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Residential Electricity Bill Savings Opportunities from Distributed Electric Storage

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SUMMARY

Cost reductions have made distributed electric storage systems (DES) located behind-the-meter, like Tesla's Powerwall home battery, widely available to residential customers [1]. DES are generally known to provide wide-ranging electricity system benefits including outage management, deferred transmission and distribution investment, production cost savings, and avoided generation capacity investments [2]. These benefits and rapid cost reductions have made policymakers optimistic about the role that DES could play in an evolving electricity distribution system. However, in order to promote economically-efficient market adoption of this new technology, it is important that the private financial incentives to invest in DES are commensurate with the public benefits they provide.

For residential customers considering investing in DES for their homes, private financial incentives derive from opportunities to reduce their electricity bills. The variety and complexity of utility rates generally restricts estimates of customer electricity bill savings to broad generalizations or narrow results that are relevant only to a limited number of customers. This analysis models electricity bill savings for customers that invest in DES using a detailed database of thousands of locational electricity rates from utilities across the United States, a prototypical residential demand profile, and technical specifications of a representative home lithium-ion battery system based on Tesla's Powerwall. These results are mapped to zip codes corresponding to each electricity rate to show the geographic diversity of electricity bill savings.

The results reveal that electricity bills for residential customers with DES ranged from showing no savings compared to baseline electricity bills to more than a 40% reduction. The opportunities for customers to save on their electricity bills did not appear to correlate with urban or rural geographies. Residential customers living in adjacent areas have widely differing electricity bill savings implications which reveals potential fragmentation in the market for residential DES systems. Based on the assumptions and data availability underlying this analysis 60% of the residential customers, or over 80 million, are able to lower their electricity bills by using DES.

Of those customers that realize electricity bill savings, those savings fall far short of the cost of the battery system. The median customer would need to realize a savings three and half times the estimates found in this analysis for the purchase of the DES to be cost-effective. Previously estimated net benefits of DES generally exceed the customer electricity bill savings found here and in some cases exceed the costs of the DES. The shortfall between social value and private customer value suggests that traditional utility rate design does not

adequately reflect the net benefits that a customer with DES provides the system, or that additional remuneration methods may be needed to bridge that shortfall.

As costs for DES continue rapid declines, policy makers, regulators, and utilities must ensure that the societal benefits of residential customer investments are reflected in customer incentives for those investments. Analysis techniques such as the one presented in this paper, complemented by exploration of other means of compensating customers, can be used to examine the discrepancies between societal value and customer benefits of DES investment, identify rate structures that fairly compensate DES owners, and monitor national progress towards reformed electricity rates.

KEYWORDS
Distributed Energy Storage, DES, Electric Storage, Residential, Battery, Value, Rates, Tariffs

1. Introduction

Cost reductions have made distributed electric storage systems (DES) located behind-the-meter, like Tesla's Powerwall home battery, widely available to residential customers [1]. DES are generally known to provide wide-ranging electricity system benefits including outage management, deferred transmission and distribution investment, production cost savings, and avoided generation capacity investments [2]. These benefits and rapid cost reductions have made policymakers optimistic about the role that DES could play in an evolving electricity distribution system. However, to promote economically-efficient market adoption of this new technology, it is important that the private financial incentives to invest in DES are commensurate with the public benefits they provide.

For residential customers considering investing in DES for their homes, private financial incentives derive from opportunities to reduce their electricity bills. The variety and complexity of utility rates generally restricts estimates of customer electricity bill savings to broad generalizations or narrow results that are relevant only to a limited number of customers. This analysis, relying on a detailed database of electricity rates across the United States, estimates electricity bill savings for customers that invest in DES.

2. Overview of Electricity Rate Structures

Electricity rates, also called tariffs, are the prices and price structures that establish how customers pay for electric power. Rates serve two important roles in both regulated and unregulated electric power systems: they provide revenue for utilities that generate and deliver electric power, and send economic price signals to customers. This analysis examines the role of electricity rates as price signals for retail customers considering investing in DES.

The electricity bill savings opportunities offered by DES are defined by electricity rates. This section describes the attributes of electricity rates that enable DES owners to lower their electricity bills and how those attributes relate to system costs. These attributes are used to model the electricity bill savings opportunities for customers who invest in DES.

2.1. Components of an Electricity Rate

A customer's electricity bill is determined by one or more attributes of their demand profile. Most electricity rates only consider one attribute, total energy use, in calculating a customer's electricity bill. However, electricity rates that better reflect a customer's demand profile can align private incentives with system costs and lead to more economically-efficient investment decisions. Several pricing mechanisms exist that facilitate this alignment of system costs and user charges.

The cost of providing service generally fall into one of two component categories: fixed cost and variable cost. Fixed costs include the cost of the physical assets needed to serve a customer base, and variable costs include the incremental costs of using those fixed assets to deliver electricity.

Two types of charges are commonly used in customer electricity bills to reflect fixed and variable costs: the demand charge and the energy charge. The design of these charges determines how a customer may achieve energy bill savings from the use of DES. Demand charges are proportional to the magnitude of the customer's peak demand during a pre-specified time interval, and usually priced per kilowatt ($/kW). The economic rationale underlying the demand charge is that it reflects the fixed asset costs of providing service proportional to the contribution of each customer to those costs. Energy charges are relate to the variable costs of providing service by charging for each unit of energy that a customer consumes, typically priced per kilowatt-hour ($/kWh). Electricity rates incorporate one or both of these components.

The prices customers are charged for energy and demand can change as a function of additional attributes of demand: cumulative consumption and time of use.

2.2. Pricing as a Function of Consumption

Consumption-based pricing means that marginal prices (prices for each consecutive unit of consumption) are a function of how much has already been consumed in a particular time period. This pricing regime can apply to energy or demand. Traditional economic theory suggests that customers base consumption choices on marginal price signals: the higher the price for each marginal unit of energy or power, the greater the incentive for a customer to forgo consumption of that unit.

Electricity rates can reflect consumption though increasing, decreasing, or flat marginal prices. Decreasing marginal prices provide a weak incentive to forgo consumption, whereas increasing marginal prices provide the most pronounced incentive to reduce energy consumption, especially for customers with high levels of consumption compared to users in their same rate class.

2.3. Pricing as a Function of Time

The logical basis for time-differentiated prices is not that costs inherently change with time, but that costs change as a function of peak demand and peak demand is a function of time. In a typical electric energy supply curve, when instantaneous demand increases the cost of the marginal unit of energy increases. Furthermore, peak demand also determines the amount of physical infrastructure and generating capacity needed on the system.

Some utilities design rate structures such that energy and/or demand charges are increased during typical periods of high demand to reflect the increased marginal costs of energy and demand. And because both energy *and* demand costs are driven by peak demand, a rate design that increases *either* energy or demand prices during that period should have similar impacts on customer behavior.

Importantly, pricing as a function of consumption and time are not mutually exclusive. One customer may face two increasing marginal price curves, one for the weekend and one for weekdays. Or another customer could have an increasing marginal price schedule for peak hours and a flat schedule for off-peak periods of the day. This analysis captures all combinations of these utility rate-design attributes.

2.4. Potential Electricity Bill Savings from DES

The ability for a customer to lower their electricity bills by using a DES depends on complex financial trade-offs inherent in each customer's rate design. DES located behind a customer's electricity meter can be used to change the timing of electricity purchases from the grid. This offers two potential electricity bill savings. First, if a utility charges a consumer based on peak demand, the DES can be used to lower the customer's peak demand and thereby reduce their demand charges. Second, if a utility charges time-dependent rates, DES can be used to purchase more electricity than needed when prices are low and decrease purchases when prices are high, thereby lowering their effective average prices.

There are limitations to the use of DES. Batteries are not perfectly efficient, creating a trade-off in taking advantage of these electricity bill savings: a customer will always buy more electricity to charge the battery than they save by discharging it. Therefore the added costs of charging and discharging the DES must be weighed against the electricity bill savings of changing the timing of electricity purchases.

Though time-dependent pricing for energy and demand charges have an economic rational and provide an opportunity for DES owners to lower their electricity bills, most residential customers pay for electricity based only on energy charges. Such rates provide no opportunity for a reduction in electricity bills and due to efficiency losses of the battery would actually increase the electricity bill of a customer that actively relied on DES to change the timing of their purchases.

3. Methods

The complexity and variety of rate design, and its implications for electricity bill savings offered by DES, have traditionally posed a challenge to researchers examining the cost-effectiveness of DES for residential customers. The following sections detail the approach used to overcome the variety and complexity of electricity rates in order to estimate the electricity bill savings for customers that invest in DES subject to electricity rates across the United States.

3.1. Data

The data that informs this analysis include a database of utility rate structures, a modelled residential customer demand profile, and utility demographic data.

The utility rate structure data include over 45,000 utility rates for more than 4,500 utilities in the United States [3]. This user-submitted and expert-reviewed dataset of electricity rates provides detailed prices and price structures for residential, commercial, industrial and lighting customer classes. The weaknesses of this data are: despite a structured input method, there is no guarantee that all data accurately reflect the rate structures they represent; that not every utility and not every utility's rate options are accounted for; some of the rates may be out of date; and there could be selection bias inherent in the submission process. Nonetheless, this dataset represents a substantial collection of rate structures and is of suitable fidelity for this generalized analysis.

The residential electricity profile used to model electricity bill savings was retrieved from a database of modelled hourly demand profiles whose design, local climate, and energy use patterns vary regionally. The modelled demand profile is for a residential customer with a typical three bedroom, one bathroom house [4]. The particular demand profile used for this analysis is for Cherry Point, North Carolina for a Typical Meteorological Year (TMY3).

Other data required for this analysis includes the number of customers served by each utility [5], utility service areas delimitated using zip codes [3], and zip code cartographic boundaries [6]. Data for the energy storage device are loosely based on Tesla's recently-announced Powewall home energy storage device [7]. The Powerwall is a Lithium-ion battery with a capacity of 10 kWh, a power output of 2.0 kW, and an estimated cost of $5,000 per 9 years [8]. The battery is assumed to have an 85% round-trip efficiency.

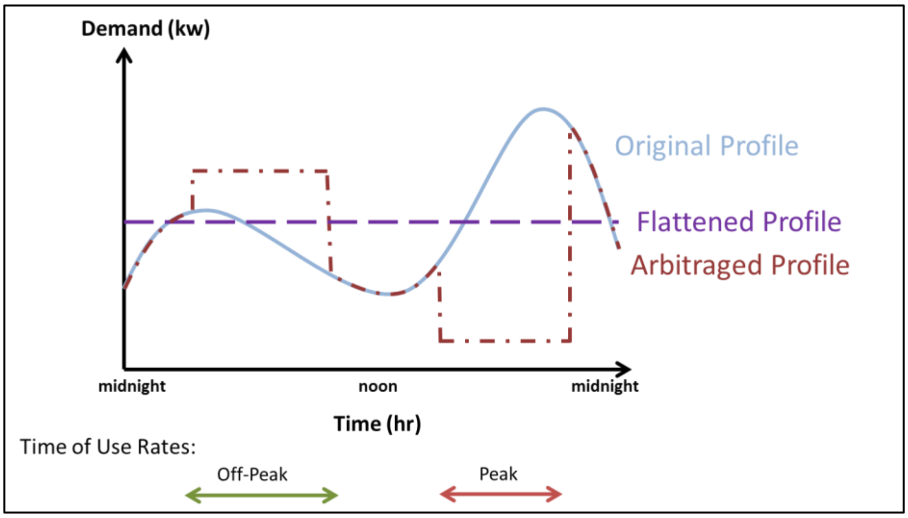
3.2. DES Operational Schemes

To elucidate the electricity bill savings opportunities from the use of DES, two operational schemes are investigated that seek to exploit different components of an electricity bill by changing the timing of electricity purchases relative to the original electricity demand profile (Figure 1).

The Flattened Profile uses the battery's capabilities to flatten the load profile to minimize demand changes. In this case, peak demand was reduced from a daily average of 2.5 kW to a constant 1.5 kW.

The Arbitraged Profile uses the battery's capabilities to reduce energy use during peak pricing periods and increase energy use during off-peak pricing periods to take advantage of time-differentiated pricing, subject to the physical battery constraints. The peak and off-peak periods used for this analysis were 3pm-8pm for peak and 1am-5am for off-peak. Electricity demand is unchanged during other periods.

Figure 1—Illustration of adjusted load profiles to reflect operational regimes for DES examined here.

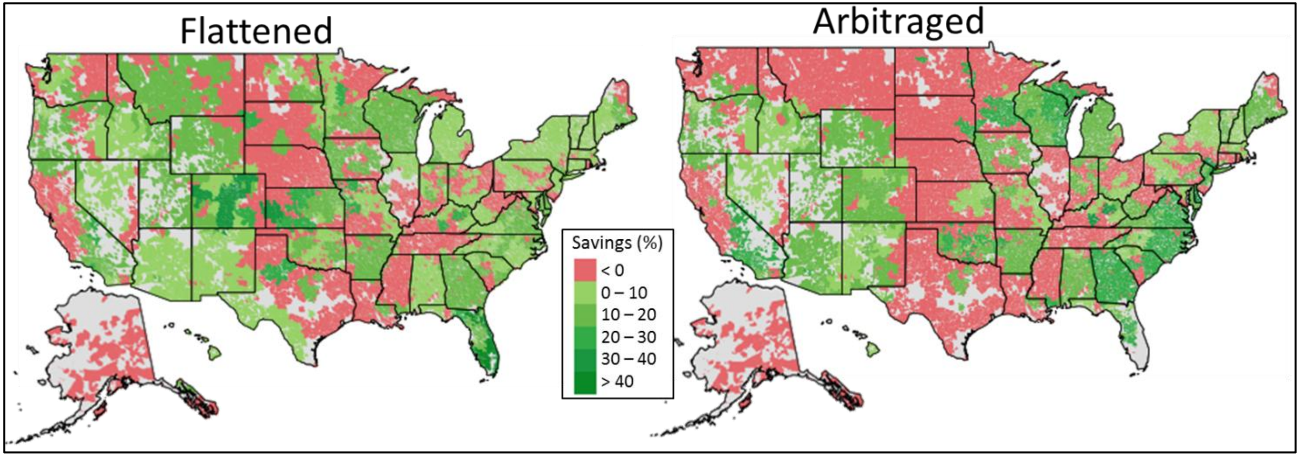


The original and adjusted load profiles were used to calculate the electricity bills that they would incur for each rate in the rate database. The electricity bills are calculated using the statistical analysis software R and are found by summing each bill component for each utility rate structure [9]. Electricity savings (or added costs) are calculated by taking the difference, per rate structure, between the original demand profile and the adjusted demand profiles. The results of the electricity bill calculations are merged with the cartographic service area data for mapping the results using QGIS [10].

4. Results and Discussion

Figure 2 shows the estimated electricity bill savings as a percent of the original electricity bill for customers in each zip code of the United States for which data exists. Each zip code may have several utility rates applicable to that area, so only the largest electricity bill savings per zip code are shown on the maps. This view provides an optimistic perspective into the national savings opportunities, though in reality customers will not necessarily subscribe to the electricity rate that that provides the greatest DES savings and the map does not reflect the number of customers in each area.

Figure 2 - Gross residential customer electricity bill savings for the flattened and arbitraged demand profiles.

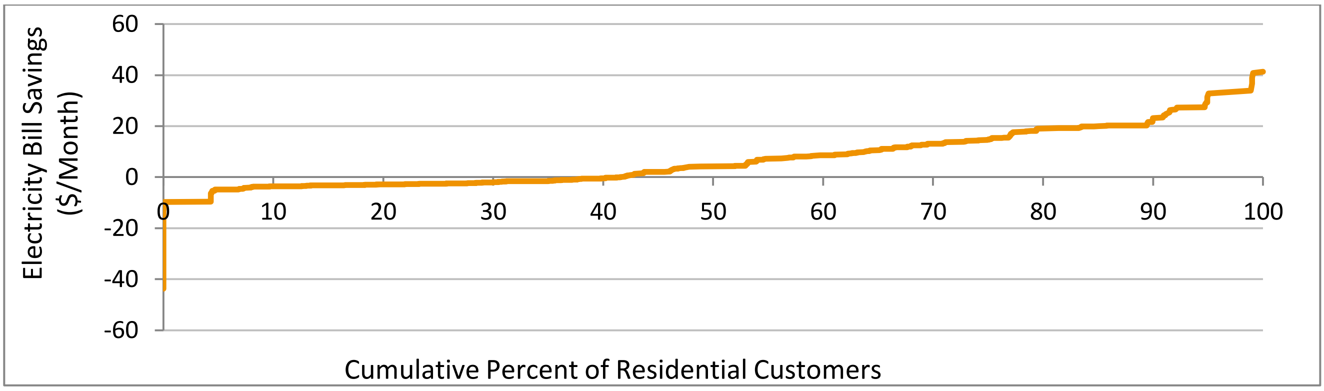


Electricity bills for residential customers with DES ranged from showing no savings to more than 40% decrease in electricity bills. The opportunities for customers to save on their electricity bills are geographically similar for the flattened and arbitraged demand profiles, but appear to lack geographic correlation with urban or rural areas. Some states appear to have homogenous electricity bill savings, perhaps reflecting state-wide utility service territories that offer the same rates across their state, or regulations requiring all utilities within a given state to offer particular rate structures.

Some adjacent areas where residential customers living in close proximity have widely differing electricity bill savings implications. This geographic heterogeneity and fragmentation of favourable electricity rates may add transaction costs in those regions and thereby inhibit growth of the residential DES industry. The impact of this heterogeneity on industry development may warrant further analysis by policymakers wishing to promote the use of DES.

Figure 3 shows the cumulative distribution of electricity bill savings, excluding the cost of DES, for the most favourable demand profile examined for each electricity rate. Given the assumptions and data availability for this analysis, 40% of utility customers are unable to decrease their electricity bills by purchasing and operating DES. However, this analysis suggests that over 80 million residential customers are able to lower their electricity bills through one of the two simple operational regimes examined. For a DES supplier, this is a very large market with utility rates that provide a return on investment in energy storage devices. However, the savings realized by customers are not yet commensurate with the costs of distributed energy storage devices.

Figure 3 - Cumulative customer distribution of gross electricity bill savings.

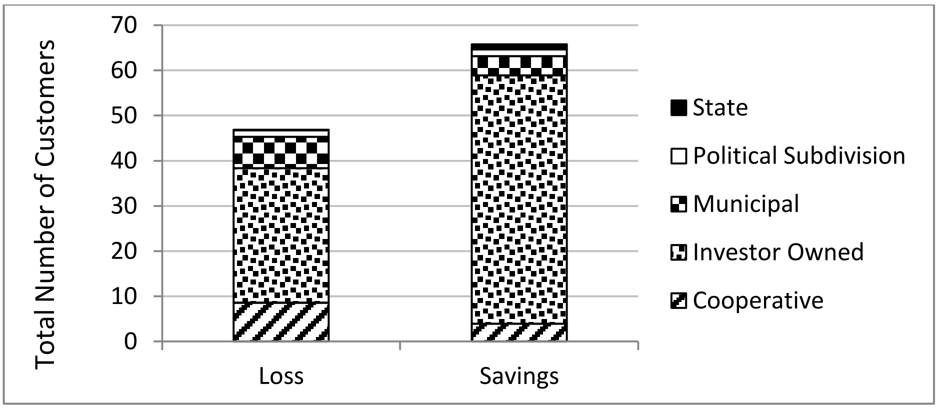


Of those customers that realize electricity bill savings, those savings fall far short of the cost of the battery system. Under the assumptions outlined above, the distributed energy storage device would cost an average of $46/month with no financing costs and $53/month with a modest 3% discount rate. Not a single residential electricity bill savings found here reach either of these values, suggesting that pure financial savings alone are not enough to incentivize customers to purchase DES. Of those customers that experience an electricity bill reduction, the median shortfall between the savings and the lower estimate of the cost of the battery is $33/month. The median customer would need to realize a savings three and half times the amounts found here for the purchase of the DES to be financially cost-effective.

Several studies attempting to find the net benefits of distributed energy storage generally find benefits to exceed the customer electricity bill savings found here and in some cases to exceed the costs of the battery system. Brattle finds net benefits to be $27.5/month,[1] Sandia finds the benefits of energy storage for deferring electric supply capacity alone is worth $30 to $60/month,[2] and EPRI for the California Public Utility Commission finds the net benefits of electric energy storage to be between roughly $30 and $120 per month [2, 11, 12].[3] Where the net benefits exceed the cost of the distributed energy storage system, installation of that system would be to the benefit of society. However, the shortfall between social value and private customer value suggests that traditional utility rate design does not adequately reflect the net benefits that a customer with DES provides the system, or that additional remuneration methods may be needed to bridge that shortfall.

The results of this analysis suggest that some utility ownership entities provide greater value to distributed energy storage systems than others. Figure 4 shows that customers served by investor owned and state owned utilities are more likely to reap private benefits from purchasing a distributed energy storage system, while customers served by cooperatives and municipal utilities are likely to fair worse. These results may suggest that investor-owned utilities have more sophisticated rate structures that could serve as a model for other utility owners.

Figure 4 – Number of customers served by utility ownership types that either experience a gross financial loss or savings on their electricity bill by using a distributed energy system.



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[1] Brattle's highest incremental net benefit was found to be $100/kW-yr. An instantaneous peak power of 3.3 kW is used to calculate the normalized net benefit.

[2] Benefit Type 2, Electric Supply Capacity, Table ES-1.

[3] For breakeven costs of $1000 to $4000/kW installed.

This analysis did not examine DES paired with distributed generation technologies like solar photovoltaic. Though some analyses suggest that solar paired with storage can offer customers savings over retail power purchases [13], more detailed analyses that consider retail rate design find that net energy metering policies effectively discourage customers from relying on DES [14].

The emphasis placed here on rate design should be complemented with further study of alternative means to compensate customers that invest in DES. In California, regulators and the power system operator are beginning to allow aggregators to bundle distributed resources in order to provide bulk system benefits [15]. These aggregators pay owners of DES in exchange for control of their systems, complementing the value customers receive from electricity bill savings. Storage mandates or portfolio standards that allow utilities to use behind-the-meter storage to meet their obligations are another way to provide financial incentives to DES owners. California has such policy and a proposed U.S. Senate bill would create a national standard [16, 17]. Locational rates that provide DES owners remuneration commensurate with their locational value of their investment could be effective at eliciting the most valuable installations of DES, though the equity and customer re-distributional impact of such rate schemes should be closely examined.

5. Conclusions

By modelling electricity bills with rate structures around the country, this analysis found that customer investment in DES can provide electricity bill savings for over 80 million residential customers. However, electricity bill savings opportunities are geographically heterogeneous and highly dependent on local rate structures, and the savings are significantly lower than the normalized cost of the DES. Furthermore, the electricity bill savings that customers realize are not commensurate with the net system benefits that DES provides. The shortfall between social value and private customer value suggests that traditional utility rate design does not adequately reflect the net benefits that a customer with DES provides the system, and additional remuneration methods may be needed to bridge that shortfall.

As costs for DES continue rapid declines, policy makers, regulators, and utilities must ensure that the societal benefits of residential customer investments are reflected in customer incentives for those investments. Analysis techniques such as the one presented in this paper, complemented by exploration of other means of compensating customers, can be used to examine the discrepancies between societal value and customer benefits of DES investment, identify rate structures that fairly compensate DES owners, and monitor national progress towards reformed electricity rates.

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