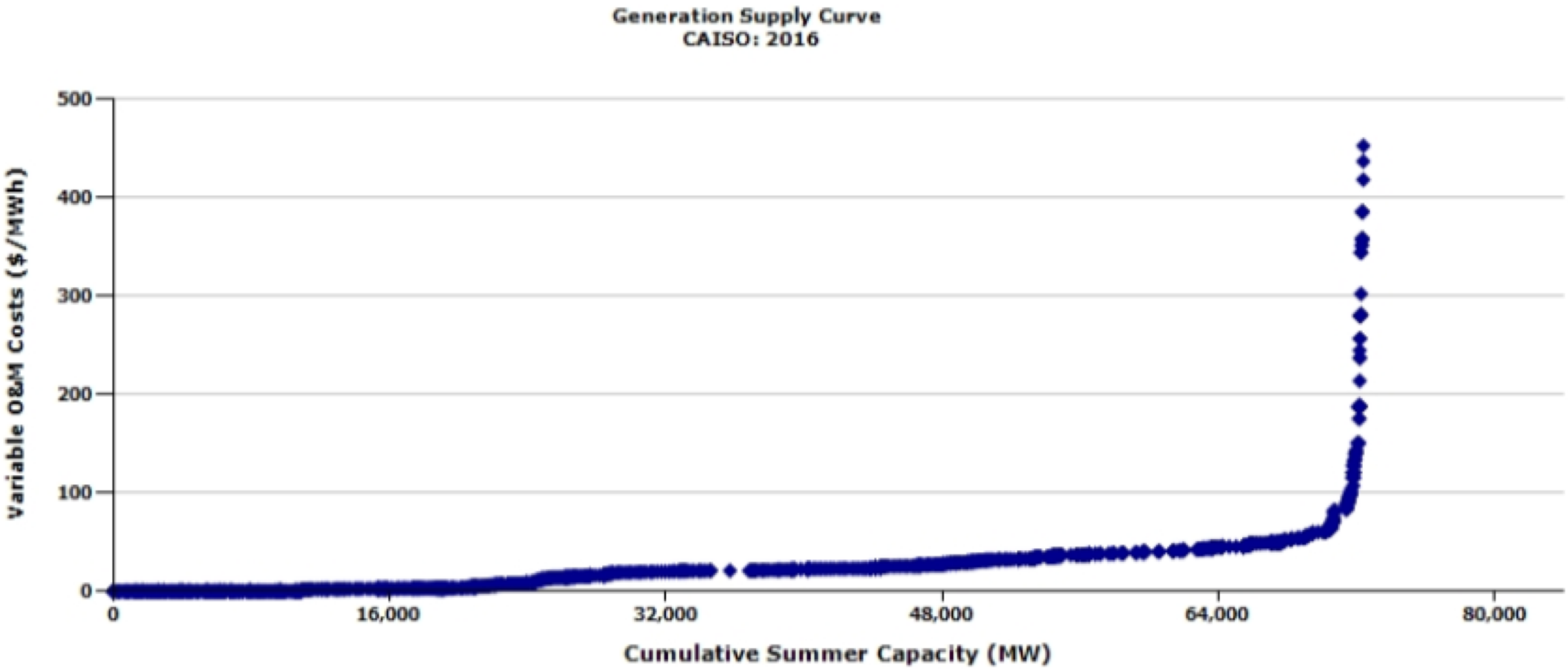
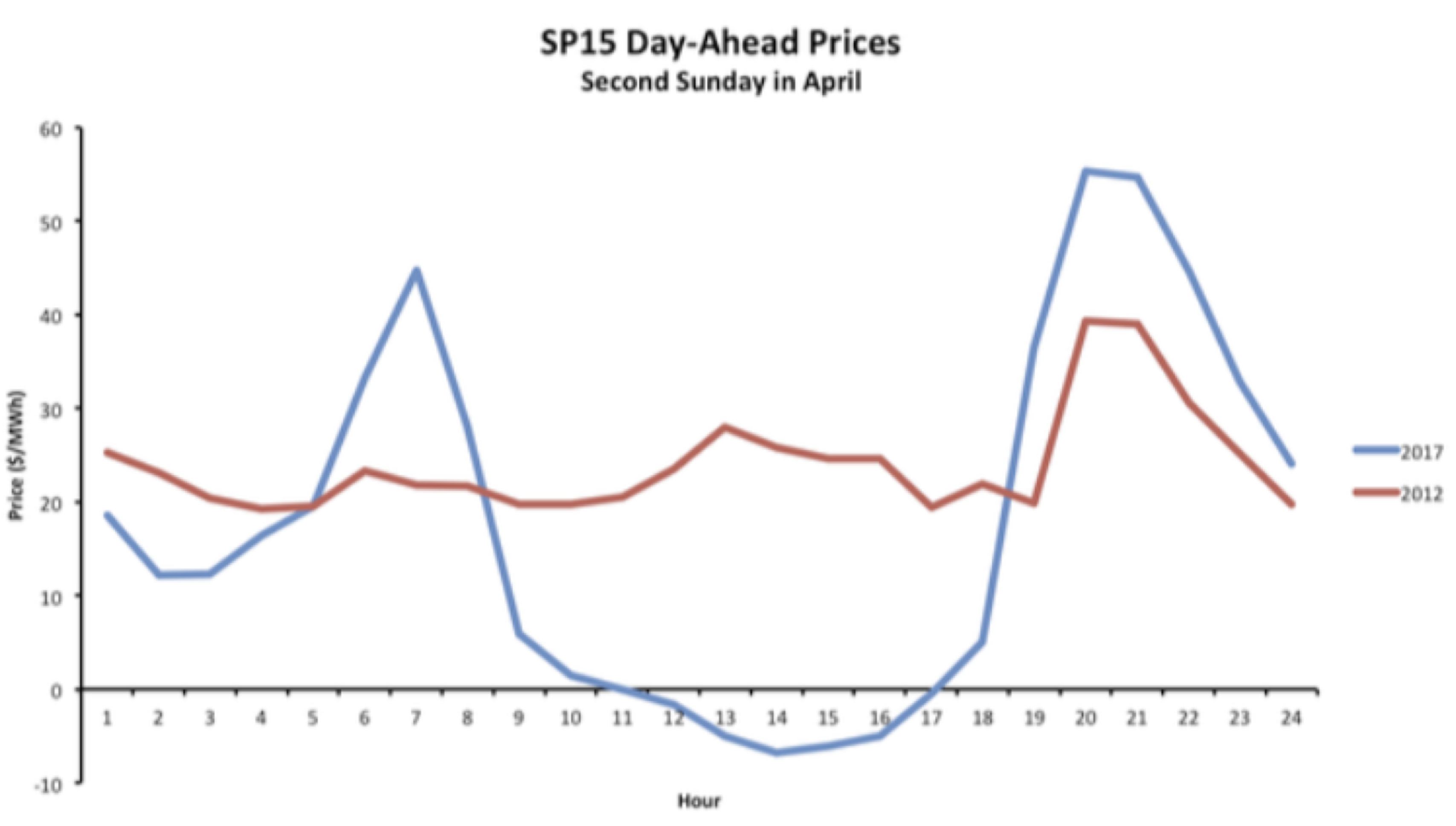
November 2018

# The Value of Electricity Varies Enormously

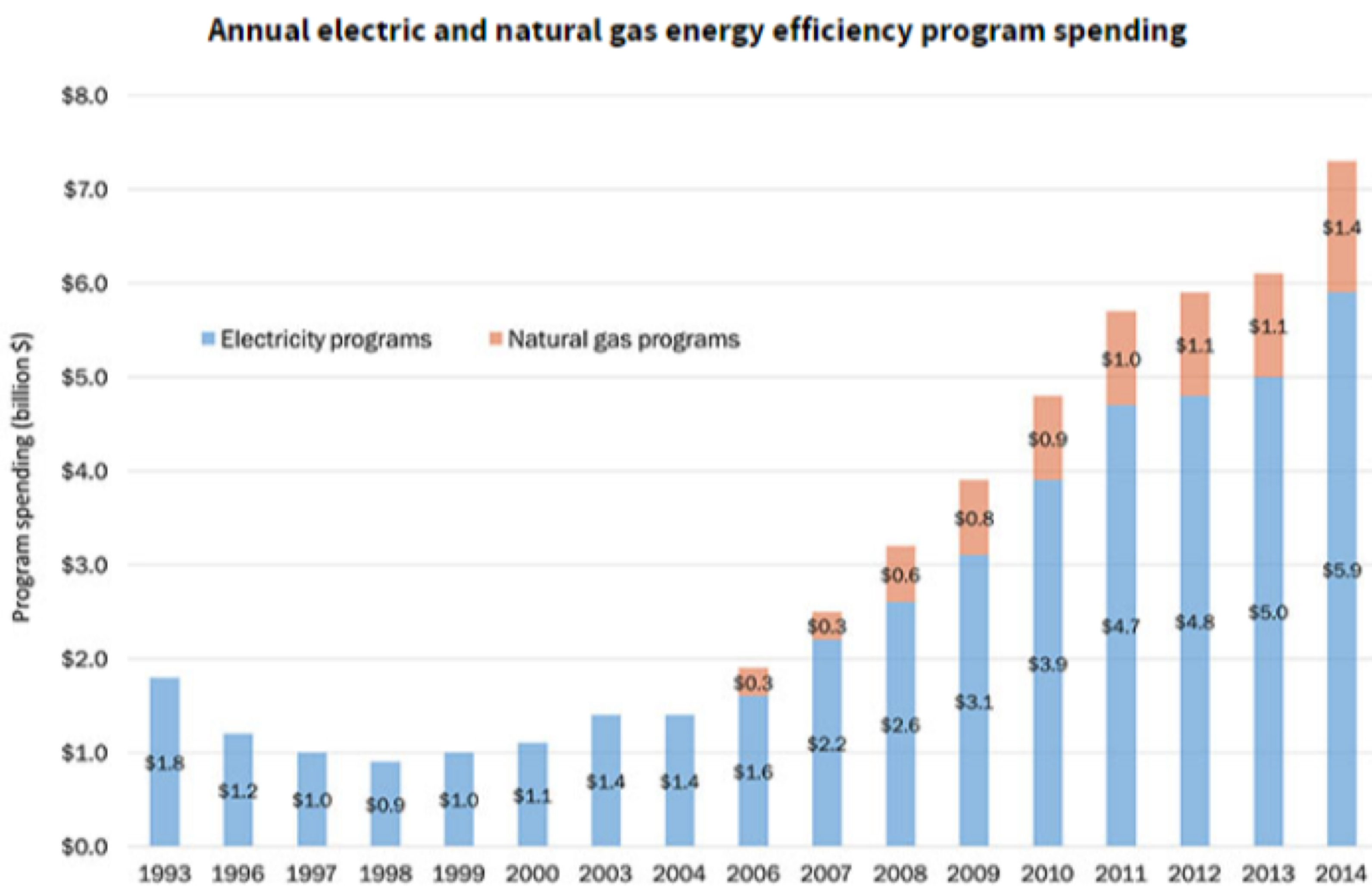


# Negative Prices




*These features of electricity markets are well known, yet the vast majority of analyses of energy-efficiency policies ignore this variation.*

# Spending on Subsidy Programs is Large and Growing




Source: ACEEE

## Research Questions

- When does energy efficiency save electricity?
- Are savings correlated with wholesale electricity prices?
- Are savings correlated with capacity values?
- How much does accounting for timing matter?
- How much does the timing premium vary across investments?

# Smart Meter Data

| Advanced Metering Infrastructure (AMI) | |
|---|---|
| 2007 | 2,202,222 |
| 2008 | 4,190,244 |
| 2009 | 8,712,297 |
| 2010 | 18,369,908 |
| 2011 | 33,453,548 |
| 2012 | 38,524,639 |
| 2013 | 47,321,995 |
| 2014 | 51,710,725 |
| 2015 | 57,107,785 |

Source: EIA

# Paper Overview

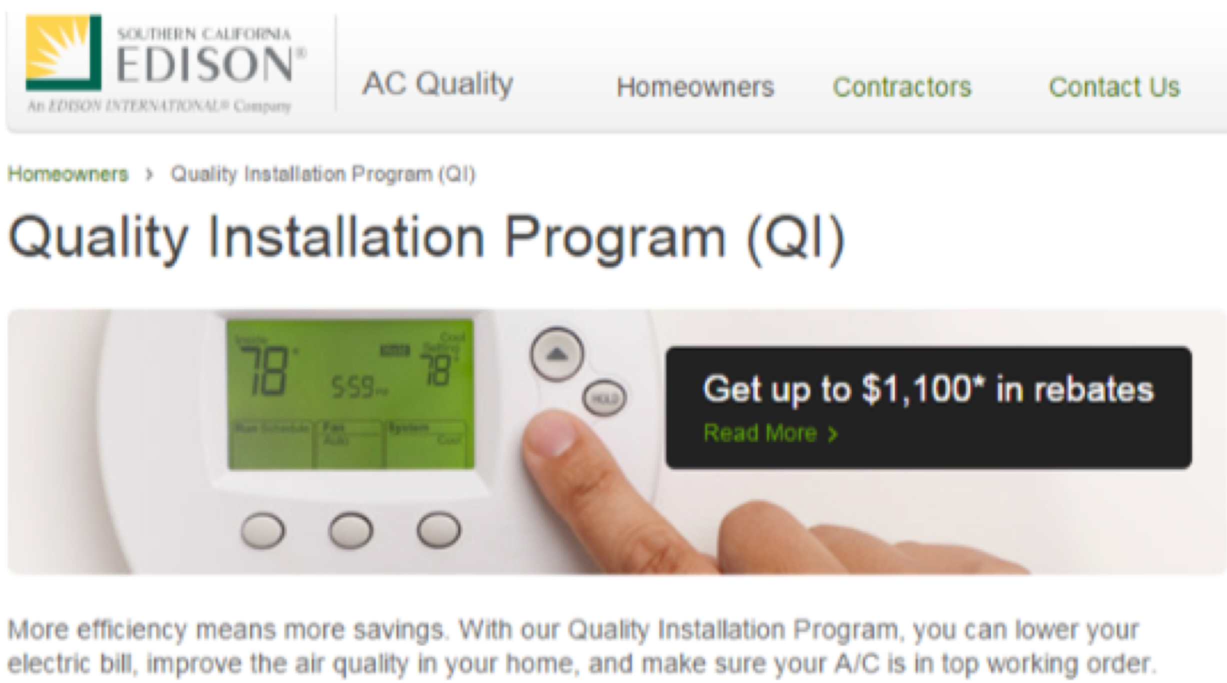
- We focus on an air conditioner program in California.
- We use smart-meter data to measure energy savings by hour-of-day and month-of-year.
- We find that savings tend to occur when the value of electricity is high, especially after accounting for capacity market prices.
- Accounting for timing increases the private value of savings by about 40% relative to the naive calculation
- We use engineering estimates to calculate timing premiums for a range of other investments.

# Related Literature

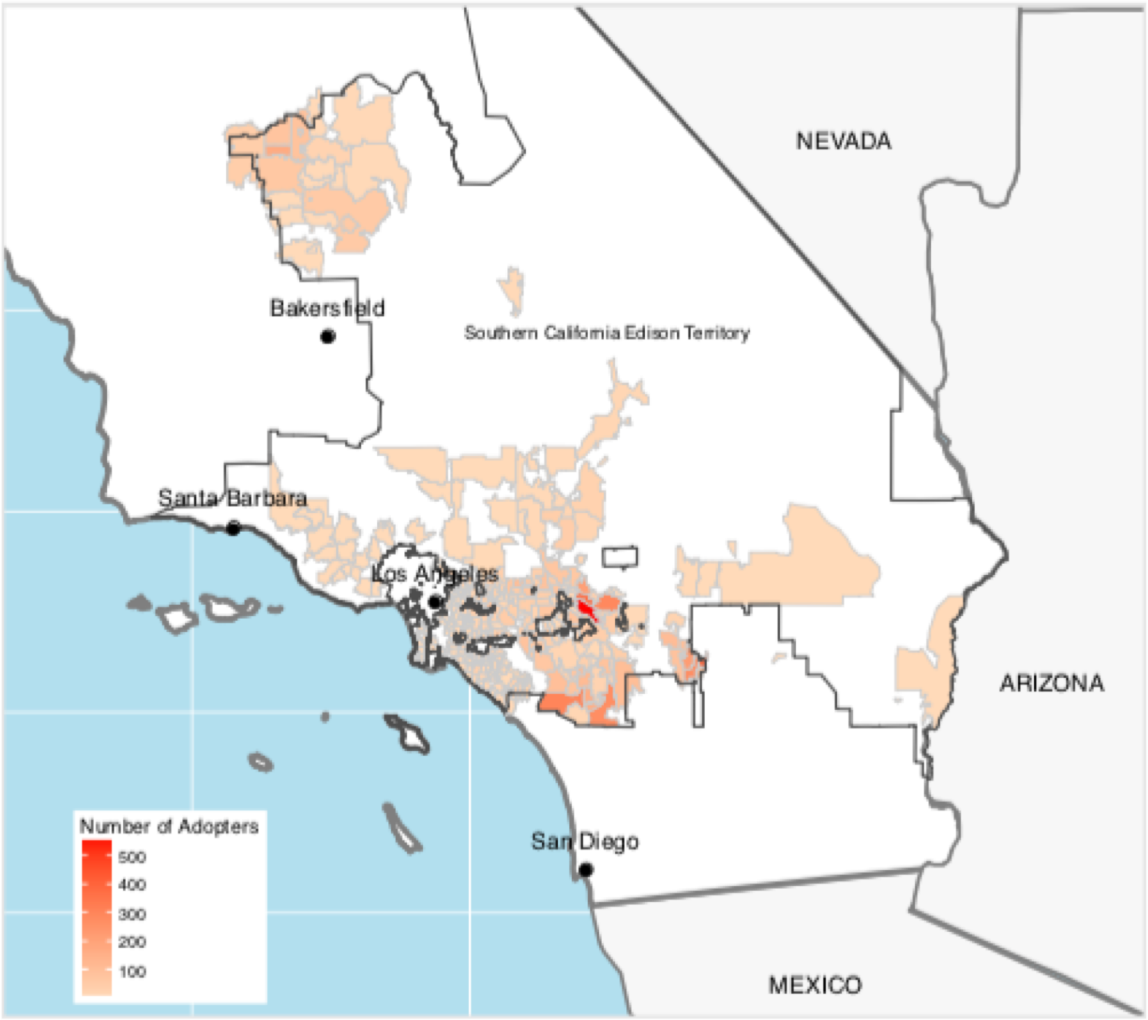
- **Energy Efficiency Program Evaluations**
  (Boomhower and Davis, 2014; Davis et al., 2014; Houde and Aldy, Forthcoming; Fowlie et al., 2015; Novan and Smith, 2016; Allcott and Greenstone, 2015)
- **Location and Energy Efficiency**
  (Callaway et al., 2015)
- **Capacity Markets for Electricity**
  (Bushnell, 2005; Cramton and Stoft, 2005; Joskow, 2006; Joskow and Tirole, 2007; Alcott, 2013)
- **Real-Time Electricity Pricing**
  (Borenstein, 2005; Borenstein and Holland, 2005; Holland and Mansur, 2006)

# Our Empirical Application

- Southern California Edison's *Quality Installation Program*
- Provides rebates to households who install an energy-efficient CAC
- $500 to $1,100 depending on climate zone and AC unit



# Hourly Smart Meter Data




- 6,000 participants
- 150,000 non-participants (sampled randomly)

- 9-digit zip code
- Hourly consumption, 2012 – 2015

# Empirical Strategy

$$y_{iht} = \alpha + \beta 1[New\ Air\ Conditioner]_{it} + \gamma_{ihm} + \omega_{ht} + \epsilon_{it}$$

| | |
|---|---|
| $y_{it}$ | Average consumption by household $i$ in hour-of-day $h$ during week-of-sample $t$ |
| $\gamma_{ihm}$ | Household by hour-of-day by month-of-year fixed effects |
| $\omega_{ht}$ | Week-of-sample by hour-of-day fixed effects |

We measure the change in electricity consumption before and after installation.

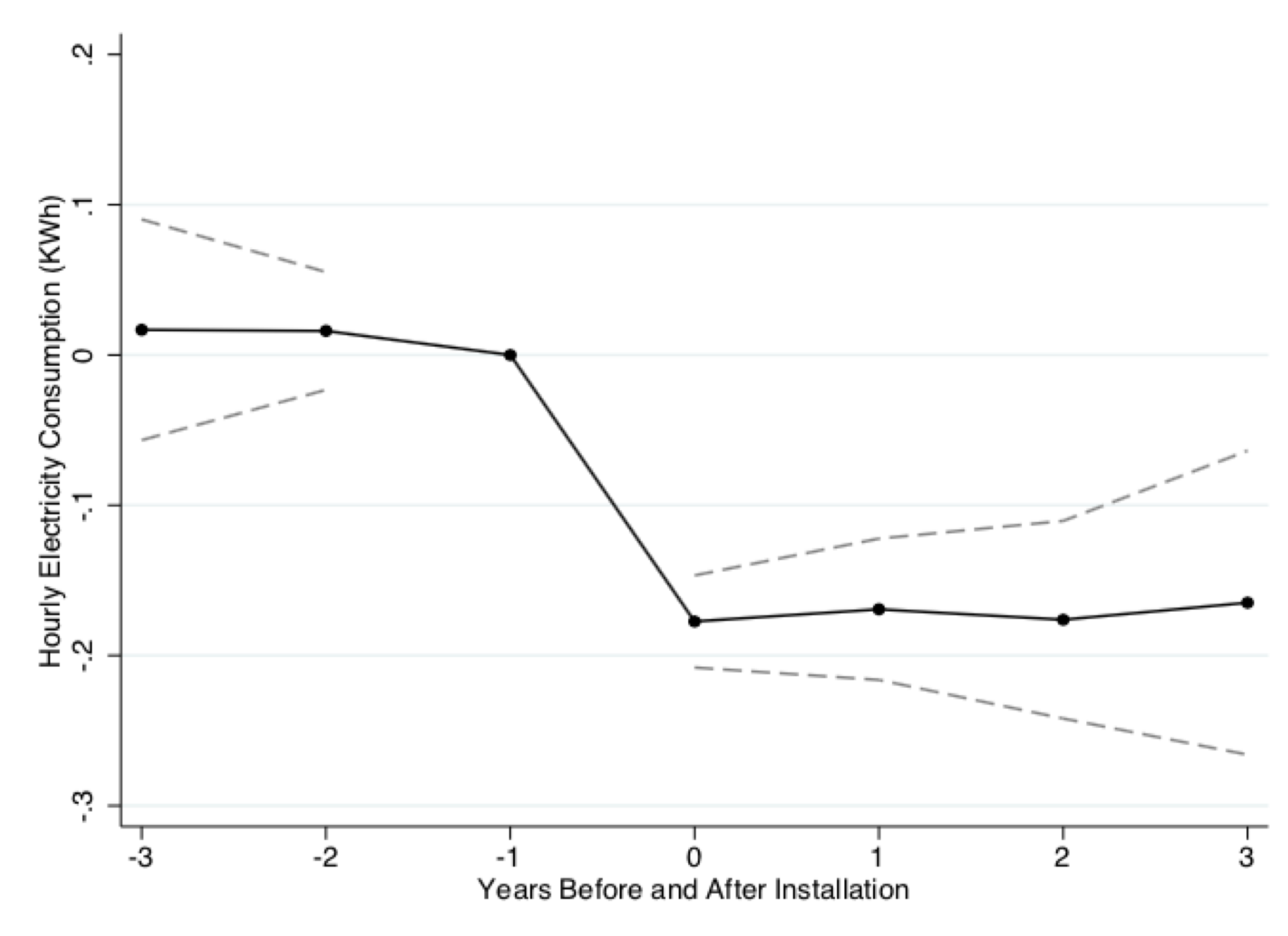
In our main results we allow $\beta$ to vary by hour-of-day and month-of-year.

Our event study design relies on variation in timing of installation.

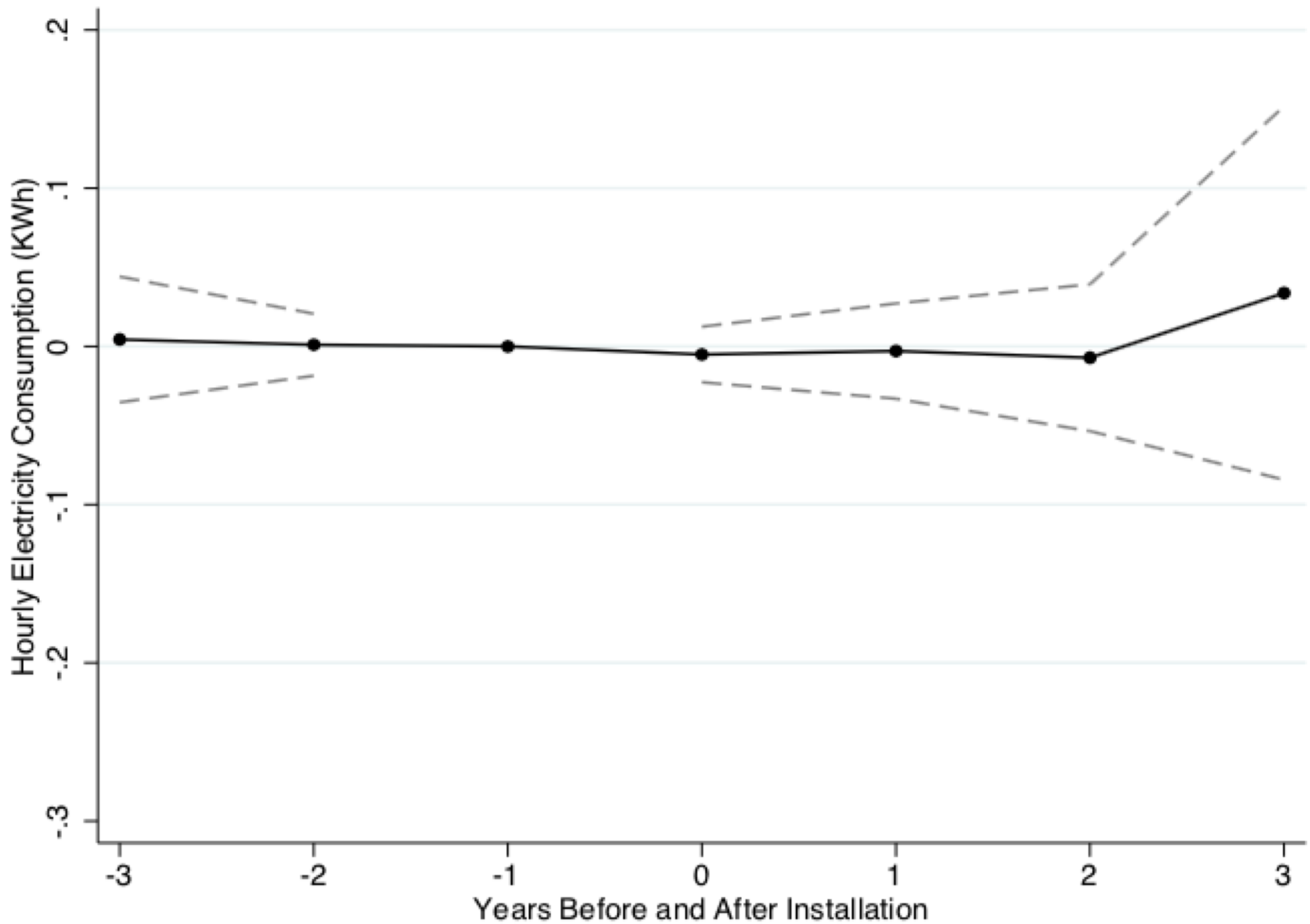
Some specifications use non-participants as a comparison group.

Detailed household and time fixed effects included throughout.

# Summer Electricity Savings



# Winter Electricity Savings

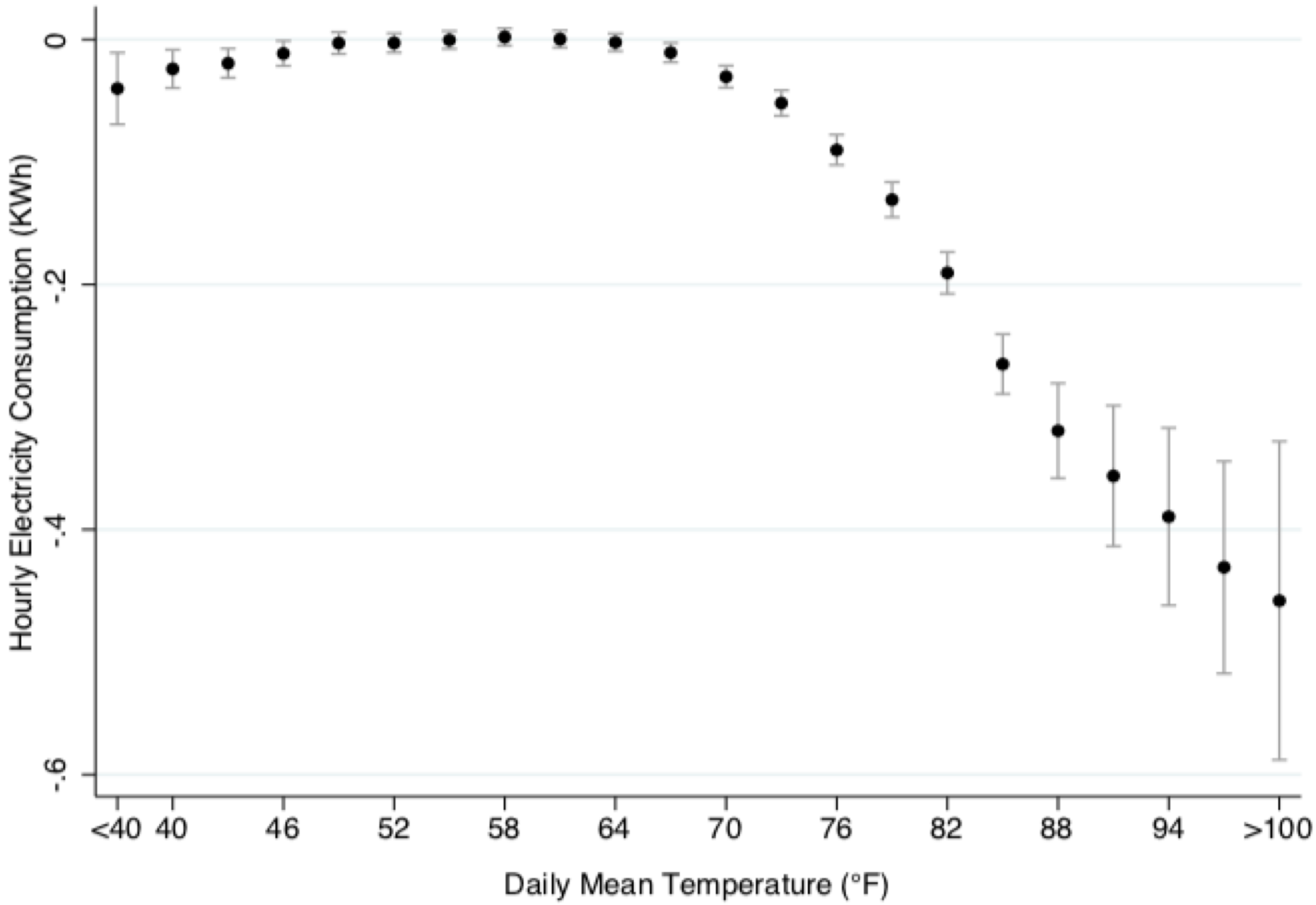


# Average Annual Energy Savings

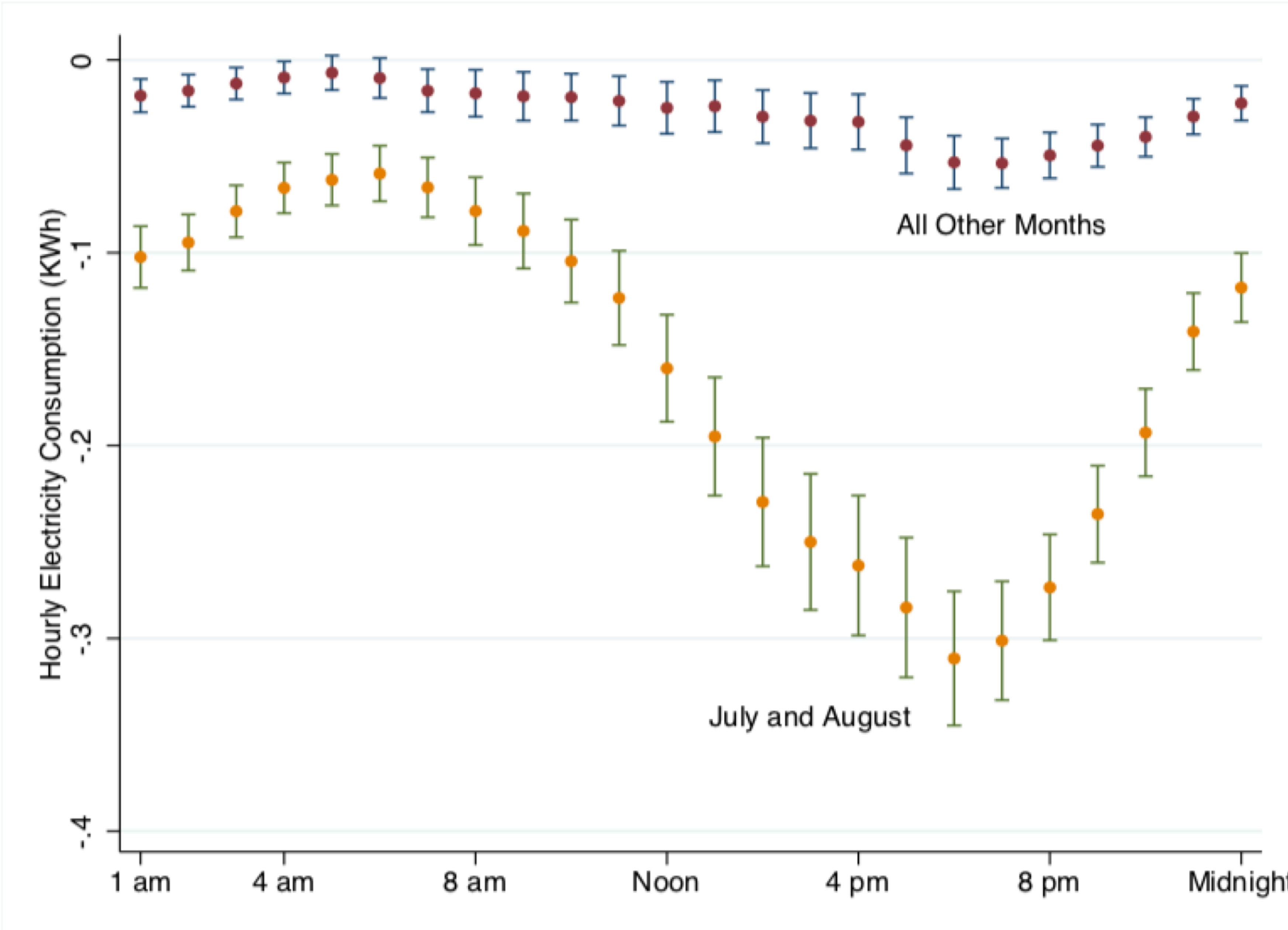
| | (1) | (2) | (3) |
|---|---|---|---|
| Energy Savings Per Household (kWh/year) | 375.3 | 358.0 | 436.3 |
| | (32.2) | (32.2) | (36.0) |
| Household by hour-of-day by month-of-year fixed effects | Y | Y | Y |
| Week-of-sample by hour-of-day fixed effects | Y | | |
| Week-of-sample by hour-of-day by climate zone fixed effects | | Y | Y |
| Drop 8 weeks pre-installation | | | Y |
| Number of observations | 28.6 M | 28.6 M | 27.3 M |
| Number of households | 5,973 | 5,973 | 5,972 |

Notes: Dependent variable in all regressions is average hourly electricity consumption measured at the household by week-of-sample by hour-of-day level. Standard errors are clustered by nine-digit zip code.

# Electricity Savings by Temperature

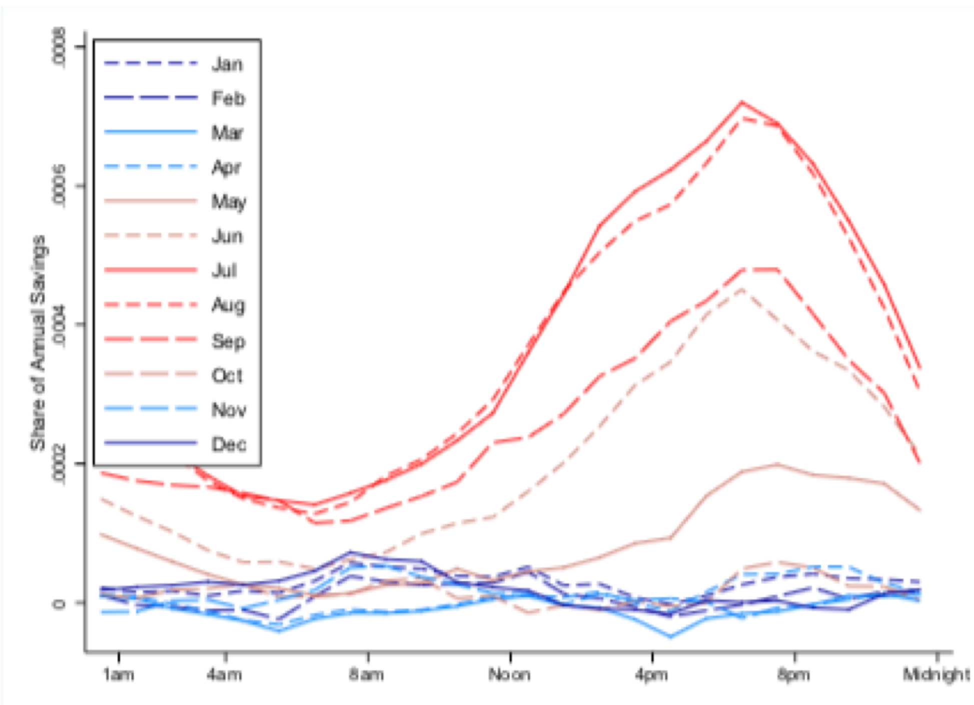


# Electricity Savings by Hour-of-Day

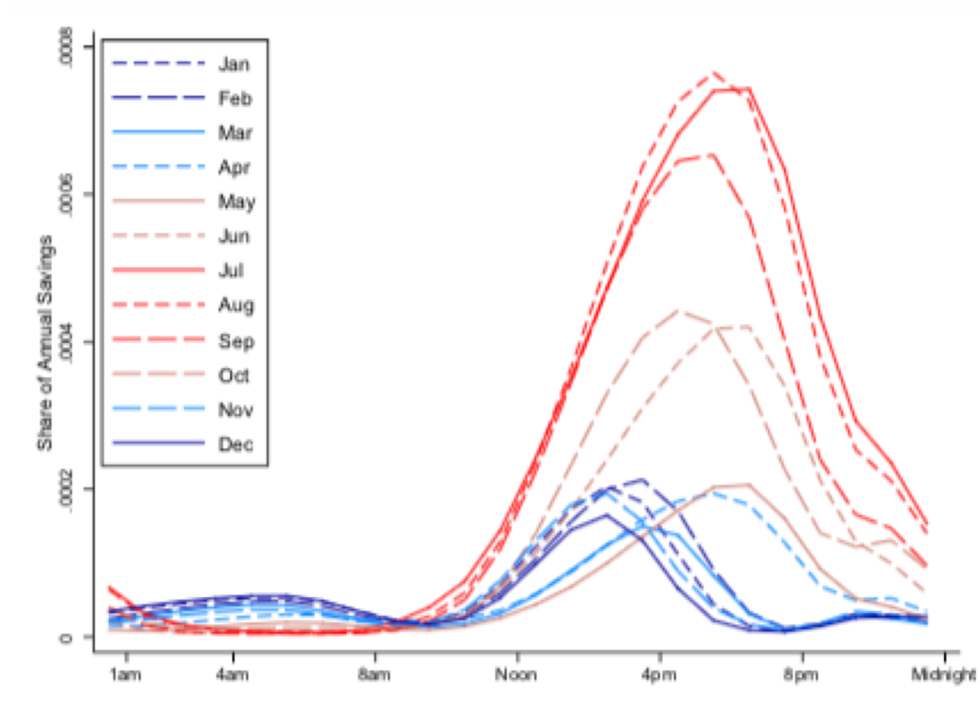


# Comparing to Engineering Predictions

## Estimated Savings Profile




## Engineering Predictions



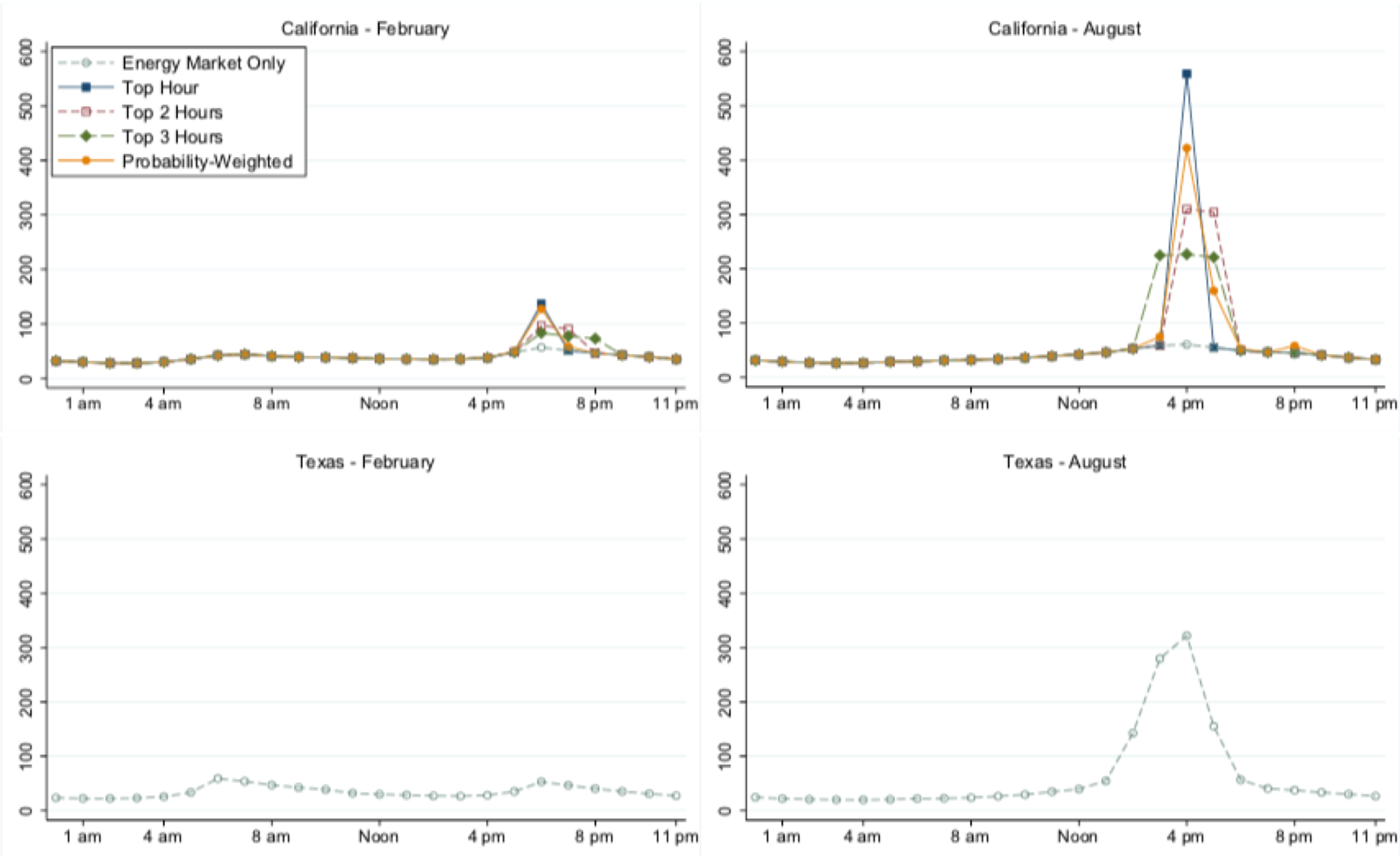
# We Now Turn to Valuing Savings

We collect hourly wholesale electricity prices.

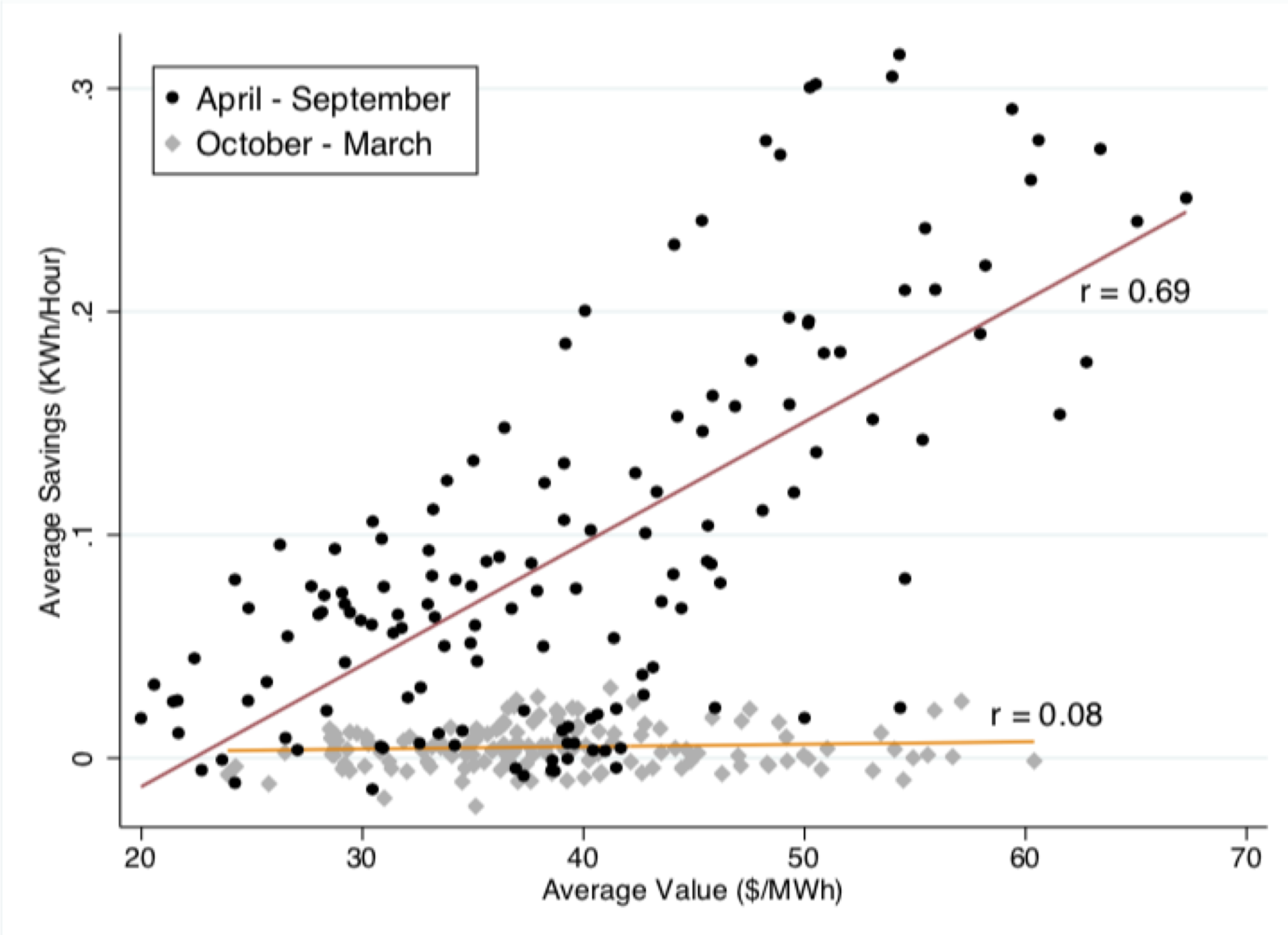
We also collect monthly and annual prices from U.S. capacity markets.

We assign capacity payments to the highest demand hours of the year.

# Comparing California to Texas



# Correlation Between Savings and Energy Prices



# The "Timing Premium" is About 40%

| | Energy Prices Only | Energy Plus Capacity Prices, Various Assumptions | | | |
|---|---|---|---|---|---|
| | | Capacity Value in Top 3% of Hours | Capacity Value in Top 6% of Hours | Capacity Value in Top 9% of Hours | Capacity Value Allocated Probabilistically |
| | (1) | (2) | (3) | (4) | (5) |
| Average Value ($/MWh) | | | | | |
| (A) Accounting for Timing | $45.09 | $69.78 | $70.60 | $69.92 | $69.87 |
| (B) Not Accounting for Timing | $40.31 | $51.06 | $51.01 | $50.96 | $51.03 |
| Timing Premium ($\frac{A-B}{B}$) | 12% | 37% | 38% | 37% | 37% |

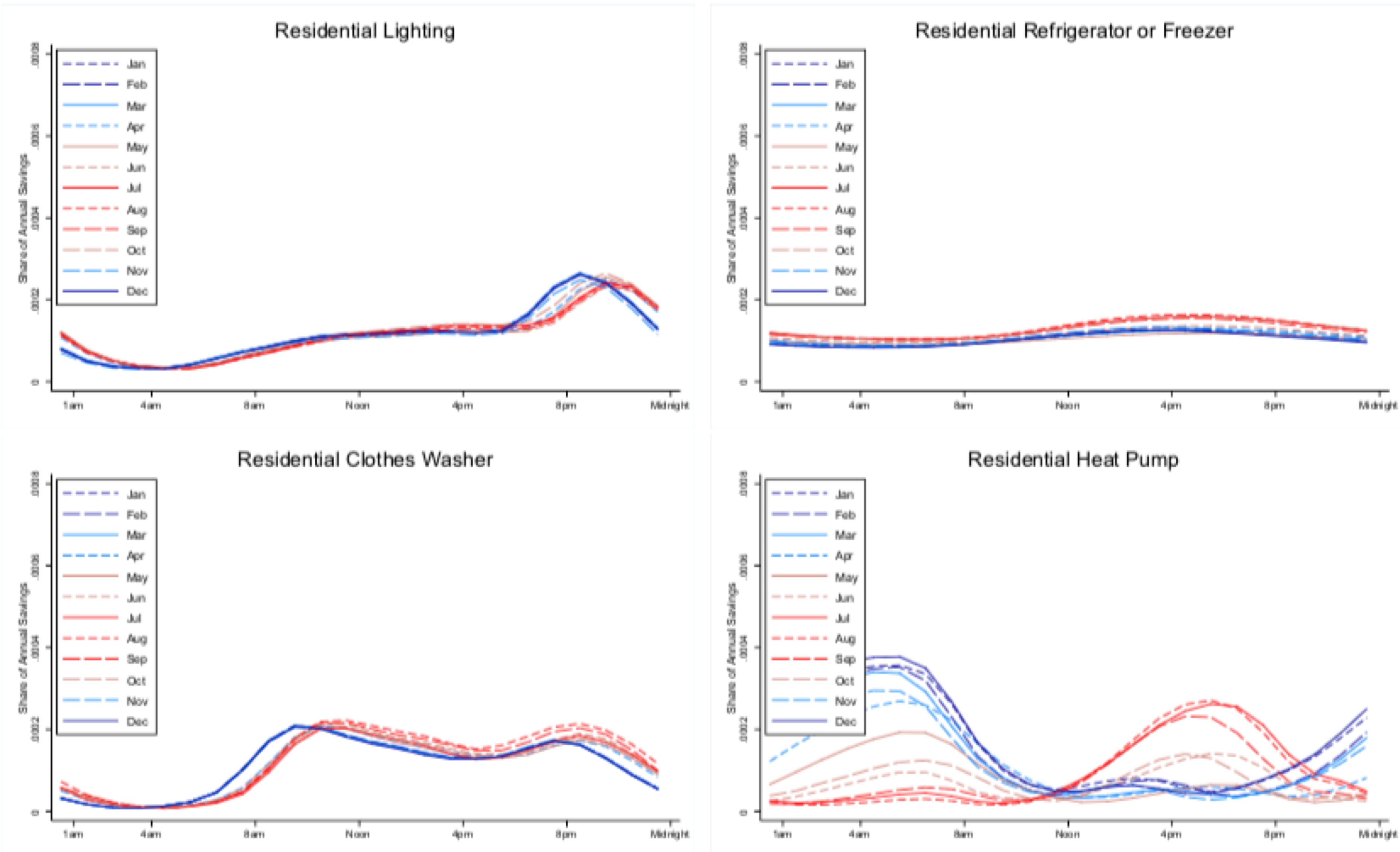
# How Might This Premium Change in the Future?

Timing Premiums For 2024

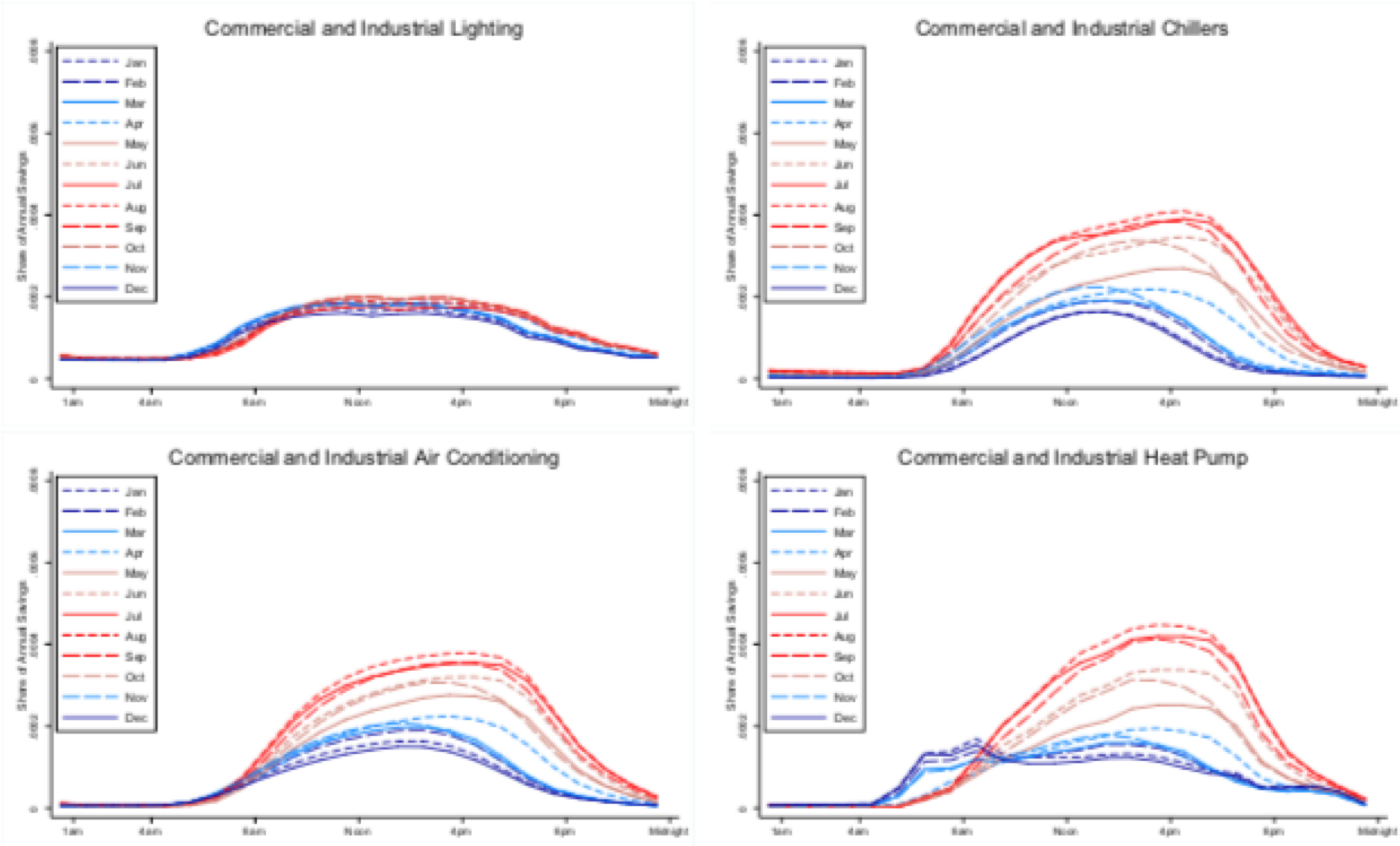
| Energy Prices Only | Energy Plus Capacity Prices |
|---|---|
| 30% | 50% |

Note: We used forecast prices from from Denholm et al. (2015).

# Profiles for Other Investments



# Profiles for Other Investments



# Timing Premiums for Selected Investments

| | California (CAISO) | Texas (ERCOT) | Mid-Atlantic (PJM) | New York (NYISO) |
|---|---|---|---|---|
| A. Residential | | | | |
| Air Conditioning | 37% | 39% | 17% | 14% |
| Lighting | 3% | -5% | -2% | -1% |
| Clothes Washers | 2% | 2% | 4% | 7% |
| Heat Pump | -1% | -1% | -4% | -5% |
| Refrigerator or Freezer | -1% | -5% | -5% | -3% |
| B. Commercial and Industrial | | | | |
| Heat Pump | 32% | 31% | 18% | 17% |
| Chillers | 27% | 26% | 14% | 15% |
| Air Conditioners | 25% | 24% | 14% | 15% |
| Lighting | 3% | 0% | 1% | 4% |

# Conclusion

- Timing matters for energy efficiency
- Air conditioning has a significant "timing premium"
- Critical to incorporate capacity values in these calculations
- Overall, a remarkably wide range of value across investments
- Range likely to grow even wider as we add more renewables to grid
- Time to move discussion away from total savings toward total value


# Is The Duck Curve Eroding the Value of Energy Efficiency?

Edward Burgess, Director, Strategen Consulting

November 1, 2018

# STRATEGEN CONSULTING

Strategen provides insight to global corporations, utilities and public sector leaders, helping them to develop impactful and sustainable clean energy strategies

### CLIENTS

We work with governments, utilities, research institutions, technology providers, project developers, and large energy users seeking to evaluate and implement next generation grid and clean energy technologies.

### MARKETS

Our exclusive focus on clean energy and advanced grid technologies means we bring our clients a sophisticated understanding of industry trends, market drivers and regulatory policy.

### SERVICES

Our clients come to us for our expertise in developing business models, commercial strategies, financing tools and regulatory support that empower them to create sustainable value and long-term solutions.

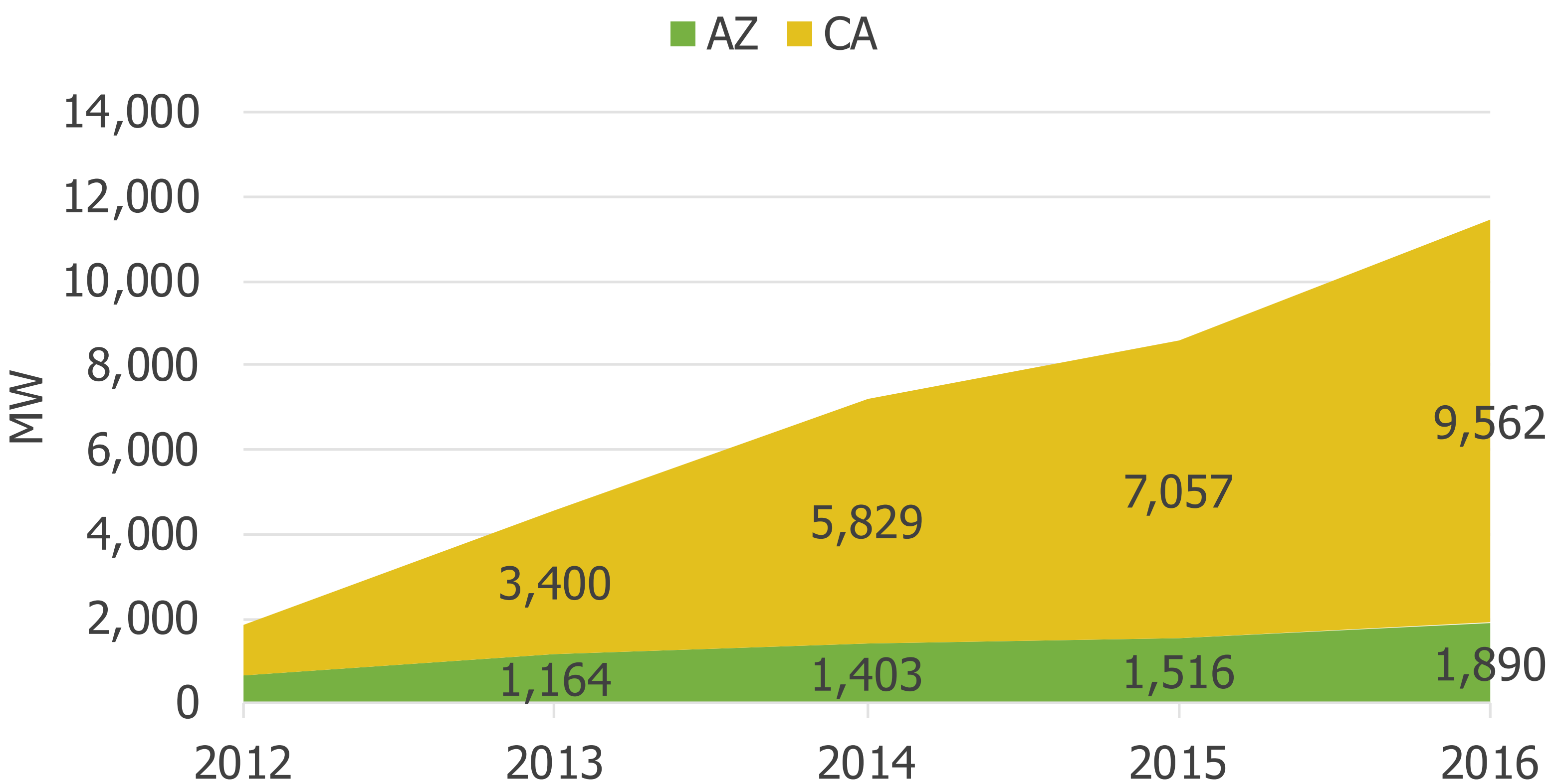
### TEAM

Our team is comprised of well-respected thought leaders and industry experts who have played instrumental roles in shaping the power sector's transformation in the 21st century.

## Today's Topics

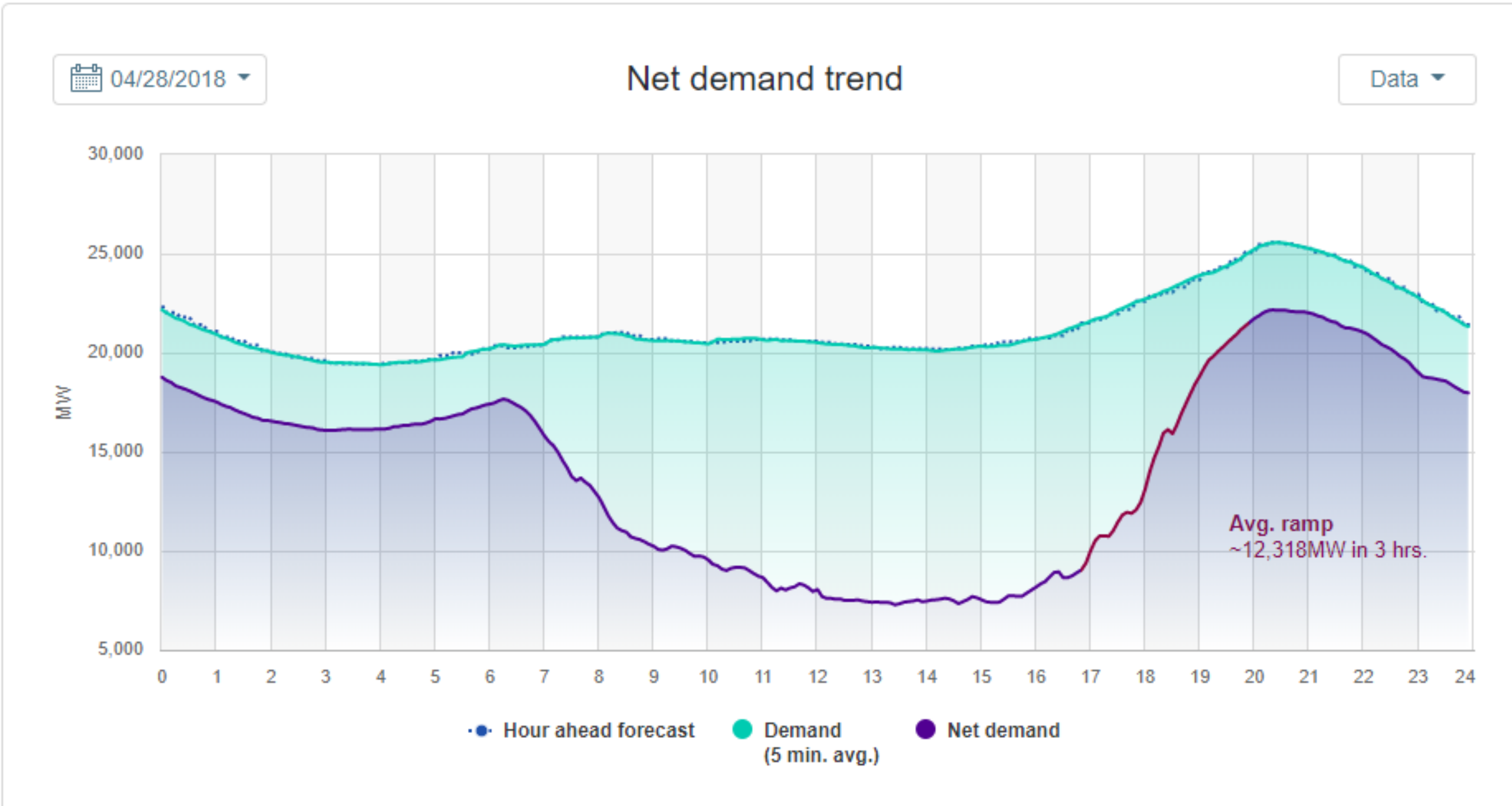
- Energy market trends in the Southwestern U.S.
- Recently proposed changes to utility demand-side management (DSM) programs in the region
- Analysis of implications for current and future DSM cost-effectiveness

# Solar PV deployment in California and Arizona



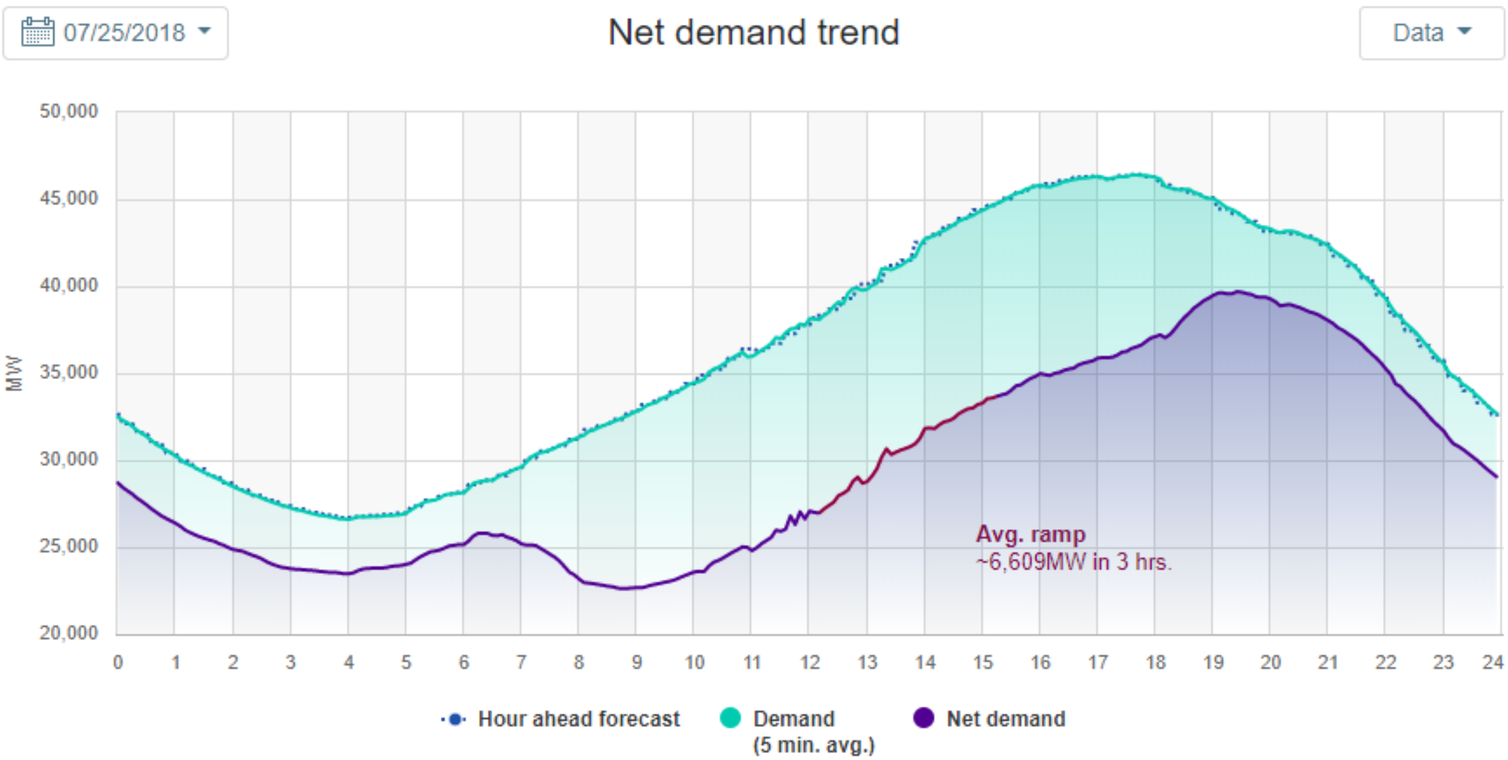

Source: EIA-860 https://www.eia.gov/electricity/data/state/existcapacity_annual.xls

# A day in the life of the California Independent System Operator (CAISO) in April




Source: California ISO, http://www.caiso.com/TodaysOutlook/Pages/default.aspx

# A day in the life of the California ISO (in July)




Source: California ISO, http://www.caiso.com/TodaysOutlook/Pages/default.aspx

# Western wholesale markets are evolving

- Western utilities already have significant exposure to California market prices.
- Many western utilities now participate in the Western Energy Imbalance Market (real-time only).
- Fewer bilateral transactions are occurring at traditional trading hubs (e.g. Palo Verde) in favor of ISO market participation.
- CAISO is exploring expanded day-ahead market offerings for non-CA utilities.

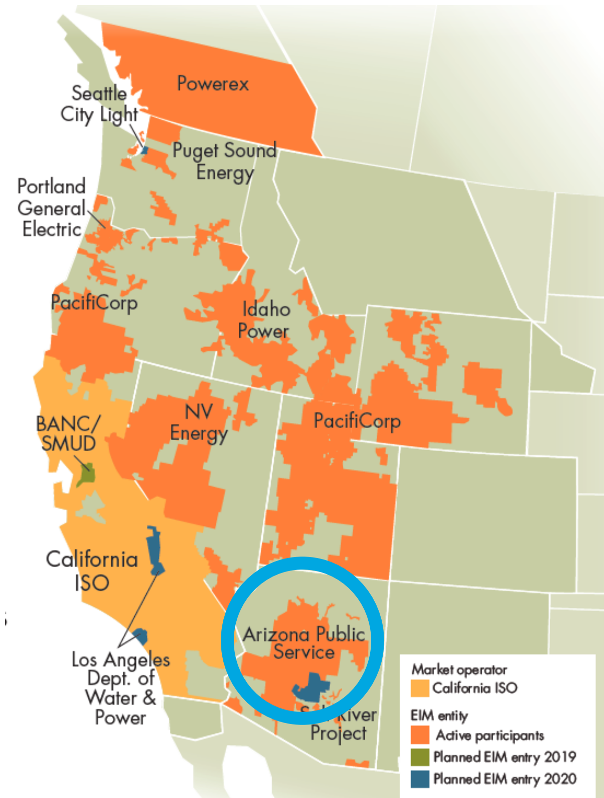
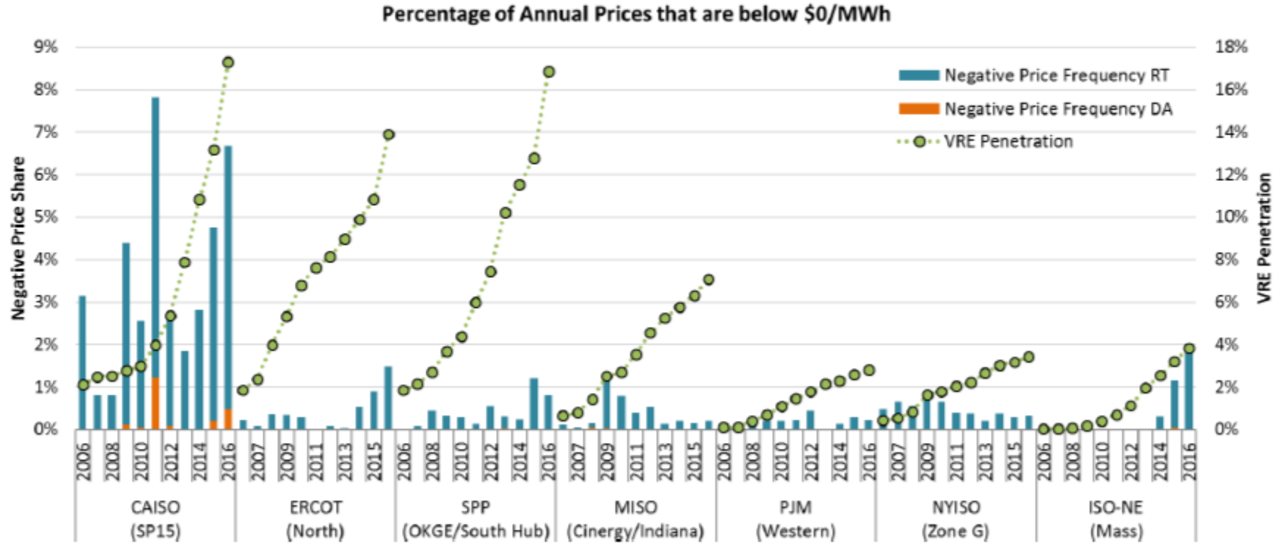



Image source:

# Negative Prices at Many Large Trading Hubs Are Rare, but Increasing in Some with VRE

CAISO unique in high frequency of negative prices; VRE does appear to play a role, but not exclusively, in driving these events

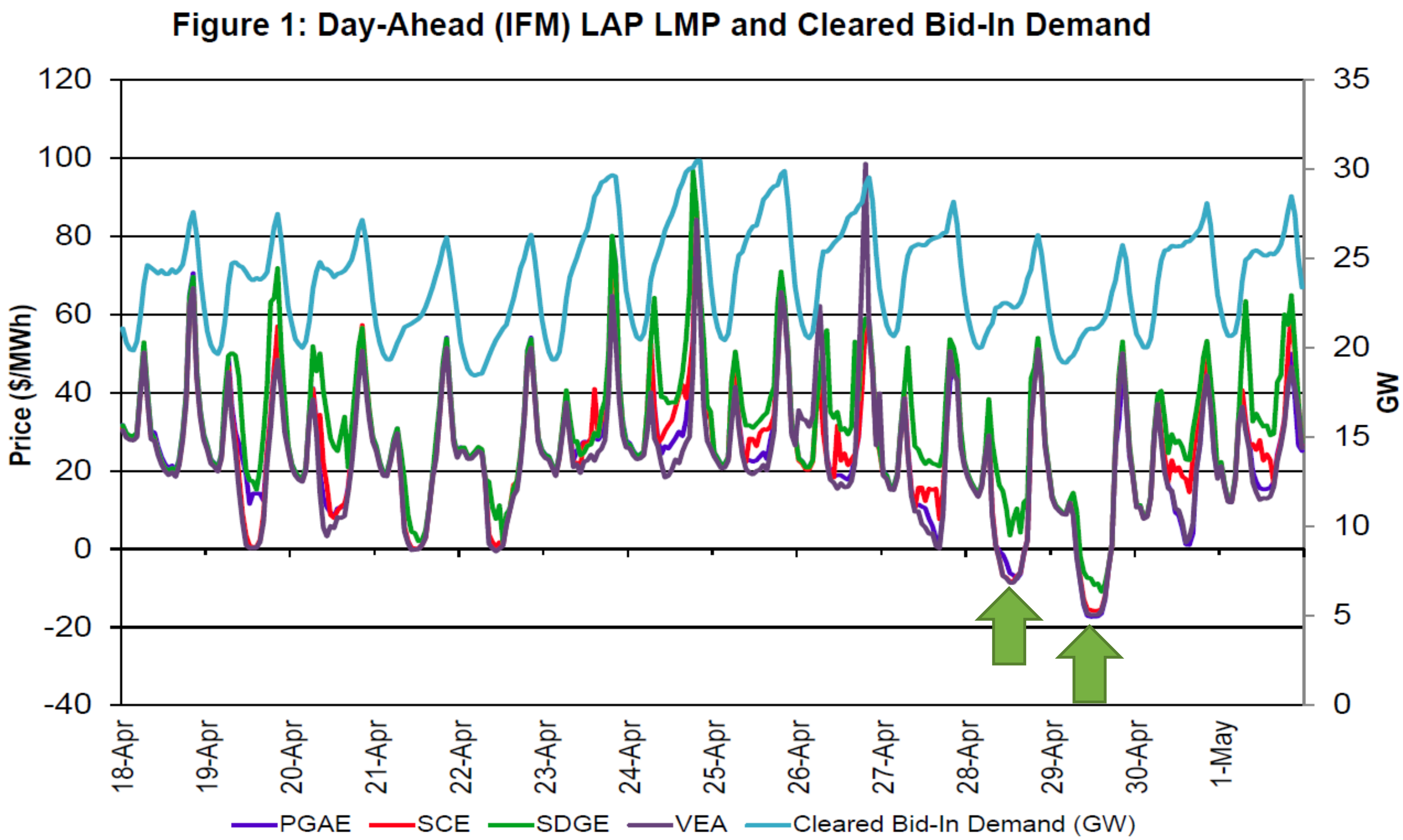



*Focuses on selected major trading hubs; negative prices almost non-existent in day-ahead market (though lower average real-time prices may also lower average day-ahead prices)*



Source: Wiser, R. et al. 2017. "Impacts of Variable Renewable Energy on Bulk Power System Assets, Pricing, and Costs." Lawrence Berkeley National Lab, Energy Markets and Policy Group. https://emp.lbl.gov/publications/impacts-variable-renewable-energy

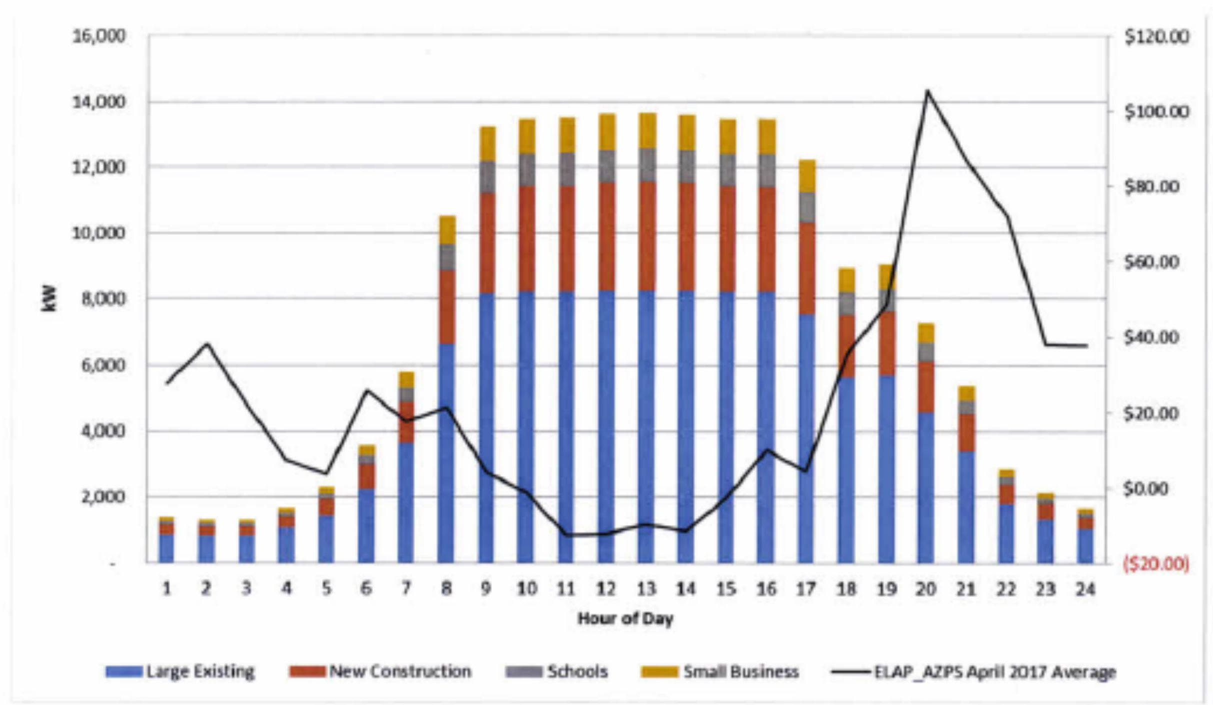
# Negative clearing prices now exist in the CAISO day-ahead market




Source: CAISO Weekly Market Performance Report, http://www.caiso.com/Documents/WeeklyMarketPerformanceReport_Apr18_2018_May01_2018.pdf

# Arizona Public Service 2018 DSM Plan (proposed)

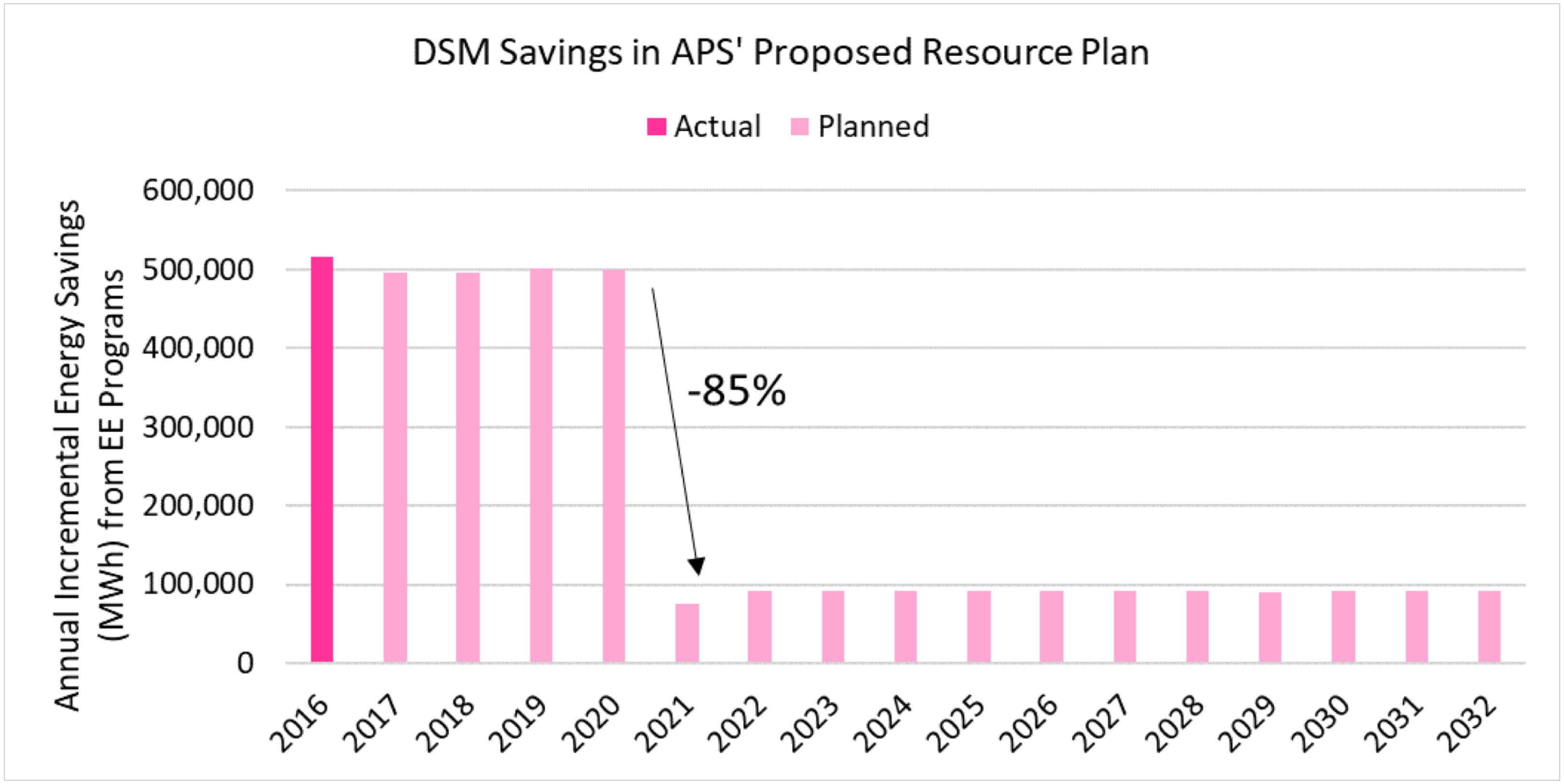
Figure 3 – April 2017 Hourly Market Prices and Example DSM Savings Load Shape




- "Continuing to promote EE savings during the middle of the day, when prices are shown as below, can actually harm customers by limiting the ability to take advantage of negative pricing."
- "…a new opportunity now exists within DSM to strategically build load in the middle of the day through load shifting, vehicle electrification, and reverse demand response."

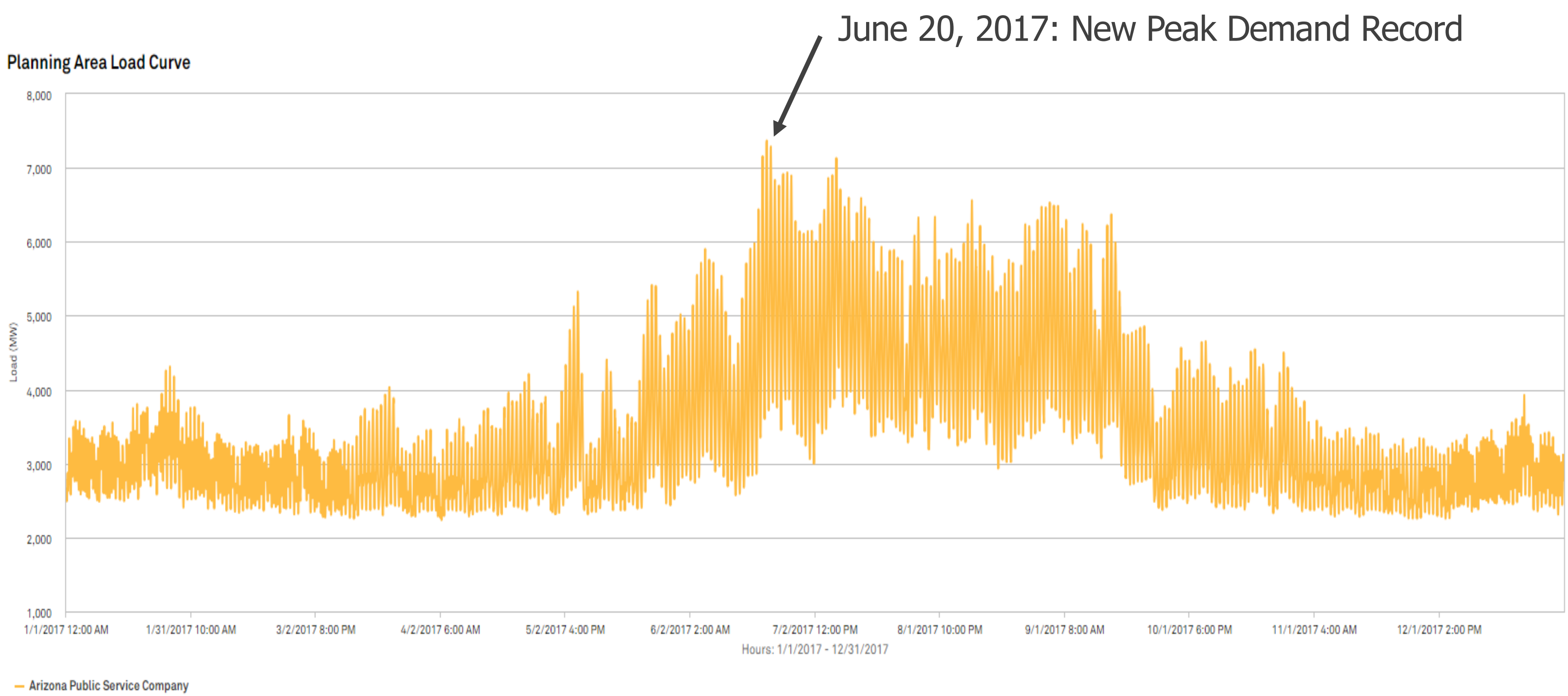
Source: APS Proposed 2018 Demand Side Management Implementation Plan, http://images.edocket.azcc.gov/docketpdf/0000182484.pdf

# Arizona Public Service 2017 Integrated Resource Plan



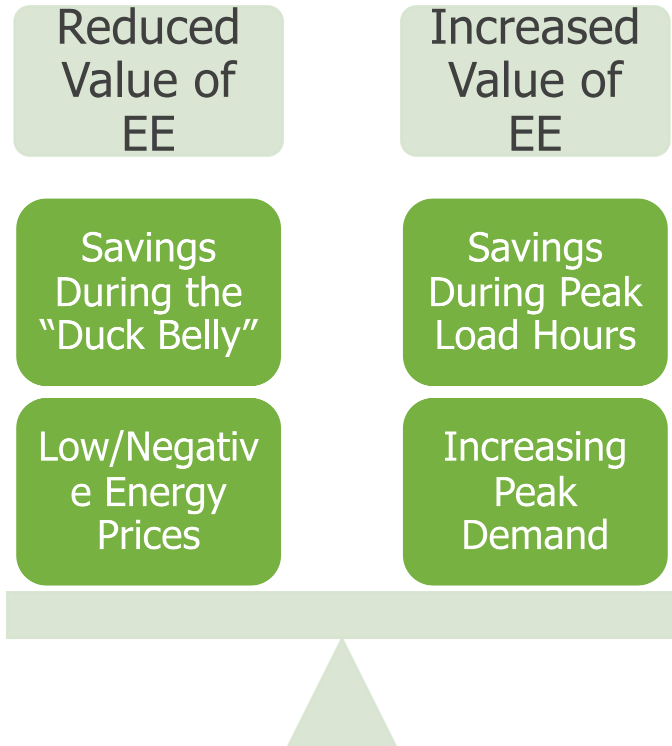

Source: Arizona Public Service, 2017 Integrated Resource Plan. Arizona Corporation Commission Docket No. E-00000V-15-0094. http://images.edocket.azcc.gov/docketpdf/0000178832.pdf

# APS Hourly Load and System Peak

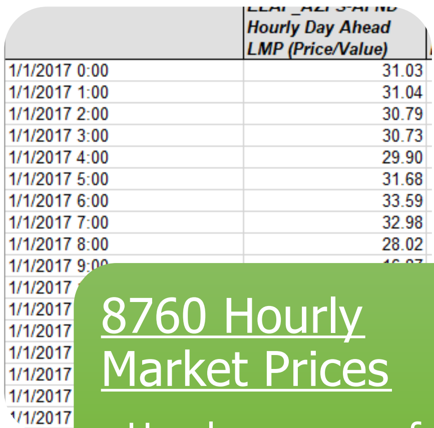



Source: S&P Global

# What is the value of Energy Efficiency (EE) now and going forward?

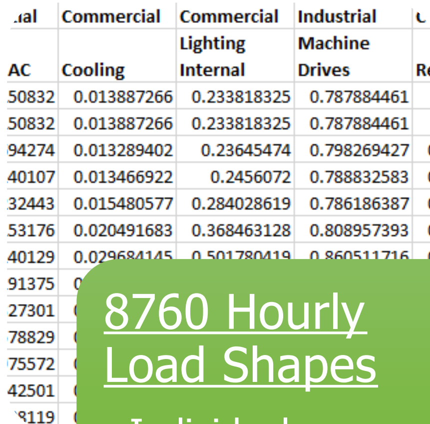


# Analytical Approach



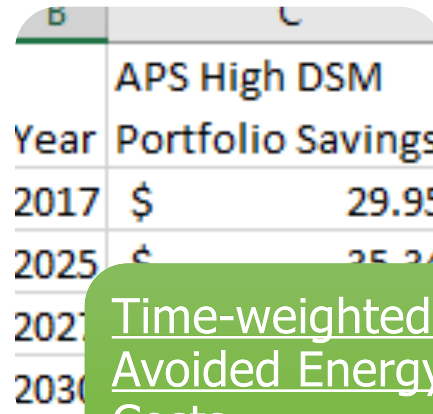

**8760 Hourly Market Prices**

- Hourly average of RT EIM market data for APS load area for 2017
- Forecasted hourly prices for APS




**8760 Hourly Load Shapes**

- Individual measures constructed from EPRI Load Shape Library
- APS Aggregated DSM Portfolio Load Shape

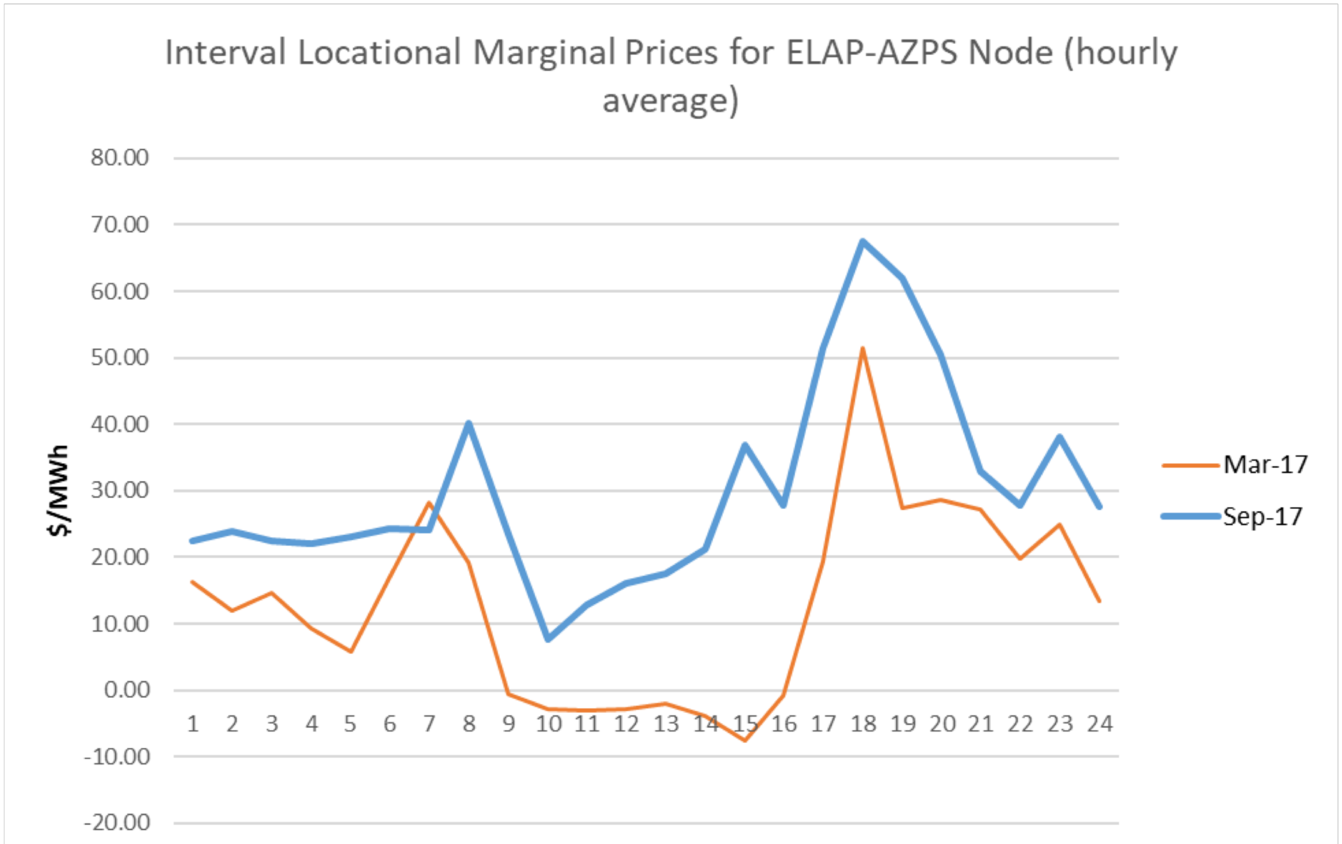



**Time-weighted Avoided Energy Costs**

- $/MWh

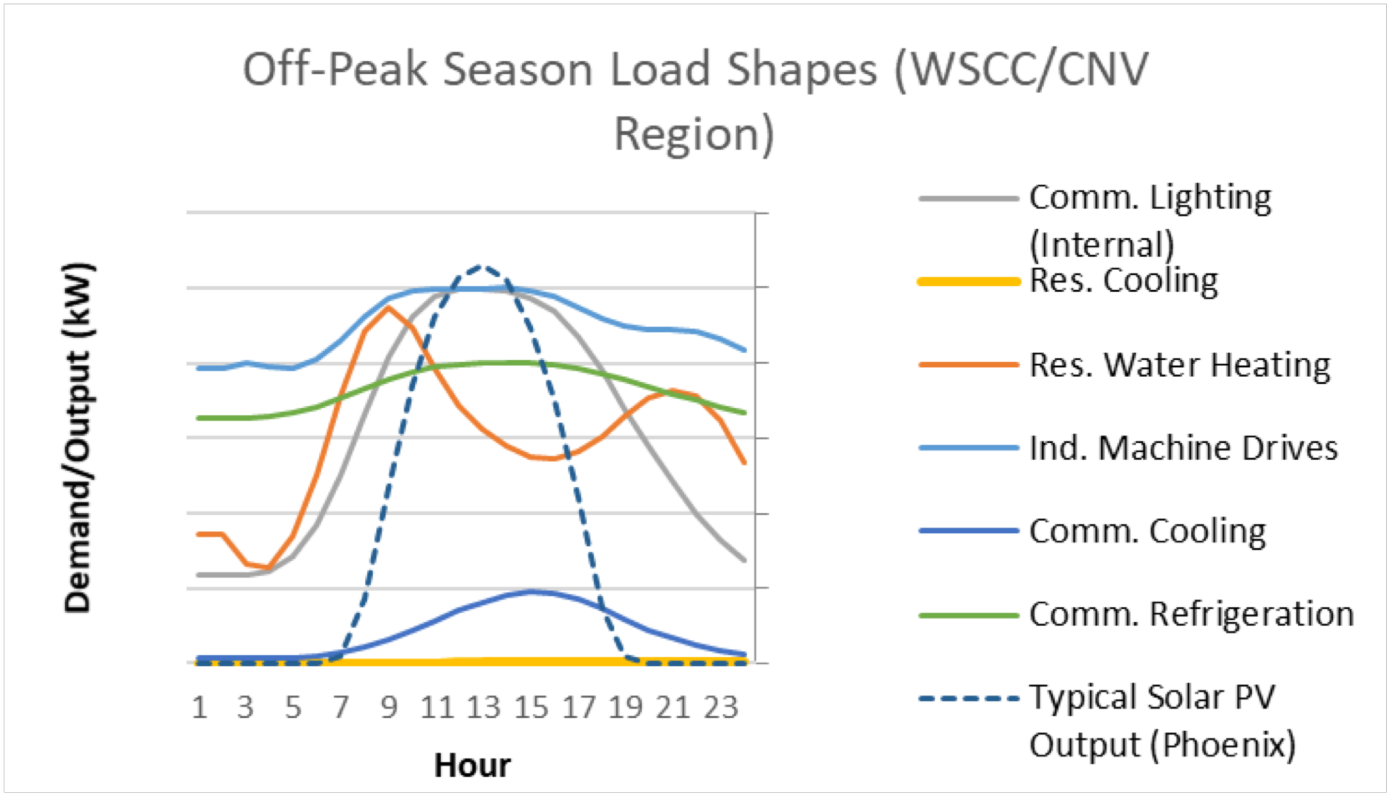
Caveat: This analysis focuses on wholesale Energy value *only*. EE measures can yield many additional value streams, including avoided Capacity costs, avoided Transmission and Distribution system costs, and avoided Environmental costs that were not assessed here.

# Recent Real-Time Market Prices for APS




Source: CAISO OASIS http://oasis.caiso.com/mrioasis/logon.do

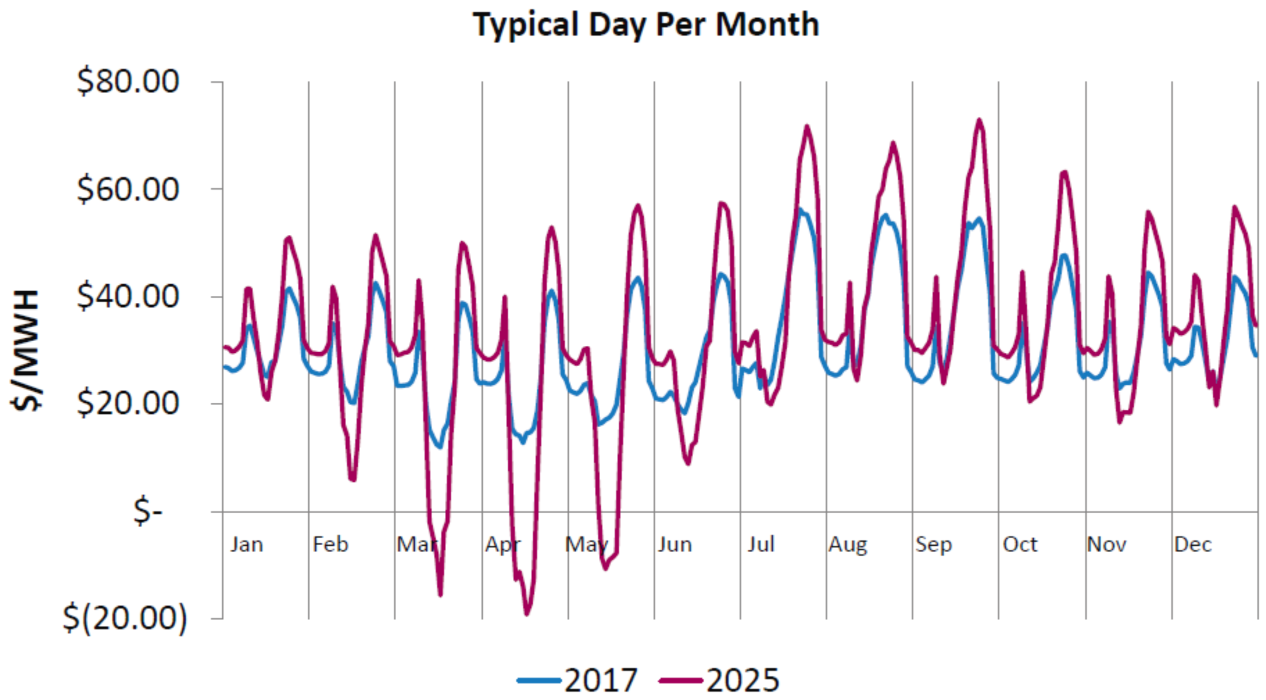
# DSM Measure Load Shapes




Source: Electric Power Research Institute (EPRI). 2018. *EPRI Load Shape Library*. http://loadshape.epri.com/enduse, National Renewable Energy Laboratory (NREL), 2018. System Advisor Model. https://sam.nrel.gov/

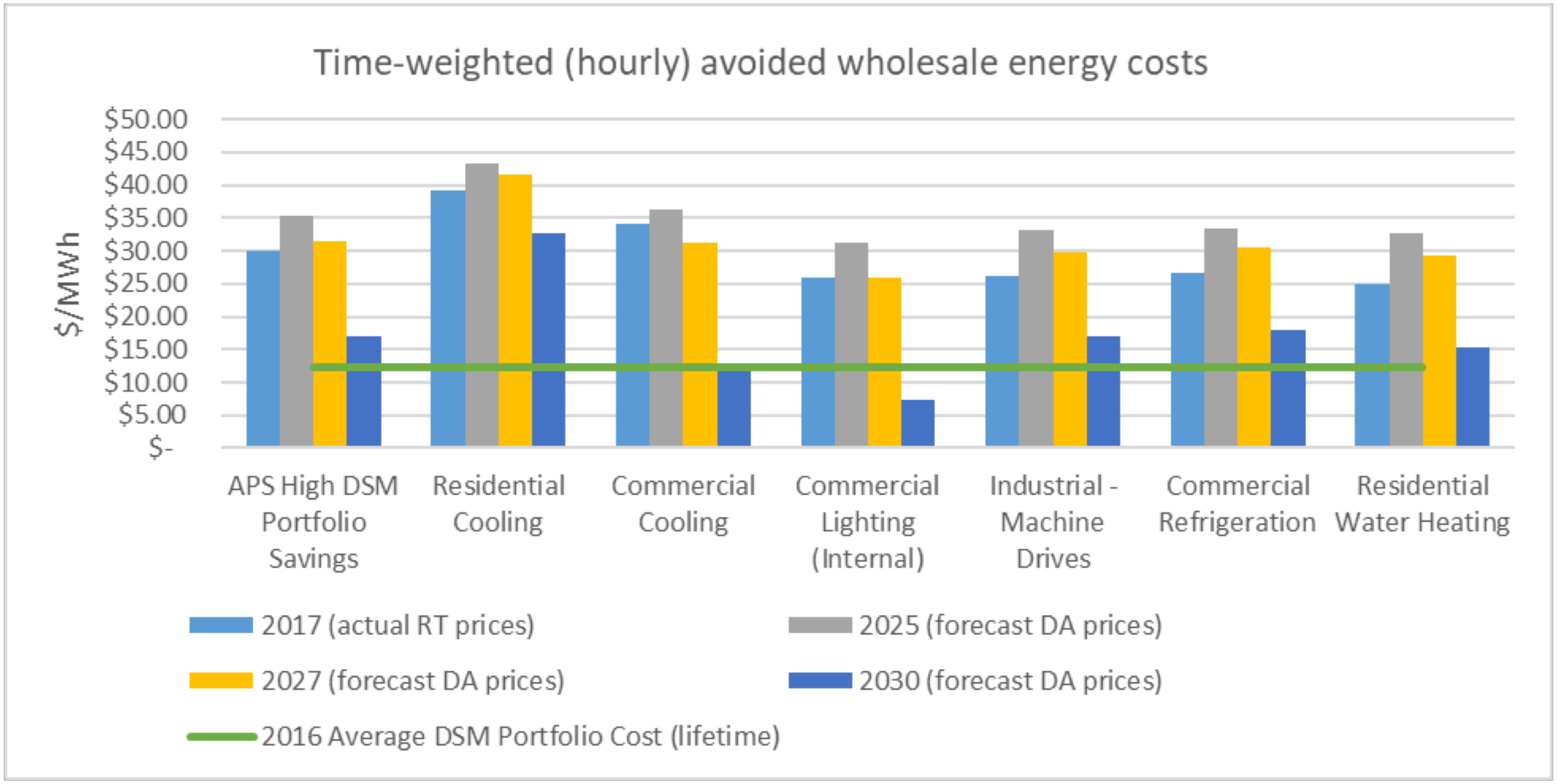
# Forecasted Day-Ahead (Hourly) Market Prices

- Includes anticipated effects of California's 50% RPS (by 2030)




Source: Arizona Public Service, *2017 Integrated Resource Plan*. Arizona Corporation Commission Docket No. E-00000V-15-0094.
http://images.edocket.azcc.gov/docketpdf/0000178832.pdf

# Results



Time-weighted (hourly) avoided wholesale energy costs
$/MWh
$50.00
$45.00
$40.00
$35.00
$30.00
$25.00
$20.00
$15.00
$10.00
$5.00
$-
APS High DSM Portfolio Savings
Residential Cooling
Commercial Cooling
Commercial Lighting (Internal)
Industrial - Machine Drives
Commercial Refrigeration
Residential Water Heating
2017 (actual RT prices)
2025 (forecast DA prices)
2027 (forecast DA prices)
2030 (forecast DA prices)
2016 Average DSM Portfolio Cost (lifetime)

# Conclusions

- Increased renewable penetration (especially solar PV) introduces a new time dimension to the value of EE savings.
- The marginal value of EE savings is affected by increased solar PV penetration. These effects have been limited to date, but are growing quickly in some regions.
- A full annual and multi-year perspective is needed to evaluate the total impact of solar PV on EE measure/portfolio value (i.e. to avoid cherry-picking data).
- Time-weighted analyses of EE measure values will be increasingly important going forward as RE penetration increases.
- Existing DSM portfolios appear robust even in high PV areas, but may need to be adjusted over time to reflect changing grid needs.
- More robust data on EE measure load shapes and projected wholesale prices (i.e. 8760 hourly resolution, regionally specific) will be helpful for improving DSM program evaluation going forward.

# Thank You!

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# References

# References


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- ———. 2018b. *CAISO OASIS* http://oasis.caiso.com/mrioasis/logon.do
- Electric Power Research Institute (EPRI). 2018. *EPRI Load Shape Library*. http://loadshape.epri.com/enduse

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- Tucson Electric Power (TEP), 2017a. *TEP Proposed 2018 Demand Side Management Implementation Plan*. https://www.tep.com/wp-content/uploads/2017/08/2017_81_tep_ee_implementation_plan.pdf
- ——— , 2017b. *TEP 2017 Integrated Resource Plan*. https://www.tep.com/wp-content/uploads/2017/04/TEP-2017-Integrated-Resource.pdf
- Wiser, R. et al. 2017. "Impacts of Variable Renewable Energy on Bulk Power System Assets, Pricing, and Costs." Lawrence Berkeley National Lab, Energy Markets and Policy Group. https://emp.lbl.gov/publications/impacts-variable-renewable-energy

Energy+Environmental Economics

# *Time Specific Valuation in California*

Snuller Price, Senior Partner

Energy + Environmental Economics (E3)

# Update on TSV in California

California has been using hourly estimates of value and benefits for nearly 20 years in its evaluation of buildings.

## History

- Where has California used time-specific values?
- Why have we taken on the additional complexity?

## Future

- What are the emerging aspects of TSV in evaluation?

**Take-away message.** Using TSV you can decompose the value of the grid by hour, and provide much better estimates of building measures and of dynamic features.

# California Building Energy Code

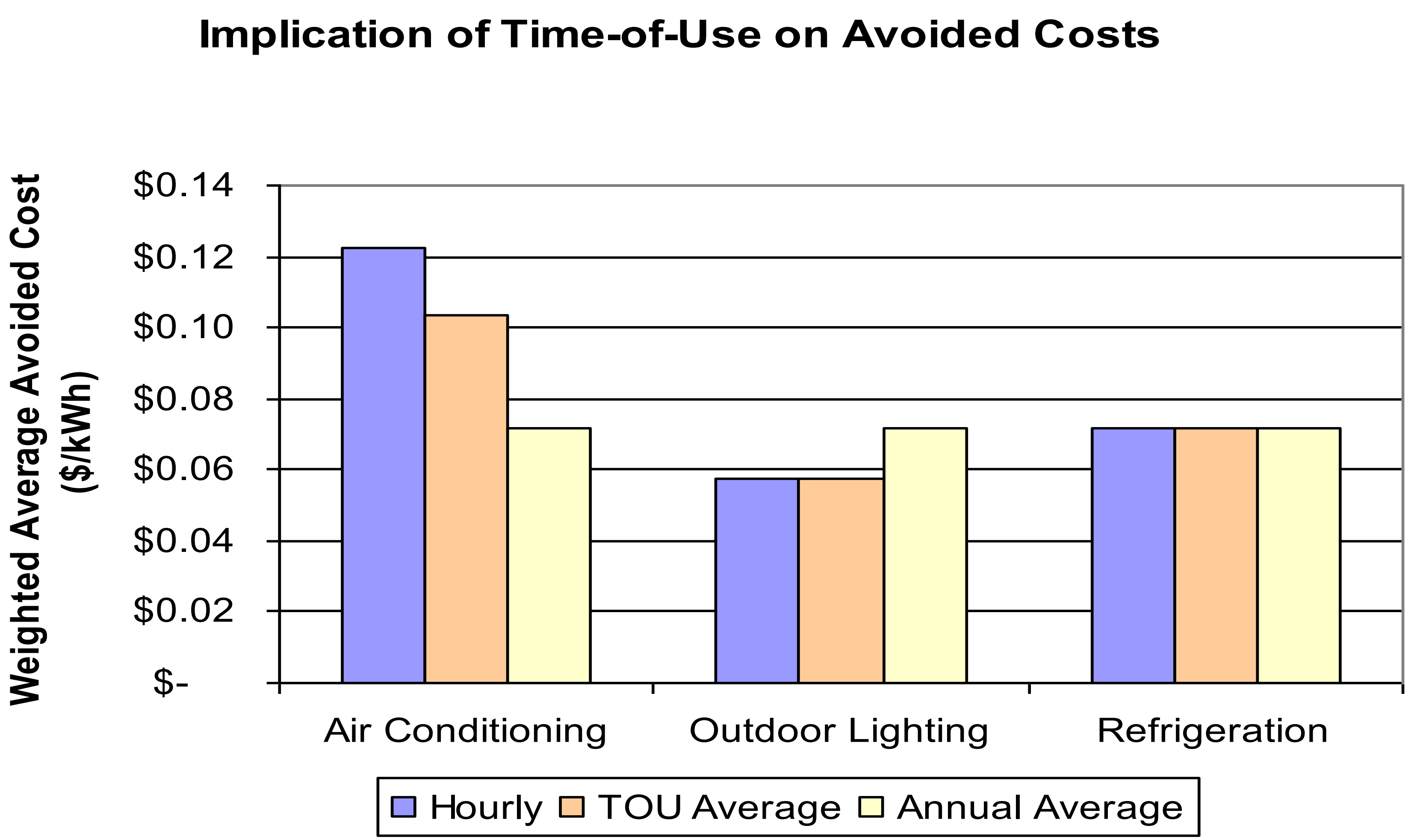
+ **Development of Time-Dependent Values (TDV) for the California Energy Commission began in 1999, adopted and implemented in the building code for construction beginning in 2006**

+ **Why?**
  - In new construction there are many different building designs and features that affect energy use.
  - TDV gives the CEC a metric on overall energy cost that gives architects flexibility in building design and prioritizes reductions at times when most valuable.
  - Initial focus of TDV was on providing signals to significantly increase the air conditioning loads in buildings, through higher rated equipment and better building shell.

# California PUC Energy Efficiency Program Cost-effectiveness

- **Development of the Avoided Cost Calculator (ACC) for use in the evaluation of the California's energy efficiency programs, now expanded to all distributed energy resources (e.g. DR, storage, EVs). Adopted by the CPUC in 2004, now updated annually.**
- **Why?**
  - There was a surge of effort to reduce peak loads in response to the California electricity crisis including a particular focus and significant increase in energy efficiency spending
  - The ACC was developed to appropriately value capacity, including both generation and distribution across a wide set of potential energy efficiency and now DR, storage, EV, other DERs

# Example of the impact of using time specific avoided costs




Example from California Avoided Cost Analysis – circa 2004

# Components of the ACC

| Component | Description |
|---|---|
| **Generation Energy** | Estimate of hourly wholesale value of energy |
| **Generation Capacity** | The costs of building new generation capacity to meet system peak loads, allocated to top LOLP hours |
| **Ancillary Services** | The marginal costs of providing system operations and reserves for electricity grid reliability |
| **T&D Capacity** | The costs of expanding transmission and distribution capacity to meet peak loads |
| **Monetized Carbon (cap and trade)** | The cost of Cap and Trade allowance permits for carbon dioxide emissions associated with the marginal generating resource |
| **GHG adder** | The cost of reduced GHG emissions on the supply side including least cost renewable portfolio, storage, and integration less the cap and trade amount |

# Generation Capacity Value by Hour

- **In today's system (2020), summer peak net loads drive loss of load probability**
- **Probability of insufficient generation by hour and month**

Solar has been driving net peak later in the day

**Weekday**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 1.14E-14 | 0 | 8.18E-17 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 2.4E-12 | 0 | 7.52E-13 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 5.66E-11 | 5.95E-15 | 1.07E-12 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 1.9E-09 | 9.19E-13 | 1.23E-09 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 2.32E-15 | 1.27E-06 | 4.12E-10 | 1.29E-07 | 0 | 0 | 0 |
| 13 | 0 | 0 | 0 | 0 | 0 | 3.3E-13 | 1.26E-05 | 1.97E-06 | 4.89E-06 | 0 | 0 | 0 |
| 14 | 0 | 0 | 0 | 0 | 0 | 1.73E-10 | 8.21E-05 | 0.000149 | 0.000178 | 3.83E-17 | 0 | 0 |
| 15 | 0 | 0 | 0 | 0 | 2.36E-14 | 1.44E-08 | 0.001125 | 0.007563 | 0.005466 | 3.11E-11 | 0 | 0 |
| 16 | 0 | 0 | 0 | 0 | 9.1E-13 | 9.16E-07 | 0.004592 | 0.021677 | 0.017763 | 9.16E-09 | 0 | 0 |
| 17 | 0 | 0 | 0 | 0 | 8.18E-10 | 1.66E-06 | 0.006291 | 0.022581 | 0.018713 | 0.000149 | 0 | 0 |
| 18 | 3.7E-14 | 0 | 0 | 0 | 5.87E-10 | 2.76E-05 | 0.009768 | 0.036938 | 0.150035 | 9.59E-05 | 3.59E-13 | 3.31E-08 |
| 19 | 0 | 0 | 0 | 0 | 1.52E-07 | 0.000647 | 0.038944 | 0.118919 | 0.131879 | 0.000265 | 0 | 1.1E-10 |
| 20 | 0 | 0 | 0 | 0 | 1.13E-06 | 0.000566 | 0.041596 | 0.069837 | 0.034631 | 8.2E-07 | 0 | 3.45E-11 |
| 21 | 0 | 0 | 0 | 0 | 3.86E-11 | 2.65E-07 | 0.000873 | 0.000904 | 0.000288 | 0 | 0 | 4.73E-20 |
| 22 | 0 | 0 | 0 | 0 | 0 | 0 | 3.76E-09 | 8.92E-10 | 1.82E-08 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

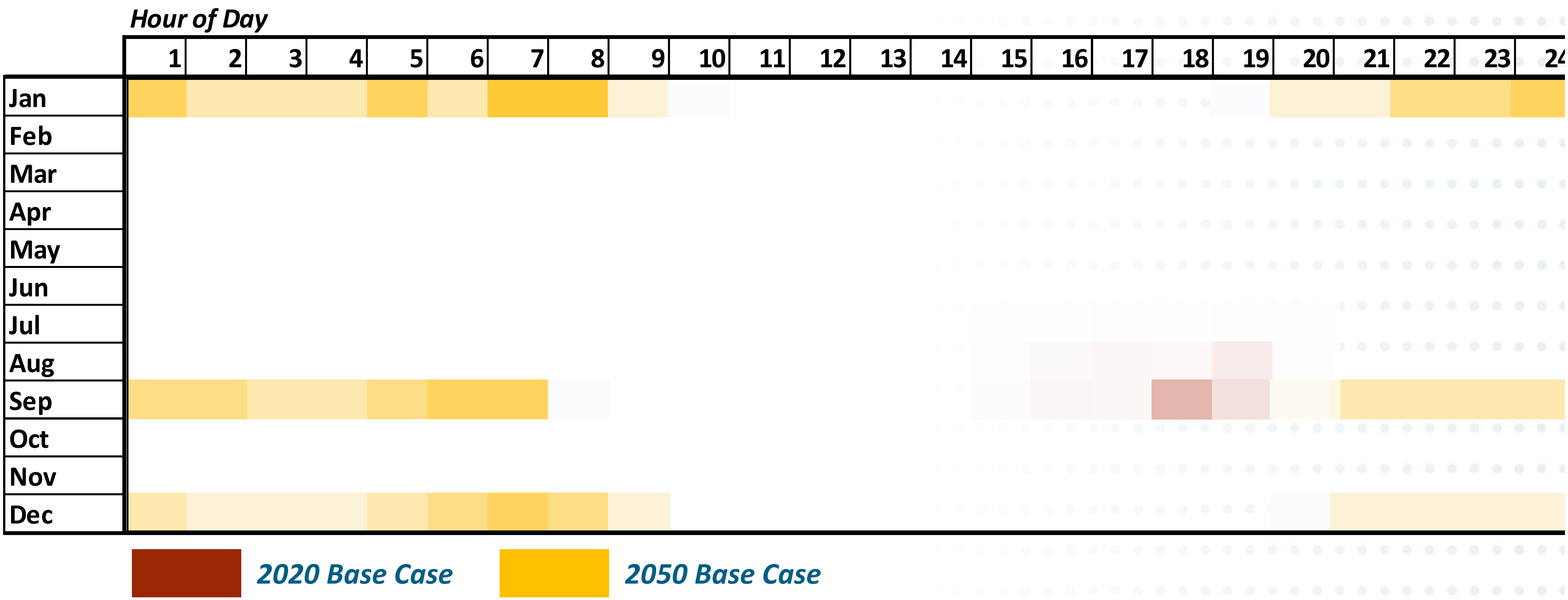
**Weekend**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 9.45E-15 | 0 | 1.63E-16 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 4.68E-11 | 0 | 5.94E-11 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 7.06E-07 | 0 | 6.44E-08 | 0 | 0 | 0 |
| 13 | 0 | 0 | 0 | 0 | 0 | 0 | 2.54E-06 | 7.22E-18 | 2.98E-06 | 0 | 0 | 0 |
| 14 | 0 | 0 | 0 | 0 | 0 | 6.39E-18 | 3.06E-07 | 7.3E-12 | 3.4E-06 | 0 | 0 | 0 |
| 15 | 0 | 0 | 0 | 0 | 0 | 4.32E-15 | 4.9E-06 | 7.2E-08 | 0.000126 | 0 | 0 | 0 |
| 16 | 0 | 0 | 0 | 0 | 0 | 1.71E-12 | 1.76E-05 | 1.89E-06 | 0.000501 | 0 | 0 | 0 |
| 17 | 0 | 0 | 0 | 0 | 2.12E-18 | 9.79E-12 | 6.53E-05 | 4.32E-06 | 0.00085 | 3.67E-10 | 0 | 0 |
| 18 | 5.31E-14 | 0 | 0 | 0 | 0 | 5.24E-10 | 0.000102 | 1.44E-05 | 0.074815 | 2.98E-10 | 1.11E-14 | 3.14E-14 |
| 19 | 0 | 0 | 0 | 0 | 2.99E-13 | 1.01E-07 | 0.013717 | 3.9E-05 | 0.104481 | 1.57E-09 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0 | 9.49E-12 | 6.82E-08 | 0.019146 | 5.55E-05 | 0.042522 | 1.85E-12 | 0 | 0 |
| 21 | 0 | 0 | 0 | 0 | 0 | 3.48E-12 | 0.000948 | 1.04E-07 | 7.58E-06 | 0 | 0 | 0 |
| 22 | 0 | 0 | 0 | 0 | 0 | 0 | 1.28E-07 | 0 | 8.55E-12 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# 2050 Stressful Reliability Conditions in a SB100 Scenario

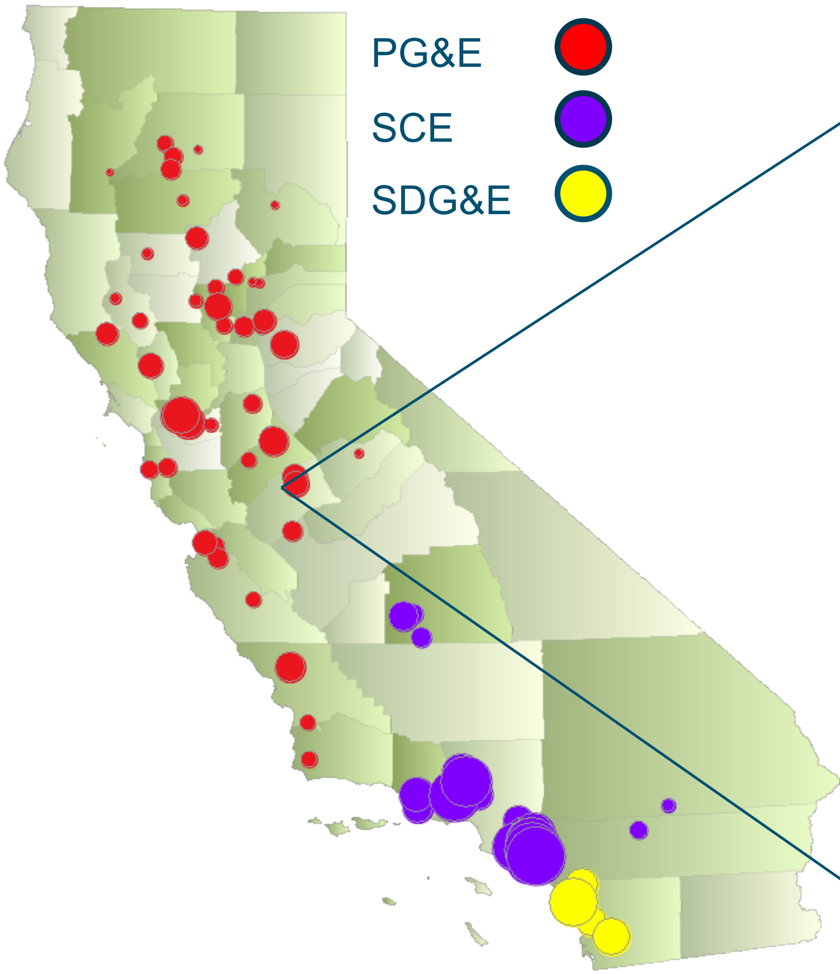
- **In today's system (2020), summer peak loads drive loss of load probability**

- **In 2050's system, an abundance of solar + storage reduces the probability of reliability conditions during the summer peak and shifts loss of load probability to low renewable production hours i.e. night and winter**



# Distribution Capacity by Hour

## Distribution Resources Planning (DRP) Process




Distribution 'Hot Spots'

**Heatmap of LNBA Local T&D Costs (Total $/kW in each month/hour)**

Individual — Hour of the Year (hour starting PST)

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Feb | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mar | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Apr | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.3 | 0.1 | 0 | 0 | 0 |
| May | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 1 | 0.4 | 0.1 | 0 | 0 |
| Jun | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 1.8 | 1.3 | 0.8 | 0.4 | 0.1 |
| Jul | 0.3 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 3 | 2.4 | 1.8 | 1.3 | 0.8 | 0.5 |
| Aug | 0.4 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 3 | 2.4 | 1.8 | 1.3 | 0.9 | 0.6 |
| Sep | 0.3 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 3 | 3 | 4 | 4 | 4 | 4 | 3 | 3 | 2.2 | 1.6 | 1.2 | 0.8 | 0.6 |
| Oct | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 2 | 2 | 1.2 | 0.8 | 0.5 | 0.3 | 0.1 |
| Nov | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Dec | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Heatmap of DER average hourly output (not adjusted for losses or dependability)**

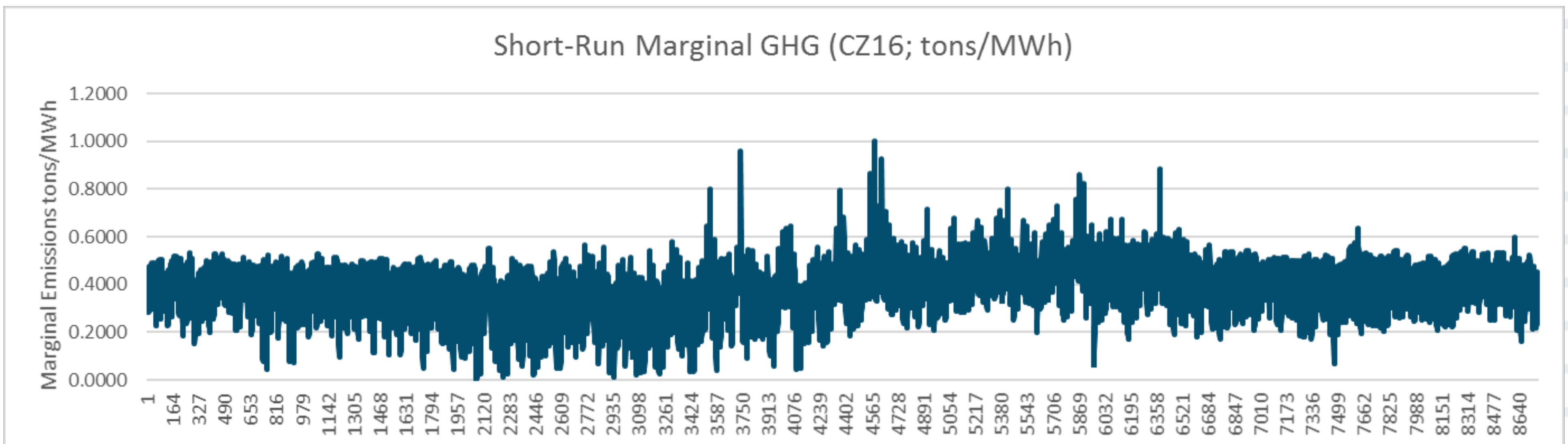
Hour of the Year (hour starting PST)

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7.33 | 292 | 694 | 890 | 1103 | 1157 | 1199 | 1103 | 850 | 213 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Feb | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 87.1 | 451 | 815 | 1046 | 1249 | 1248 | 1241 | 897 | 728 | 554 | 42.1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mar | 0 | 0 | 0 | 0 | 0 | 0 | 20.1 | 370 | 926 | 1452 | 1717 | 1883 | 1946 | 1897 | 1636 | 1354 | 845 | 185 | 0 | 0 | 0 | 0 | 0 | 0 |
| Apr | 0 | 0 | 0 | 0 | 0 | 0.74 | 167 | 599 | 1126 | 1510 | 1794 | 1969 | 2094 | 2013 | 1791 | 1356 | 902 | 445 | 12.9 | 0 | 0 | 0 | 0 | 0 |
| May | 0 | 0 | 0 | 0 | 0 | 38.8 | 308 | 817 | 1311 | 1722 | 2061 | 2177 | 2146 | 2125 | 1864 | 1479 | 958 | 530 | 78.9 | 0 | 0 | 0 | 0 | 0 |
| Jun | 0 | 0 | 0 | 0 | 0 | 51.1 | 289 | 705 | 1146 | 1572 | 1876 | 2097 | 2217 | 2190 | 1989 | 1617 | 1109 | 603 | 235 | 0.42 | 0 | 0 | 0 | 0 |
| Jul | 0 | 0 | 0 | 0 | 0 | 28.1 | 222 | 591 | 1145 | 1654 | 2090 | 2300 | 2338 | 2278 | 1991 | 1651 | 1161 | 633 | 236 | 0.21 | 0 | 0 | 0 | 0 |
| Aug | 0 | 0 | 0 | 0 | 0 | 2.24 | 156 | 552 | 1000 | 1556 | 1990 | 2244 | 2310 | 2266 | 2007 | 1581 | 1058 | 483 | 20.5 | 0 | 0 | 0 | 0 | 0 |
| Sep | 0 | 0 | 0 | 0 | 0 | 0 | 90.9 | 494 | 972 | 1351 | 1834 | 2129 | 2203 | 2097 | 1807 | 1365 | 822 | 188 | 0.13 | 0 | 0 | 0 | 0 | 0 |
| Oct | 0 | 0 | 0 | 0 | 0 | 0 | 18.3 | 372 | 883 | 1353 | 1730 | 1882 | 1898 | 1823 | 1478 | 1025 | 403 | 13.1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nov | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 162 | 593 | 941 | 1144 | 1351 | 1325 | 1221 | 971 | 647 | 70.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Dec | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 25 | 373 | 677 | 919 | 1088 | 1158 | 1104 | 778 | 549 | 82.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Output from LNBA Tool

# California Marginal Emissions Rates

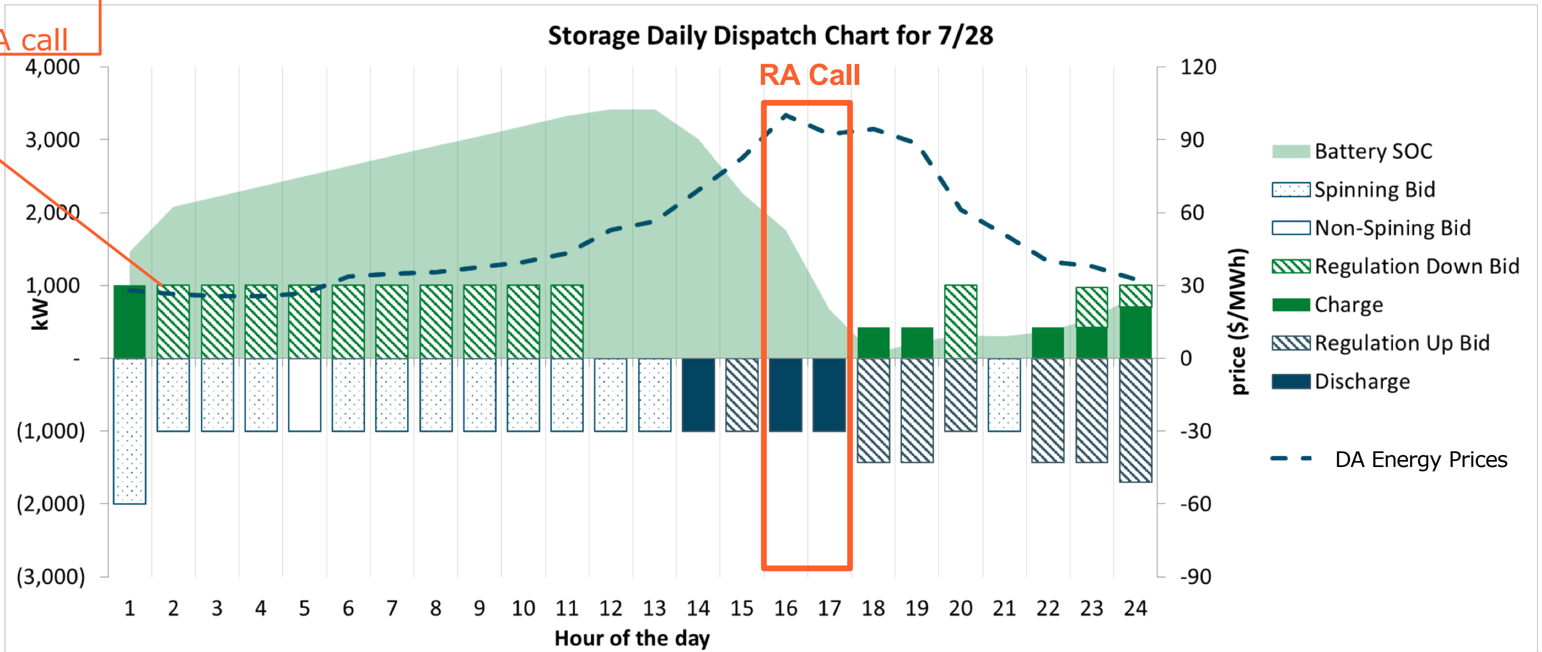
+ **E3 is working with California state agencies to develop hourly marginal emissions rates**
  - California Energy Commission, Air Resources Board, California Public Utilities Commission
+ **Approaches vary, and there is quite a bit of research on the topic of estimating lifecycle GHG emissions**

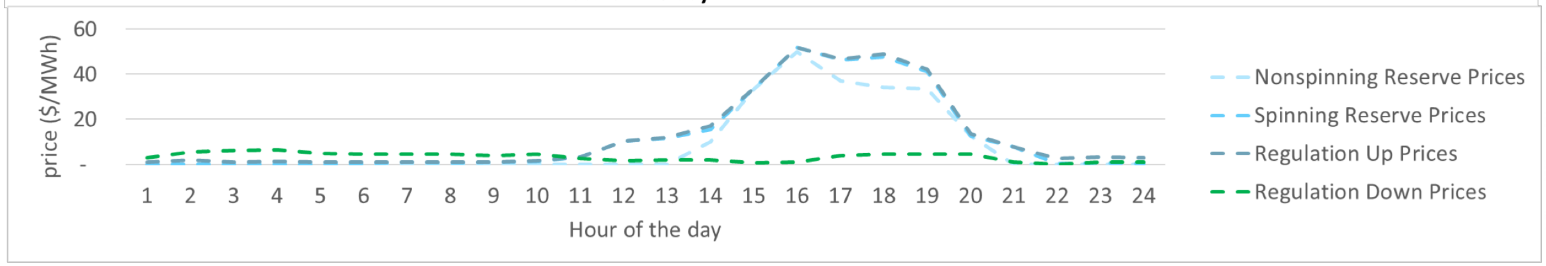


# Battery Storage Example

+ **1 MW 4-hour battery with 85% round trip efficiency**
  - Historical 2016 SP15 DA CAISO prices
  - With RA call at hour 16 and 17

Charge more to prepare for the RA call



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# Questions?

**Please use the chat box** to send us your questions and comments. You may want to direct your question to a specific author.

The report and webinar slides are posted at https://emp.lbl.gov/projects/time-value-efficiency