E-MOBILITY AND RATE DESIGN

LIFE IN THE FAST LANE

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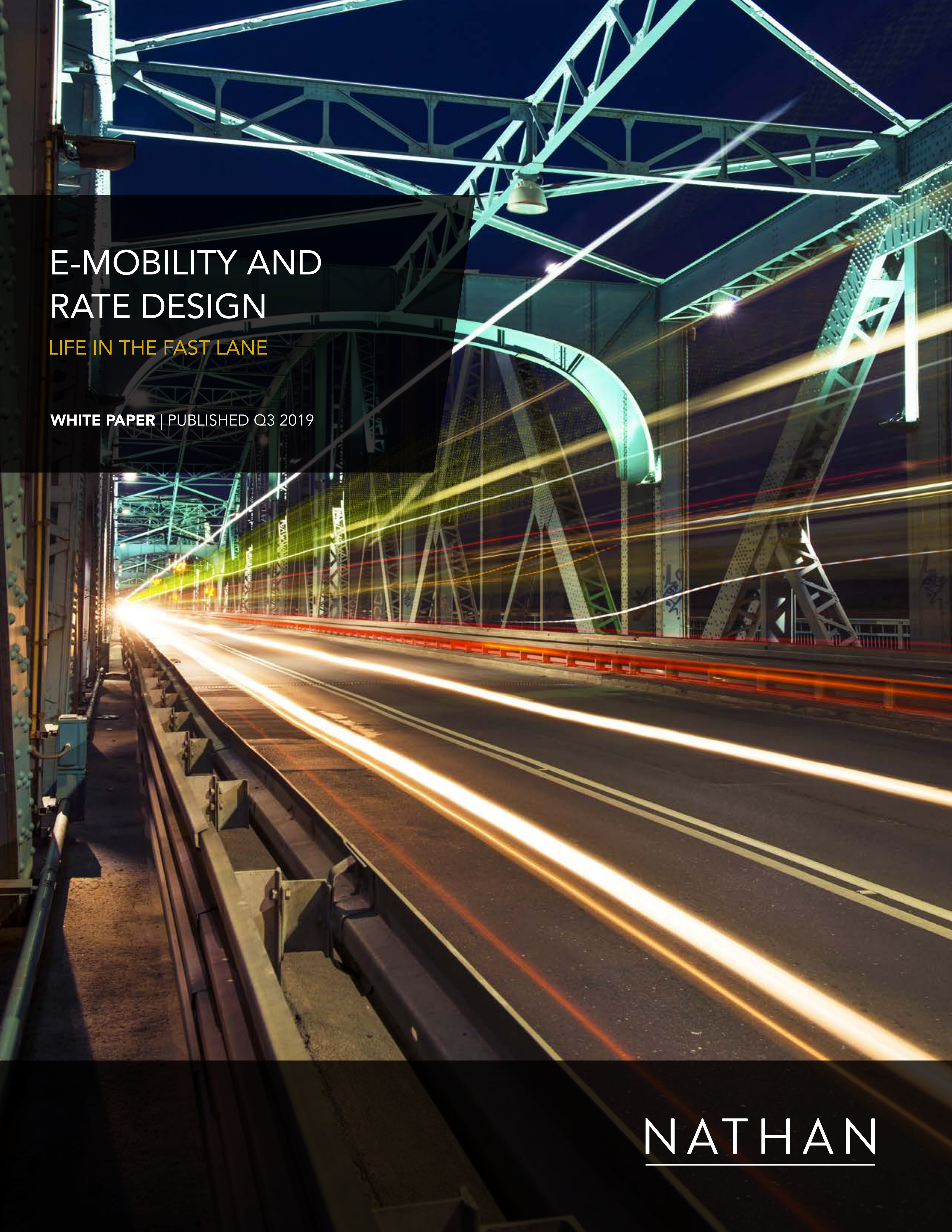

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ENERGY

E-MOBILITY AND RATE DESIGN: LIFE IN THE FAST LANE

E-MOBILITY

E-mobility, or transportation electrification, is an emerging global force. While electric passenger cars such as the Tesla Model S and the Chevrolet Bolt are the most well-known element of e-mobility, other important elements include a range of electric vehicles (EV's) such as motorcycles, buses and trucks, and even forklifts, ships and airplanes. The International Energy Agency (IEA) baseline forecast is for an increase from the current (2017) level of 3.1 million electric cars, trucks and buses worldwide to 125 million in 2030.[1] This forty-fold increase represents a compound average growth rate (CAGR) of more than 30%.

The transport sector accounts for roughly one-quarter of global greenhouse gas (GHG) emissions, and both the absolute and relative amount of transport emissions are projected to increase significantly over the next two decades.[2] Even at the substantial growth rate noted above, EV's will have only a relatively-modest 10% market share in 2030. To make a serious dent in transport GHG emissions and help address the overall climate issue, it will take more—a true e-mobility transformation.

1 International Energy Agency, *Global EV Outlook 2018: Towards Cross-Modal Electrification*, 2018.
2 Sims R. et. al., *2014: Transport. In: Climate Change; 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 2015.

As the World Bank says:

> eMobility is, at its core, a disruptive transition. That is a good thing. Transport's share of global emissions continues to rise and "business as usual" will not achieve the results needed…There is…no credible scenario…limiting the effects of climate change…unless the transport sector can correct course.[3]

There are many economic, political, social and technological factors that can influence the EV market. Some are very much within society's control, and some less so. Electric utility rate design is one factor that is both important and controllable. Done well, it can be a significant enabler. Done poorly, a significant barrier. This paper addresses how rate design can help e-mobility move into and stay in the fast lane.

RATE DESIGN

In his seminal work, *Principles of Public Utility Rates*, Jon Bonbright notes that utility rates should be designed with "the public interest" in mind. Importantly, he also notes that the public interest refers both to "economic" and "non-economic" or social considerations. [4]

On the economic side, Bonbright emphasizes that the paramount principle behind electric utility rate design is that rates should be reflective of costs: "one standard of reasonable rates can fairly be said to outrank all others in the importance attached to it by experts and by public opinion alike—the standard of cost of service."[5] In aggregate, rates must cover costs plus adequate return. Otherwise, capital will not be attracted to the industry and the utility business will not be sustainable. At a more granular level, rates for specific services or customers (or at least classes of services or customers) should be tied to specific costs for both efficiency and equity. For efficiency, rates for individual services should reflect costs. Otherwise, resources will be misallocated. For equity, rates for individual customers should minimize (unintentional) cross-subsidies. Otherwise, customers will be treated unfairly.

On the social side, Bonbright emphasizes the importance of rate design for "discouraging wasteful use of service while promoting all justified types and amounts of use."[6] In this view, rates can and should be designed to achieve social benefits such as overcoming market failure, internalizing externalities and improving social equity.

3 The World Bank, *Electric Mobility and Development*, December 2018.
4 James C. Bonbright, Principles of Public Utility Rates, Columbia University Press, 1961, pp. 26-41.
5 Ibid, p. 67.
6 Ibid, p. 291.

E-MOBILITY AND RATE DESIGN

E-mobility is one of many electricity uses that are subject to utility rates. However, it is quite unlike most other uses of electricity.

- Most obviously, e-mobility loads are inherently mobile and can potentially occur at many widely-separated locations. For example, in the Mid-Atlantic area, a typical EV might draw power on a day trip from one of perhaps half-a-dozen separate utilities. This is quite unlike most electricity loads such as home appliances, office lighting or assembly lines.
- Many e-mobility loads are battery based and can be mobile in time as well as space. They can typically be shifted by hours or even days. Although there are other electricity loads with this quality such as dishwashing or clothes drying, it is not the norm.
- E-mobility loads tend to be large and intermittent, with no demand much of the time and high demand for short intervals. Again, this is not unique but also not the norm.
- E-mobility loads often substitute directly for petroleum use, and provide both local and global environmental benefits. For example, an EV powered by gas-fired electricity generates only half the GHG emissions of a gasoline-fueled vehicle.[7] With renewable electricity, it does even better. This environmental benefit is not the norm for most electric loads.

Largely because of these special qualities, electric utility rates that were designed for, and that are adequate for other loads are fundamentally ill-suited to e-mobility. In this way, e-mobility is akin to a "stress test" for traditional rate designs. Unfortunately, traditional rate designs appear to be failing this test. Equally troubling, not only are traditional rates a problem, but incremental efforts to reform or improve these rates are also coming up short. A couple of examples may help elucidate the problems with both traditional and emerging rate designs.

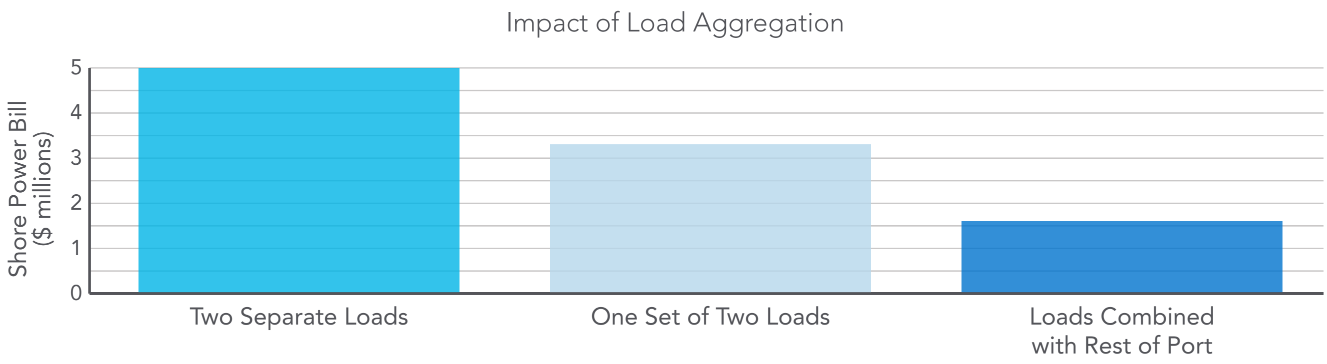
7 Rachael Nealer et. al., *Cleaner Cars from Cradle to Grave*, Union of Concerned Scientists, November 2015.

COMMERCIAL/INDUSTRIAL

Consider a real but disguised example of a seaport that wants to install two facilities for providing shore power to visiting cruise ships so they do not need to run their on-board diesel generators while in dock. This is a form of ocean-based e-mobility. Like many e-mobility loads, shore power has an extremely low load factor. Due to the nature of the cruise business, a typical installation might have a 10MW peak load and a load factor of a remarkable 2 or 3%, meaning the average load over a year is only around 30kW.

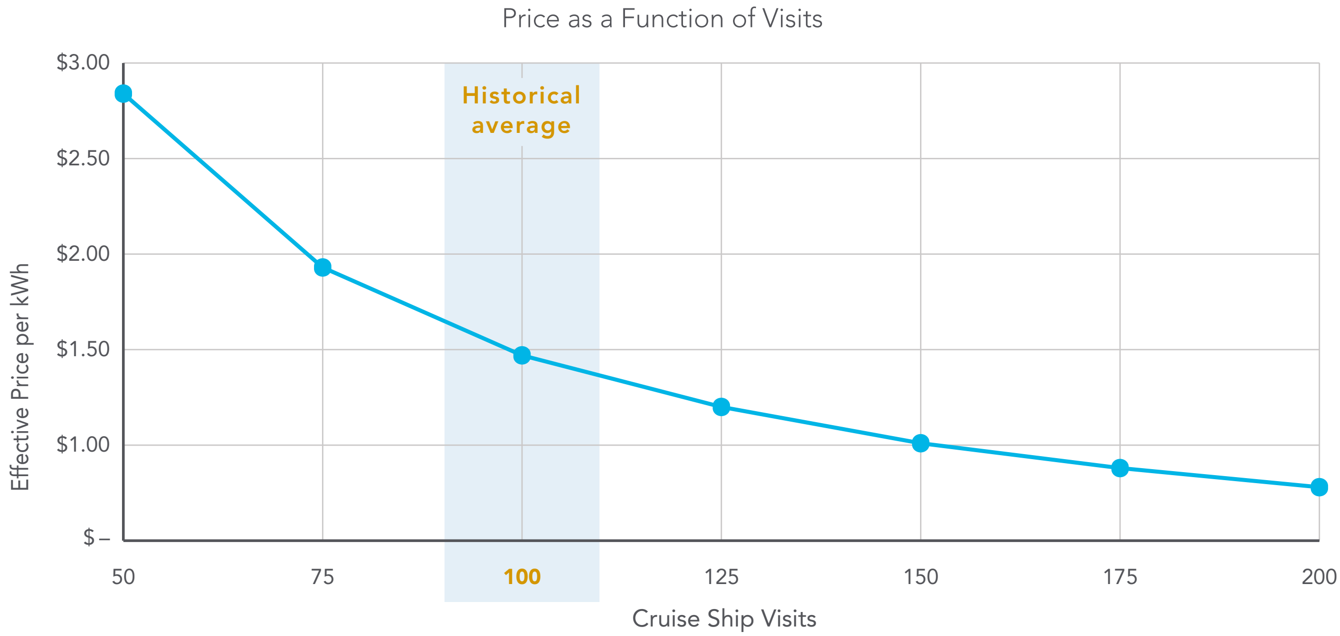
Traditional commercial/industrial rates have sizable fixed and demand charges, along with an energy charge. Depending on the circumstances, these rates can be applied at different levels of load aggregation. Using real but disguised data, the figure below compares the total electricity bill for shore power for different levels of aggregation.

If each shore power load is metered and charged separately—which would not be unusual—the annual shore power electricity bill is $5 million. If the two shore power loads are metered and charged together—again which would not be unusual—the annual shore power bill is less than $3.5 million, or one-third less. Lastly, if the two shore power loads are combined with the loads of the rest of the port in the same location—once again which would not be unusual—the shore power bill is reduced to a little over $1.5 million or more than two-thirds less than in the original case.



What does this example tell us about the ability of traditional rate design to reflect e-mobility costs? Simply that the traditional rate structure does a poor job of reflecting costs. Clearly, the costs imposed by shore power on the utility system at a single geographic location are effectively independent of how it is metered and billed. Nevertheless, the bill can differ by a factor of more than three with a modest administrative tweak. The cost to the utility cannot at the same time be $5 million and $1.5 million. Rate designs that might (or to be truthful might not) be reflective of costs for other loads are definitely not reflective of e-mobility costs.

At the same time, there is an important social benefit associated with shore power—reducing the use of diesel fuel while in port. This has both local and global environmental benefits. How does traditional rate design perform in helping achieve this goal? The figure below shows the effective price per kWh with the traditional rate design as a function of the number of cruise ship visits, assuming that there is only one shore power facility. In this example, the recent historical average is 100 visits.



As the figure shows, because of the fixed and demand charges, the effective price per kWh is very high—nearly $1.50/kWh at the historical average level of visits. At this price, electricity represents a substantial fraction—perhaps 30%—of the cost to a cruise line of visiting the port. The figure also shows that the effective price, again because of the fixed and demand charges, is very sensitive to the number of visits. If the number of visits falls say to 50% of its historical average due to a change in cruising habits, the effective price per kWh jumps to nearly $3.00/kWh and electricity represents more than half of the cost to a cruise line of visiting the port. In a competitive business such as leisure cruises, this provides a very strong incentive not to visit the port and—if at all possible—not to use shore power. This is in direct opposition to the social goal of reducing diesel use. Rate designs that might achieve other social goals do a poor job of encouraging the important environmental benefits of shore power.

Because of its extremely low load factor, shore power is a dramatic example of an e-mobility load that challenges traditional rate design. But the same issues can arise with the better-known example of EV charging. Commercial EV charging also has a low load factor that makes the application of traditional rate design very difficult. This difficulty is widely discussed, although few definitive solutions have emerged to date. Echoing our shore power example, there are even studies about the pros and cons of aggregating EV charging loads with existing building loads.[8] Of course, aggregation does nothing really to change underlying costs. The interest in aggregation as a solution for EV charging is simply an artifact of inadequate rate design. And of course, like shore power, EV's also provide environmental benefits that are not fully reflected in typical EV charging rates.

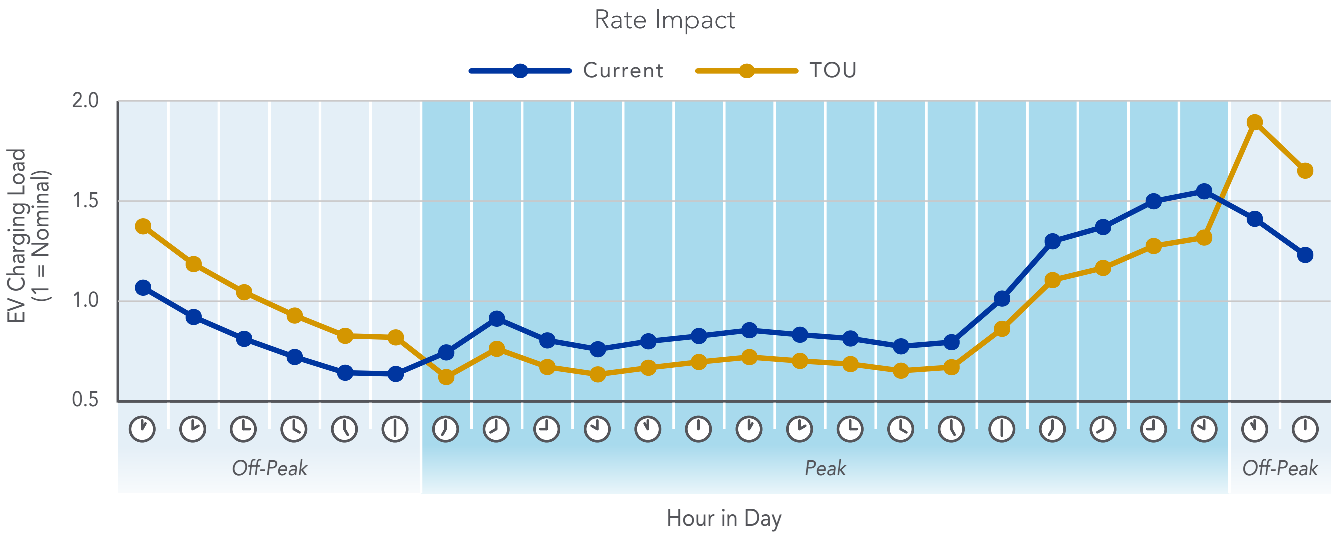
8 Robert Flores et. al., *Electricity Costs for a Level 3 Electric Vehicle Fueling Station Integrated with a Building*, Applied Energy, Vol. 191, 2017, pp. 367–384

RESIDENTIAL

The example above shows how traditional commercial/industrial rate structures with fixed and demand charges struggle with e-mobility. An example from the residential sector can help illustrate that efforts to tweak traditional rate structures also fall short.

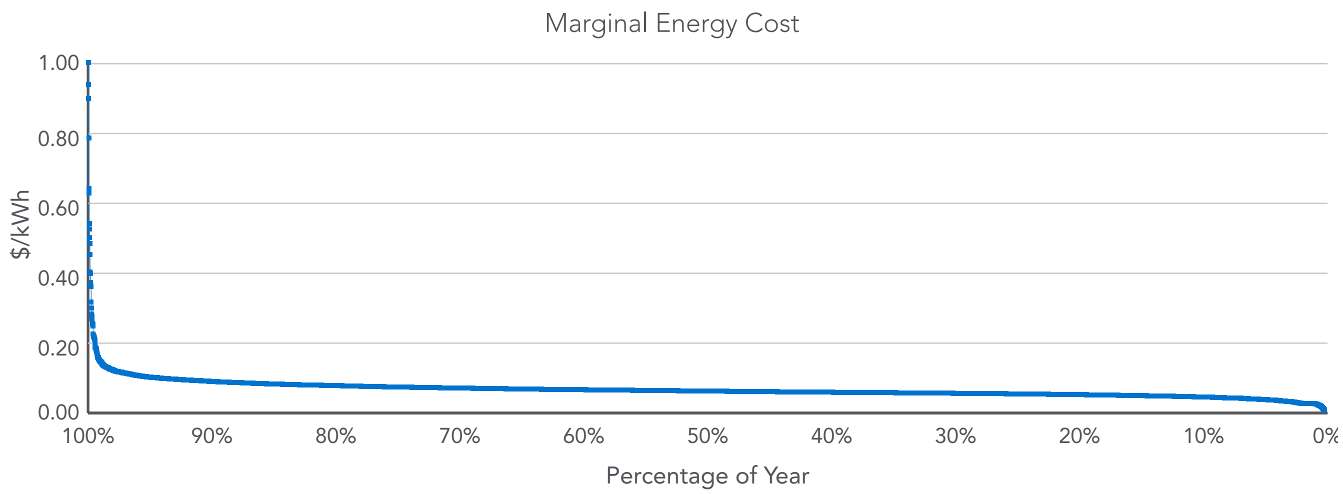
Many utilities have tiered residential rates with a fixed or customer service charge and an energy charge that increases with consumption. Although fixed costs are typically 50% of total costs, utilities typically collect only 10%-25% of residential revenue through the service charge or demand charges. Consider a real but disguised example of a utility developing a time-of-use (TOU) rate within this context for customers with EV's.

Under its normal residential rates, a typical EV customer has a bill of around $1500 with about $600 for EV charging. The utility's goal with a TOU rate is to encourage EV owners to charge their vehicles during off-peak periods when costs are low as well as provide an added incentive for customers without EV's to purchase them, all while maintaining the current service charge and net revenue. The figure below shows the projected change in EV charging behavior with the new TOU rate: $0.15/kWh off peak and $0.40/kWh on peak.



As the figure indicates, the new rate is projected to encourage a shift of only a modest fraction (less than 20%) of the EV charging load into the off peak period. The best the utility can do with a two-part TOU rate under these conditions is to provide EV buyers with a savings of $50/year. This is a very small fraction of their total utility bill and their annual EV operating cost.

What does this example tell us about the ability of this emerging rate design to achieve important social goals? Simply that this modest adjustment of the traditional tiered rate structure makes it difficult to provide a significant incentive for change. The modest savings encourage only a modest change in charging behavior, and an even more modest change in purchasing decisions.



A big part of the reason for the relatively small change in behavior is that the rate structure does a poor job of reflecting real costs. Using real but disguised data, the figure above shows the variation in marginal energy costs to the utility over the 8760 hours in a year.

As the figure shows, energy costs are typically quite low. For example, they are below $0.10/kWh more than 80% of the time and below $0.08/kWh about 30% of the time. They are above $0.40/kWh, the peak charge, well under 1% of the time and are above $0.15/kWh, the off-peak charge, well under 10% of the time. With the new rate, it still costs an average of $600 to charge an EV. However, if EV charging were conducted during the 30% of the hours with lowest cost, the actual cost to the utility would be well under $200.

What does this tell us about the ability of this emerging rate design to reflect costs associated with e-mobility? Simply that a modest adjustment of the traditional tiered rate structure does a poor job. The service charge associated with this rate doesn't cover fixed costs, so energy charges cannot be low enough to reflect the very modest real costs of shiftable loads like EV's. The gap is even bigger if the environmental benefits of EV's are included in costs. Rate designs, even emerging ones, that might do a good job of reflecting costs in other contexts struggle with e-mobility.

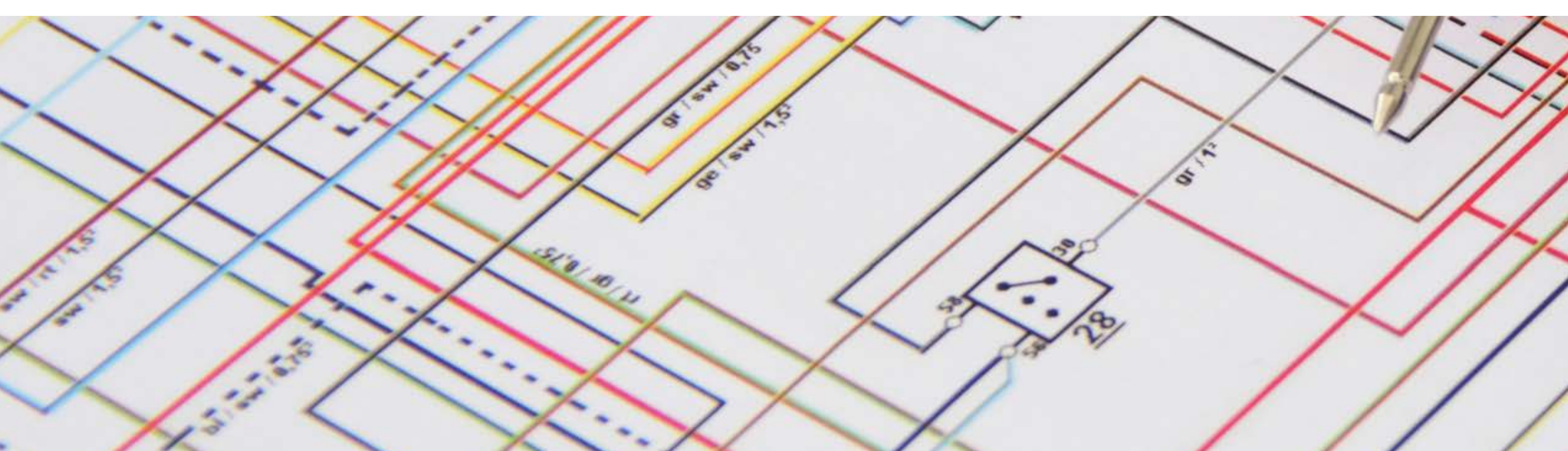
IMPLICATIONS

E-mobility is currently only a small part of the overall electricity picture. As a result, the rate design shortcomings noted above regarding economic costs and social benefits are not particularly consequential. Going forward, however, these shortcomings could stand squarely in the way of an e-mobility transformation. Now is the time to address this issue.

We suggest three principles for rate design that apply to e-mobility specifically and to electric power generally.

- **Rates should better reflect the location of load.** Rates should not simply reflect system-wide average costs since such averages only weakly represent actual locational costs. Nor should rates reflect the arbitrary aggregation or disaggregation of loads, meters, accounts or end-uses at a similar location. Costs and benefits vary by location but do not vary (much) by administrative aggregation. As the commercial/industrial example made clear, rates that vary this way are a recipe for inefficiency and ineffectiveness. Instead, utilities should treat costs at a suitably-detailed locational level. ISO's, RTO's and large utilities and are already moving towards locational pricing, but this is just the first step. Distribution locational marginal pricing (DLMP) is where the smart grid is taking us. Rates can be and should be designed and offered to better reflect locational costs and benefits, particularly for e-mobility loads.
- **Rates must better reflect the timing of load.** Costs and benefits vary substantially by hour, day and season. As the residential example made clear, rates that do not adequately reflect this time variation fall short when it comes to e-mobility. Roughly half of all U.S. customers already have smart meters that allow for time-differentiated rates.[9] Although smart meter adoption has slowed, the ongoing digital revolution ensures that utilities will have an increasing ability to vary charges by time period. Rate design needs to keep up with this ability. As with locational flexibility, rates can and should be offered to better reflect timing costs and benefits, particularly for e-mobility loads.

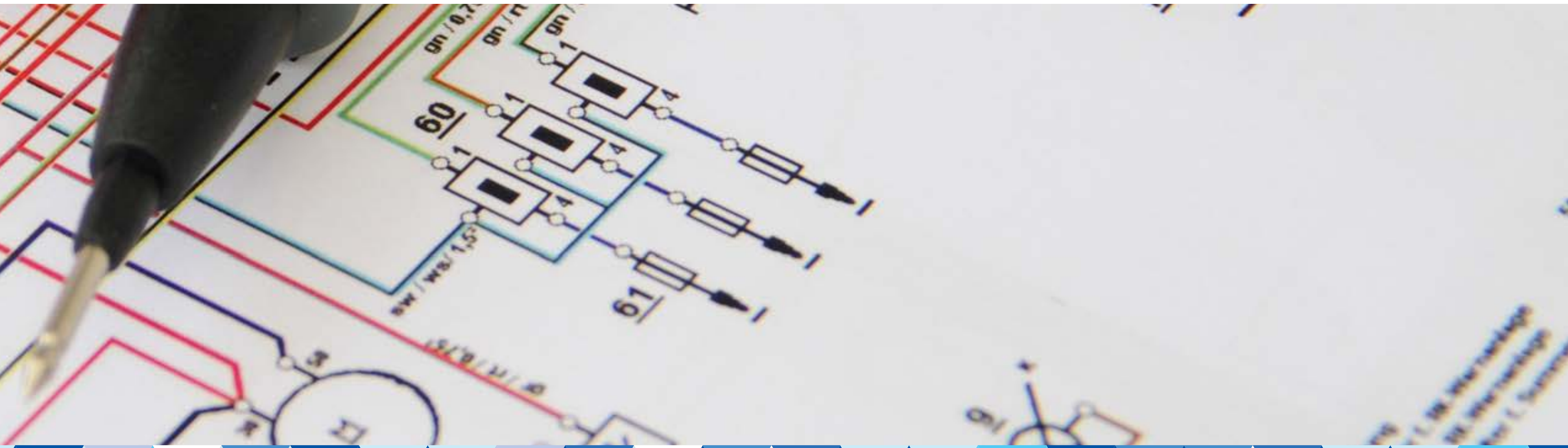
9 U.S. Energy Information Administration, *Nearly half of all electricity customers have smart meters*, December 6, 2017, https://www.eia.gov/todayinenergy/detail.php?id=34012.



- **Utilities and regulators should allow more rate customization.** Widespread significant change in rate design is difficult, yet e-mobility makes the need for change very evident. One way to address this difficulty is through greater customization; that is, to offer new and better rates as an option to specific customers over specific periods. There is now remarkable diversity in power market participants, and power market conditions are in considerable flux. With customization, rates can reflect circumstances that differ from place to place and from customer to customer, as well as conditions that change over time. E-mobility may be the most advantageous area to introduce such advanced rates. E-mobility customers are typically innovators willing to experiment, and the special benefits of e-mobility are widely accepted.

What would a rate design look like based on these principles? One good candidate is a rate that combines a location-based subscription charge with a location and time dependent energy/congestion charge along the lines of DLMP. Such rate designs have been proposed both for EV's specifically and customers generally.[10,11] In the near term, these rates could be offered to e-mobility customers to address the problems noted above. Ultimately, all customers might be afforded them. The effort required to develop and implement these rates is considerable, but the potential economic and social rewards are substantial. It's time metaphorically to "start your engines" on serious e-mobility rate design.

10 See for example: M. C. Caramanis. *It is time for power market reform to allow for retail customer participation and distribution network marginal pricing*, IEEE Transactions on Smart Grid, March, 2012.
11 Ruoyang Li; Qiuwei Wu; Shmuel S. Oren, *Distribution Locational Marginal Pricing for Optimal Electric Vehicle Charging Management*, IEEE Transactions on Power Systems, Volume: 29, Issue: 1, January 2014.




Electric Bus

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