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Decarbonization of Electricity Requires Procurable, Market-Based Demand Flexibility

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ABSTRACT

To effectively decarbonize the electric sector, utilities will need to address the growing load shape challenges driven by the variability of many renewable resources. Behind-the-meter solutions, such as energy efficiency, demand response, electrification and storage, will play an important role in grid stability, but only if they can deliver changes in demand that meet the time and locational needs of the grid. This article will discuss how smart meter interval data, combined with open source methods and software, provide transparent measurement of savings load shapes (resource curves) that enable the integration of demand flexibility into energy, capacity and carbon markets, and as a transmission and distribution resource. This allows utilities to procure demand flexibility in the same way they procure other resources by leveraging a price signal and pay-for-performance to drive innovation and attract private investment.

KEYWORDS

Energy efficiency, decarbonization, electrification, distributed energy resources, pay-for-performance, flexibility

1. Introduction

Energy efficiency is often called the first fuel and a resource, but now it needs to start behaving like one.

As more states and utilities commit to aggressive decarbonization goals, the electric grid must transition from a centralized, fossil-fuel based system to one that is anchored by clean and often distributed sources of energy such as solar and wind. Current ratepayer funded programs must transition to scalable markets that pay for grid and climate outcomes based on performance at the meter, in the same way that traditional resources are procured and financed.

It is going to take a whole ecosystem of resources both on the grid and behind the meter to enable this transition.

For years, the primary obstacle to moving toward renewable energy sources has been their cost-competitiveness. But with wind and solar representing two-thirds of all new global capacity in 2018, the challenge of clean energy has now shifted from the cost of new generation to the question of how to integrate these clean but variable resources into the grid.[1]

Grids with large amounts of solar power, such as in California and Australia, are already struggling to address the mismatch between daytime solar supply and evening demand (the "duck curve"). Regions with high penetration of wind, such as Texas and the Midwest, face similar challenges (albeit different animal shapes).[2] In all these cases, variability is contributing to regular periods of over and undersupply, and periods of negative energy prices -- where there are more clean electrons than demand to use them.[3] For example, the California Independent System Operator reports that 461 GWh of renewables were curtailed in 2018.[4] As of May 22, 2019, renewables curtailment had reached 533 GWh, exceeding all of 2018 by 17%.[5] This level of renewables in the energy mix can destabilize markets, causing swings in energy pricing. The 72 GWh of California renewables curtailment in April 2018 led to 5.3% of five-minute intervals experiencing negative generation pricing in that month.[6] For comparison, in April 2019, 191 GWh of renewables were curtailed,[7] more

than 2.5 times that of the same time period in the previous year. Not surprisingly, the frequency of negative pricing also more than doubled. As a higher penetration of renewables continues to be incorporated, recent projections indicate much higher levels of curtailment and system costs could occur, as shown in the figure below.[8]
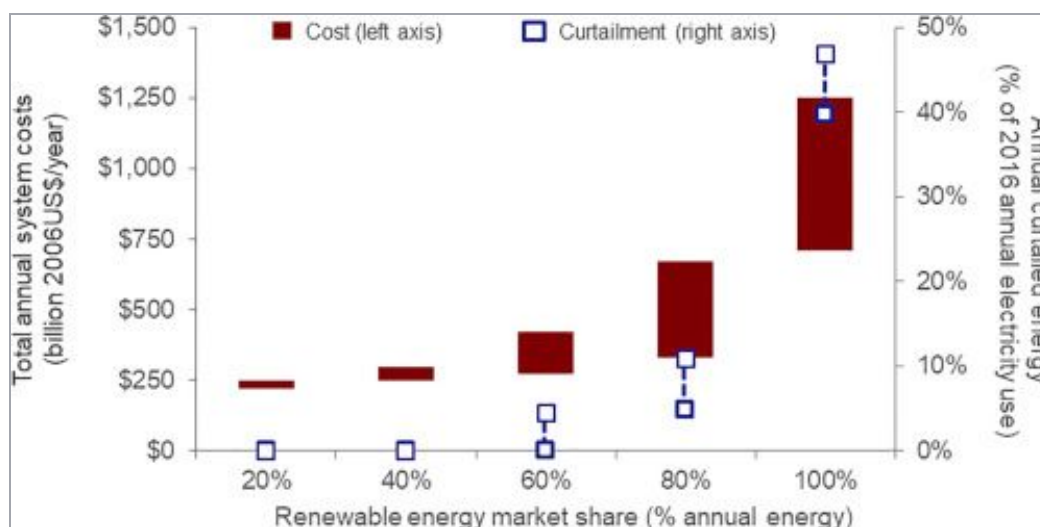

Figure 1: Nonlinear Increases in Total Annual Electricity System Cost and Curtailed Wind and Solar Energy as Renewable Energy Share Increases.[1]

[1]Jenkins, J., Luke, M., & Thernstrom, S. (2018). Getting to Zero Carbon Emissions in the Electric Power Sector. *Joule, 2*(12), 2498-2510. doi: 10.1016/j.joule.2018.11.013

Many expect energy storage technology to advance rapidly, prices to fall exponentially, and deployment to scale swiftly. However, a 2016 NREL report found that achieving 50% solar photovoltaic energy penetration in California would require between 15 and 28 GW of new storage.[9]

To put these numbers in perspective, a recent Wood Mackenzie report estimated that total annual *nationwide* storage capacity would experience a growth rate of only 4.4 GW per year by 2024.[10] Even with competitive utility-scale storage, the issue of peak demand looms large in determining the infrastructure investment needed to ensure constant resource adequacy, especially as jurisdictions approach 100% renewable generation.[11,12,13]

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# 2. Demand Flexibility Will be Essential for Affordable Decarbonization

Taken together, these challenges demonstrate that enhanced demand flexibility is essential to successfully transition to high levels of renewables at a reasonable cost and fill the growing load balancing gap. Importantly, traditional behind-the-meter utility programs must evolve into reliable resources that are incorporated into energy procurement and forecasting processes.

Modern demand flexibility focuses on time- and location-sensitive load shaping using a diverse set of solutions including energy efficiency, demand response, electrification, and storage. This flexibility is based on the change in demand at the meter rather than the measures behind it.

3. From Efficiency to Demand Flexibility

Saving energy isn't always a win anymore. Done at the wrong time (the belly of the duck, for example) saving energy mid-day when there is more solar than demand can actually make grid problems worse, cost ratepayers money (when California is paying Oregon to take clean solar electrons), and have little to no carbon impacts. On the other hand, reductions of load during peak periods can be highly valuable as a grid resource and mitigate substantially more CO_2 emissions by displacing electrons from some of the dirtiest peak power plants.

The challenge of determining the value of demand flexibility starts with how it's measured. Monthly average deemed or modeled predictions and other bespoke

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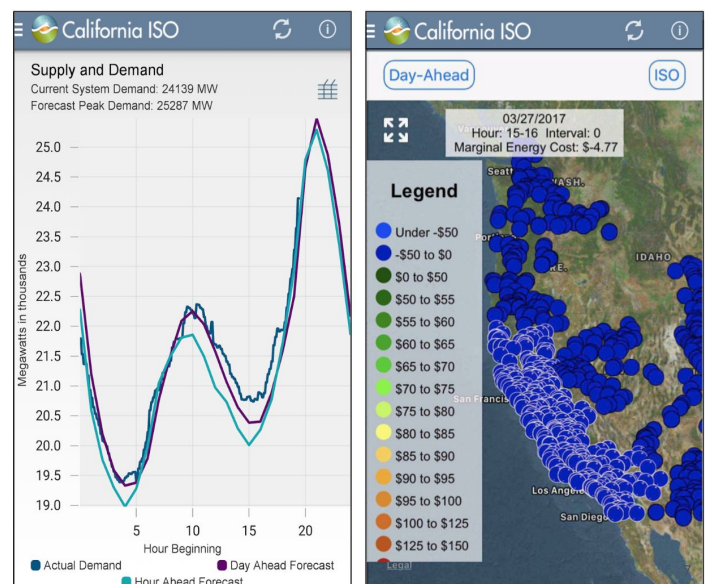
evaluation methods lead to skeptical procurement departments and markets unable to manage risk -- and therefore unable to invest. Fortunately, it is now possible to measure savings with confidence.

4. Weights and Measures for Demand Flexibility

The need for standard measurement is so important that it is called out directly in the U.S. Constitution, which gives Congress the power "To coin Money, regulate the Value thereof, and of foreign Coin, and fix the Standard of **Weights and Measures.**"[14]

The challenge of measuring flexibility comes down to the counterfactual. Once an intervention happens, there is no base case to measure against. The counterfactual for this measurement is instead a calculated value. The question is, how should that calculation be performed, and why should everyone have confidence in it?

The solution to this challenge comes from a combination of smart meter interval data, open source methods and deployable code that allows verification and replication by all parties to create, for the first time, the demand-side equivalent to a standard for measuring demand flexibility.

The [OpenEEmeter](#) open source codebase[15] allows users to process consumption data consistently and transparently in compliance with the [CalTRACK](#) consensus methods to measure the time and locational impacts from behind the meter interventions with confidence and replicability. The CalTRACK methods were developed through an open stakeholder process and have both been validated with empirical data, and are available to all parties without restriction.[16]

In May 2019, Recurve joined the Linux Foundation Energy ([LF Energy](#)) and contributed these two core open source projects to the community. LF Energy is a Linux Foundation initiative dedicated to developing and sustaining open source technology innovation in the energy and electricity sectors and is part of the Linux Foundation, the original and most respected open source organization in the world.

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5. Using Resource Curves to Procure Demand Flexibility

The ability to track the resource curve at the meter with confidence is providing utilities the information to procure behind the meter flexibility to solve grid-level load-shape problems.

The figure below results from an analysis conducted by Recurve (formerly OpenEE) and PG&E, that was presented publicly in January. Figure 2 shows the resource curve by season (average hourly impact to demand) for two PG&E programs. The top two plots show the time resource curves (time based impacts) on average and by season, for the Advanced Home Upgrade (AHUP) and the Commercial Deemed programs respectively. The bottom plot shows the avoided cost by hour for those same periods. The AHUP program is focused on home performance efficiency measures, while the Commercial Deemed program largely targeted improvements in commercial lighting and refrigeration.[17]
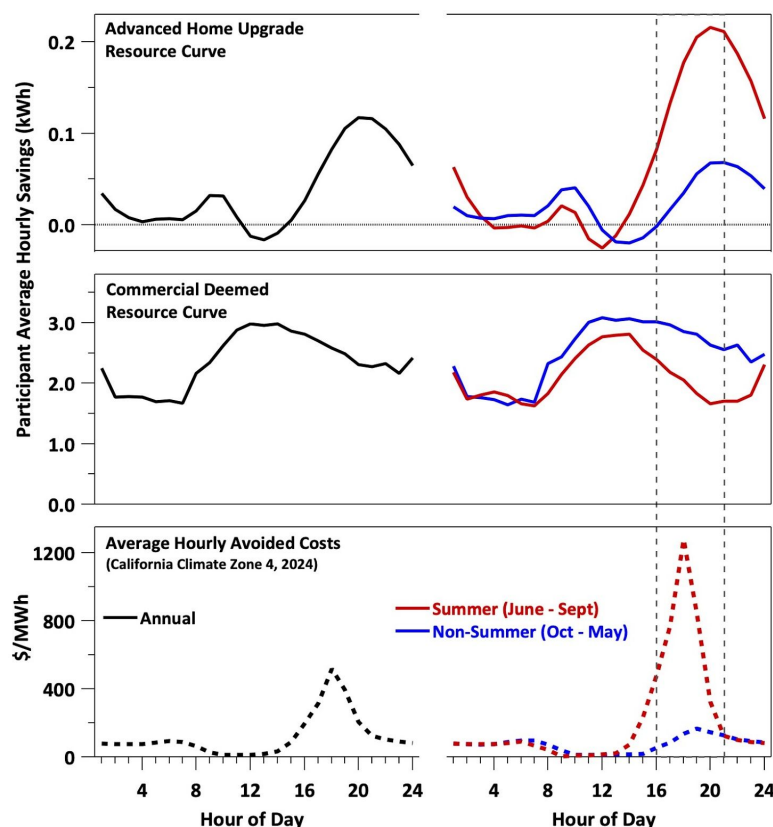

Figure 2: Resource curve by season (average hourly impact to demand) for PG&E's Advanced Home Upgrade Program (AHUP; Top) and Commercial Deemed efficiency programs (Middle). The bottom panel shows 2024 average hourly avoided costs for a representative climate zone in PG&E's service territory.[1]

[1] California Efficiency + Demand Management Council. (2019). EM&V: We are All In This Together.

The spike in summer peak avoided costs is due to high average evening capacity, transmission and distribution avoided costs that are associated with a relatively small number of summertime hours.
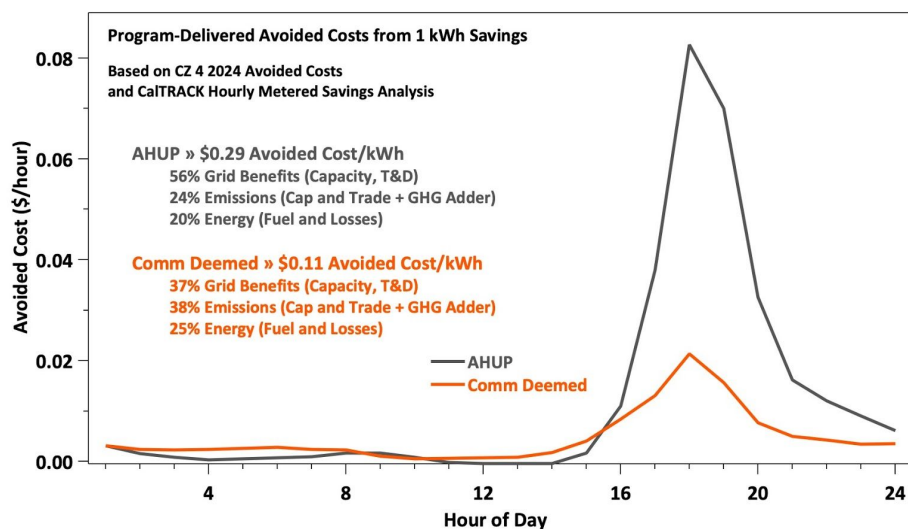

Figure 3: Shows the results of multiplying through the hourly (8760) savings load shapes of the Advanced Home Upgrade Program (AHUP) and Commercial Deemed programs by the 8760 avoided cost profile of California climate zone 4 (CZ 4) in 2024.[1] The savings load shapes are normalized to 1 kWh to provide a normalized comparison between the programs.[2]

[1] Any measure with an expected useful life (EUL) of at least five years already utilizes avoided cost projections out to 2024 to determine cost-effectiveness.

[2] California Efficiency + Demand Management Council, 2019.

The majority of electric avoided costs accrued by both the Advanced Home Upgrade Program (AHUP) and Commercial Deemed programs occur during the evening hours. Due to the propensity for the Advanced Home Upgrade Program (AHUP) to deliver savings during summer peak hours, 1 kWh equates to 29 cents in avoided costs, compared to just 11 cents for the Commercial Deemed program. The latter program delivers 30% of its savings between 8 a.m. and 3 p.m., yet these savings only yield 5% of the program's total avoided costs. In contrast, despite only delivering 6% of program savings during the summer peak hours, those savings account for 37% of avoided costs. With a high fraction of summer peak savings, the AHUP program takes advantage of high capacity, transmission and distribution avoided costs, with a majority of the program avoided costs originating from these components.

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Two conclusions are immediately apparent from this analysis.

First, whatever is done to a building creates a resource curve defined by the impact relative to the hour of the day. There are very few efficiency measures that deliver flat savings profiles, but that is often how efficiency is treated in utility load forecasting models (with the exception of some accounting for seasonal and on/off-peak variations).

Second, not all efficiency savings are created equal.

In this case, a high fraction of AHUP savings occurs during the summer evening peak period, when people are home and using air conditioning, while the Commercial Deemed program is driving baseload and mid-day savings. When combined with PG&E's avoided cost data[18] (bottom panel), it is clear that there are very real differences in the value of these resources. The dashed vertical lines indicate the summer peak as defined by PG&E's Time-of-Use rates.

In other words, energy efficiency programs that save more energy during peak times (by reducing weather-related heating and cooling needs, for example) could have much more value than those that save baseload energy overall (through lighting and refrigeration upgrades).

By integrating these measurements into a performance-based approach with more granular avoided cost information based on the full stack of grid values, utilities can reward implementers for metered results and efficiency can serve as a procurable, market-based, long-term demand flexibility resource that solves time- and location-specific grid problems.

6. The Impact of Time and Location on Carbon Accounting

Taking time and location into account is also critical when considering the carbon impacts of behind-the-meter interventions.

With increasing numbers of [states, cities, and utilities adopting carbon goals](), it is increasingly important that incentives and policies are aligned with the climate outcomes sought. Policies and actions designed to reduce carbon emissions through demand flexibility generated through efficiency, demand response, electrification, and other changes to energy use must be based on accurate carbon measurements.

[A recent Stanford study]() concluded that "current methods of estimating greenhouse gas emissions use yearly averages, even though the carbon content of electricity on the grid can vary a lot over the course of a day in some locations. By 2025, the use of yearly averages in California could overstate the greenhouse gas reductions associated with solar power by more than 50 percent when compared to hourly averages."

The carbon intensity of the California grid already varies significantly by hour and time of year, as the [CEC projections below]() (Figure 4) illustrate. These projections, which include the impacts of solar and wind combined with storage, demand response, and other resources, show the rolled up daily average CO_2 intensity of kWh by month for 2019 and forecasted to 2030.
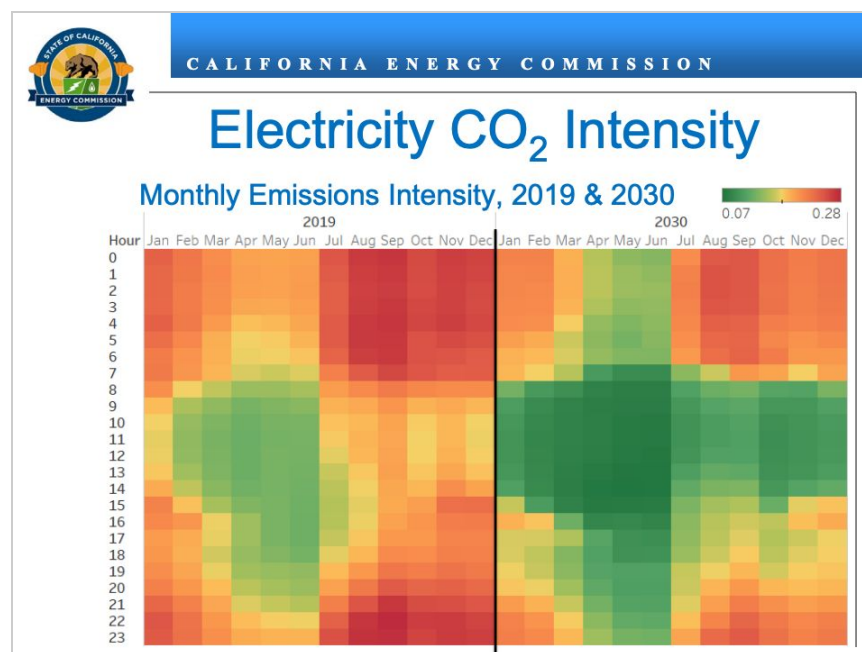

Figure 4: Daily average carbon intensity of kWh by month for 2019 and forecasted to 2030.[19]

By combining the hourly resource curve (impact to demand by hour) with the marginal carbon intensity of a kWh for that period and location, it is possible to much more accurately calculate carbon savings.

Figure 5 shows the average hourly marginal GHG impacts per MWh, again taking California Climate Zone 4 in 2024 as an example.[20]
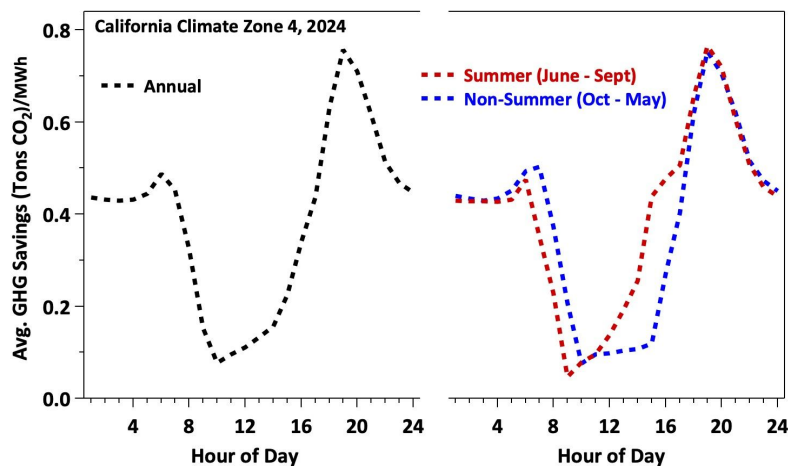

Figure 5: Forecast of average hourly marginal CO_2 intensities on annual (left panel) and seasonal (right panel) bases. California Climate Zone 4 is taken as an example.[1]

[1] Values are on an average hourly marginal basis and are computed using the CPUC's avoided cost calculator.

The dramatic dip in avoided GHG emissions corresponds to periods of high solar intensity and overgeneration. In short, if renewables are being curtailed, electricity savings will have no GHG impact. By combining the hourly resource curve (metered impact to demand on an hourly basis of Figure 2) with the marginal carbon intensity of a MWh, we can accurately calculate carbon reduction.

Figure 6 (below) shows how 1 MWh of savings through the AHUP and Commercial Deemed programs accrue avoided GHG emissions. Each data point represents the multiplication of three hourly kWh savings measurements with associated marginal avoided GHG emissions. As expected from the previous figure, we see that the AHUP savings concentrated in the GHG-intensive evening peak hours yield high avoided emissions, while both programs yield lower avoided emissions during the mid-day hours in which the CPUC forecast indicates a high propensity of overgeneration.
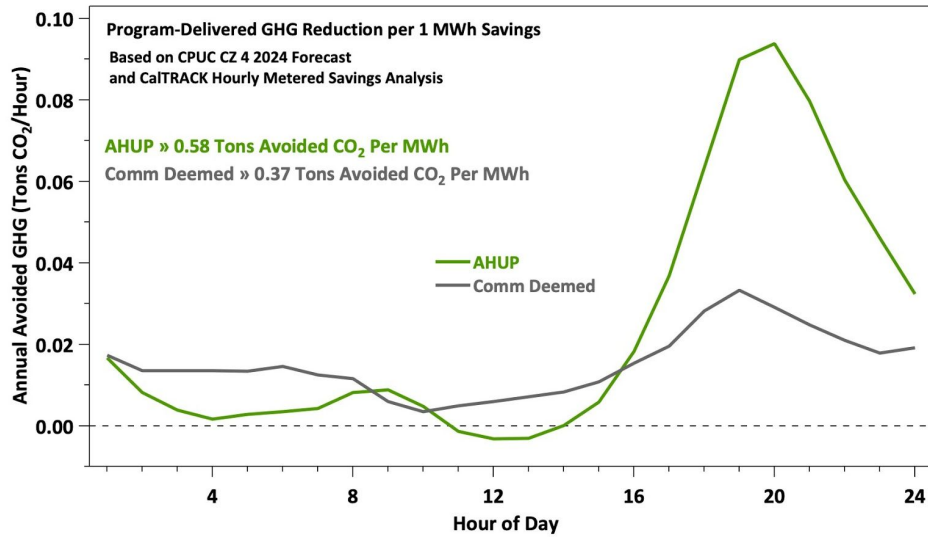
Figure 6: Accrued GHG emissions from 1 MWh of savings through the AHUP and Commercial Deemed programs.[21]

1 MWh of savings from Residential Home Performance (HVAC + shell) yields 59% more emissions reduction than 1 MWh of savings from the Commercial Deemed program because the AHUP program delivered a resource curve that did not overlap as extensively with overgeneration and displaced more carbon-intensive peaking fossil fuel generation.

The pivot from monthly averages to hourly and location specific resource curves provides a basis for policymakers, utilities and regulators to incorporate carbon and the full value stack of grid and climate benefits delivered by behind-the-meter interventions.

By measuring flexibility like a resource, we can now trade it like a resource.

7. Pay-for-Performance Markets for Demand Flexibility

In the past year, states including California, New York, Oregon and others have begun piloting and implementing pay-for-performance energy efficiency programs. Instead of basing payments on deemed savings estimates, these states are creating
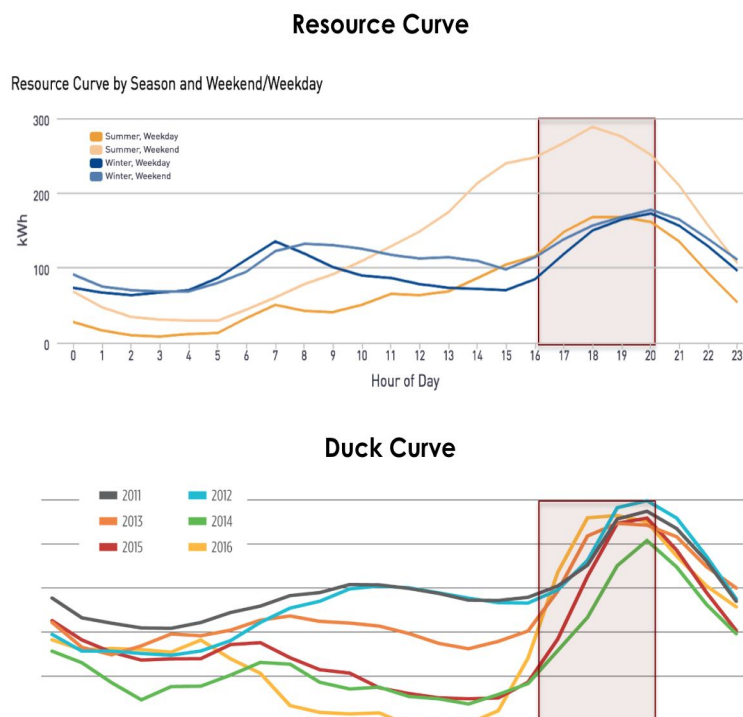
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markets that pay implementers for actual savings results calculated at the meter and normalized for weather and the occupancy of a building.

In pay-for-performance, it is important to distinguish between customer benefits and mutual grid benefits. Pay-for-performance is focused on quantifying, aggregating, and then monetizing the value of interventions that are shared (capacity, energy, transmission and distribution, and carbon), leaving the market to develop the many business models and technologies necessary to drive customer benefits and demand.

Mutual grid benefits can be paid for as a resource, and are a good deal for ratepayers so long as they are lower cost than the marginal cost of the alternatives. Building owners will pay for their private benefits (such as comfort, lower bills or resiliency), while mutual benefits are paid through utilities or other parties.

Pacific Gas and Electric (PG&E) in California is one of the earliest adopters of the pay-for-performance

Resource Curve

Resource Curve by Season and Weekend/Weekday

- Summer, Weekday
- Summer, Weekend
- Winter, Weekday
- Winter, Weekend

Duck Curve

- 2011
- 2012
- 2013
- 2014
- 2015
- 2016

Figure 7: Example of CA Res HVAC Resource Curves vs. CAISO.

procurement model. PG&E's residential efficiency pay-for-performance program uses the CalTRACK methods, deployed by the open-source OpenEEmeter, to calculate and pay efficiency aggregators for achieved savings, with a three-fold multiplier applied during the system peak period between 4 p.m. and 9 p.m.

Unlike traditional efficiency programs that have a single implementer and business model, in pay-for-performance, a utility or system operator will solicit bids and sign contracts with multiple vendors who compete for customers and to deliver savings.

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Winning aggregators enter into a Power Flex Agreement (PFA) and get paid for performance based on the portfolio-level resource curve over a set period of time. Cash flows created by these contracts can be brought forward using project finance, meaning aggregators and their customers do not need to carry the cash flow.

This type of financing is known as project or infrastructure finance and is a much lower cost source of capital than consumer credit. Rather than financing the cost of this grid infrastructure using the consumer credit and asset value of only the participants, project finance underwrites the likelihood of savings being realized.

This approach can be seen as analogous to the type of financing used by independent power producers, in which investors are paid back through the revenue stream generated by the IPP, only in this case the revenue stream comes not from sales but avoided costs (savings).

Especially in states where energy efficiency programs have either been repealed or are under attack as being too costly, financing demand flexibility based on the avoided costs to utilities could represent a much lower risk and more scalable solution for ratepayers, reserving surcharges for market transformation, low income, and other non-resource policies.[22] [23]

8. Demand Flexibility is a Virtual Power Plant

While most current pay-for-performance programs continue to use ratepayer energy efficiency portfolio funds, the grid value of flexibility is actually a virtual power plant (VPP) that increases in value when monetized through procurement and energy markets. The value of efficiency can be based on the marginal cost of the alternatives as part of the clean energy portfolio.[24]

One example of energy efficiency making this leap from ratepayer programs to the actual resource is the PG&E collaboration with East Bay Community Energy on the Oakland Clean Energy Initiative (OCEI) non-wires alternative (NWA) to enable the decommissioning of the 165 MW Dynegy peak power plant, situated near downtown Oakland.[25]

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This OCEI solicitation procured a combination of energy storage and energy efficiency that occurs in the right parts of Oakland and in the correct periods of time, with a minimum of 35% paid on metered performance.

At the same time, the California investor-owned utilities are also in the process of transitioning all customer-facing (downstream) energy efficiency programs to a third party implementation model. The first request for offers (RFO) was issued earlier this year. PG&E's response was particularly noteworthy in that it focused on the resource value of energy efficiency, specifying when savings are most valued in each service region, and encouraging embedded measurement and shared performance risk (pay-for-performance).[26]
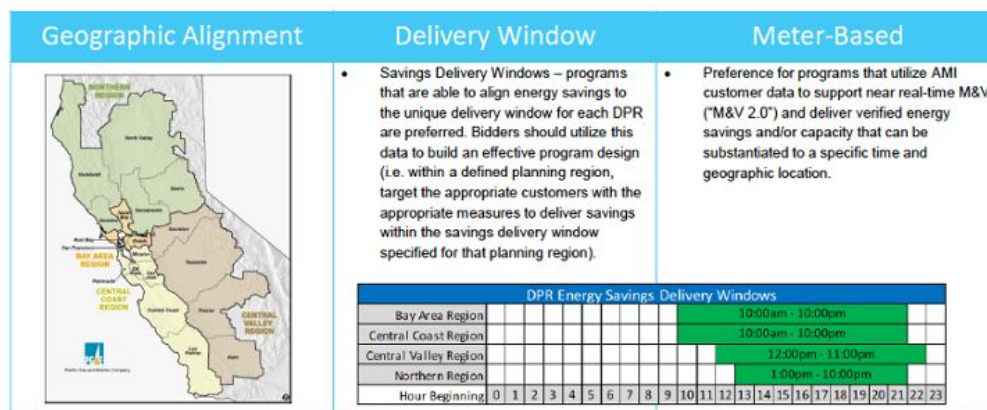
Source: PG&E.[27]

Investor-owned utilities (IOU) in California are also rethinking how they capture demand-side resources in the new mandates for carbon-driven integrated resource planning. In November, this shift was clearly articulated in joint comments by the California IOUs to the California Public Utilities Commission:

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"The advent of Pay-for-Performance programs, the growth of on-bill financing offerings, market transformation initiatives, load shifting, and integrated DR strategies, among other new strategies, are all expected to play central roles in the upcoming EE portfolios, while the traditional measure-based deemed and custom interventions that serve as the foundation for the current EE Potential and Goals modeling are becoming less prevalent." [28]

This market design is also being implemented in the residential, small/medium business, and commercial office building sectors by Marin Clean Energy (MCE), Bay Area Regional Energy Network (BayREN), Energy Trust of Oregon (ETO), New York State Energy Research and Development Authority (NYSERDA) with Con Edison, and The Massachusetts Department of Energy Resources (DOER), with more in development.

9. Using Project Finance, Not Consumer Credit

If demand flexibility can't attract capital, it won't be able to scale and achieve the vast low-cost potential locked up in existing buildings. While $8 billion a year of ratepayer investment in energy efficiency[29] sounds like a large number, in practice it's a drop in the bucket towards what will be required for real climate impact.

As a 2015 report published by the National Resources Defense Council pointed out, to meet the Paris Climate goals and keep the temperature below 1.5 degrees above pre-industrial levels, the United States will need to deep retrofit almost all buildings for efficiency. Estimating an average retrofit cost of $30,000 per building (assuming $20,000-$40,000 depending on unit type and size) for 120 million units, the total price tag of this project would be $3.6 trillion -- orders of magnitude more than current spending on ratepayer-funded efficiency programs.[30]

The solution to this problem is to move from ratepayer surcharge programs and toward energy markets and procurement that represent much larger budgets, and allow efficiency to be financed based on cash flows from grid and climate values through pay-for-performance.

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While energy saving from individual projects will vary, at the portfolio level, efficiency is a stable and predictable investment. Rather than attempt to make perfect predictions of building-level savings, procurers of efficiency and demand flexibility can manage and quantify performance risks through portfolios. While there is substantial variance in the performance of each project, the portfolio is both stable and predictable.
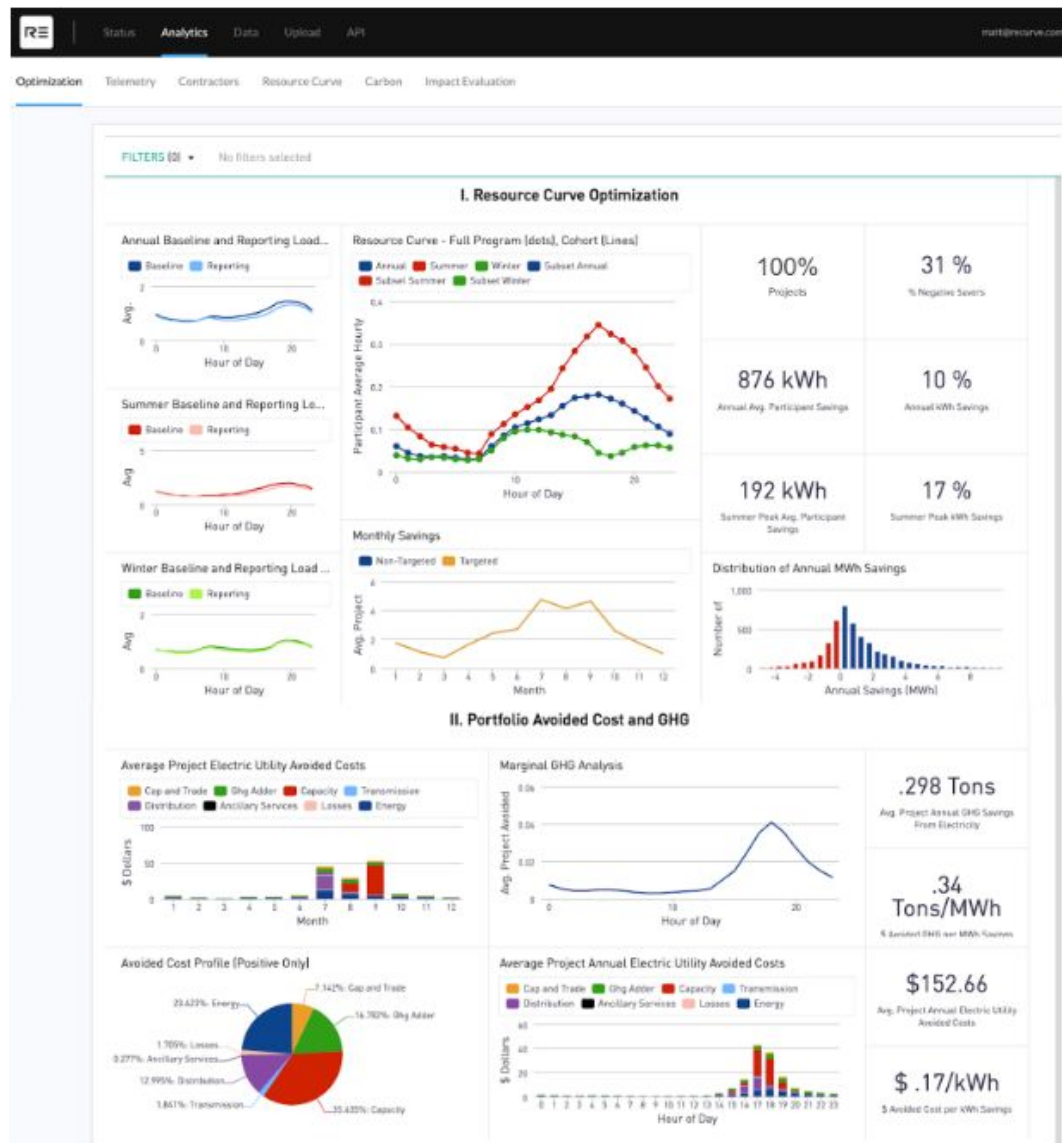
Figure 5: Portfolios of energy efficiency have winners and losers, but the probability of getting savings on average is consistent. Energy efficiency is an uncertain investment on individual projects but provides very stable and manageable risk and returns at the portfolio level.

To put it another way, while guaranteeing outcomes to a single customer is costly and difficult, a portfolio of projects can perform with consistent results. This consistency moves efficiency away from unquantifiable uncertainty towards manageable risk that can attract private project investors.

Efficiency aggregators who win pay-for-performance bids can secure capital to fund aggregated portfolios of projects. The aggregators are paid up front, and investors are paid back over time from the ongoing savings cash flow of the portfolio.

Performance risk (the risk that the portfolio won't save as much as predicted) can be managed through investment grade portfolio metered performance efficiency insurance. The first such policy has already been bound between Build it Green and HSB Munich Re.

10. Demand Flexibility is Incredibly Simple and Infinitely Complex

While pay-for-performance will enable innovation and diversity in technologies and business models, the policies and market structure needed to make this transition are actually deceptively simple.

The first principle is to make energy efficiency and flexibility work like other efficient markets by introducing price discovery, pooling to manage risk, transparent measurement, and alignment of incentives with the public interest. This will encourage competition and innovation in the market and ensure that outcomes are optimized for both customers and public benefits without picking winners.

The policy formula becomes straightforward. Treat behind-the-meter demand flexibility like other distributed resources and procure it first whenever the cost is lower than the marginal cost of grid side alternatives. Regulators should encourage utilities to redesign their energy efficiency and behind the meter programs to move

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away from technology specific, utility-driven ratepayer financed approaches toward technology agnostic, market based pay-for-performance.

Achieving a stable, clean-energy grid that incorporates both renewable and distributed energy resources requires all hands on deck. Demand flexibility has the potential to be one of the most plentiful and lowest-cost options in the mix, but to reach the scale needed to have an impact, it must behave like a resource and be allowed equal access to markets.

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