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Assessing demand side management opportunities through dynamic EV charging pricing strategy

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Summary

As electricity transitions to becoming a more widespread transport fuel we must understand the implications of pricing on industry stakeholders and consumers. Static pricing of electricity is not clearly cost reflective, reducing consumers ability to make informed purchase decisions. This paper suggests we should further research the viability of Real-Time Pricing for electric vehicle charging. Real-time electric vehicle charging could enable true cost reflection of prices, providing market signals to reduce demand or increase demand dependent on actual grid conditions.

Keywords: Demand, Dynamic Charging, EVSE (Electric Vehicle Supply Equipment), Incentive, Strategy

1 Introduction

Electric vehicle adoption is beginning to rapidly scale. In late 2018, the global electric vehicle fleet hit 4 million vehicles and in 2019 another 2.6 million are expected to be sold [1]. Automakers, governments, and consumers are all converging on an electric vehicle future. This shift to electric vehicles represents a fundamental shift in the source of transport fuel, which in the future will require migration into the Electricity Utility sector.

Work has already begun in understanding the impacts of energy demands from electric vehicle charging onto the electricity grid. However, the wider impacts across industries, stakeholders, and consumers aren't clear. How we price electric vehicle charging to deliver optimal results across stakeholder groups has yet to be established. The way electricity is priced for electric vehicle charging will be fundamentally different from how oil-based fuels are priced to drivers today. Electricity demand has greater real-time system implications that could impact pricing. We must begin research on appropriate pricing mechanisms that ensure the system implications and externalities caused by electric vehicle charging are addressed, whilst not limiting the range of pricing models available to consumers.

Can we create mutual benefits across the stakeholder landscape by rethinking how we price electric vehicle charging?

2 The EV charging value chain covers a range of stakeholder requirements

There is a range of ways that consumers, in the public and commercial sector charge their electric vehicles. This range breaks down into private charging, public charging, and in the future charging from another vehicle. The way that the energy reaches the consumer can vary, however, the parties involved are largely the same. Figure 1. Illustrates the models in the e-mobility value chain and the variations for how drivers can charge their vehicle. Complexity emerges when we assess the needs, wants, and ambitions of stakeholders in each charging model type, as shown in Table 1.

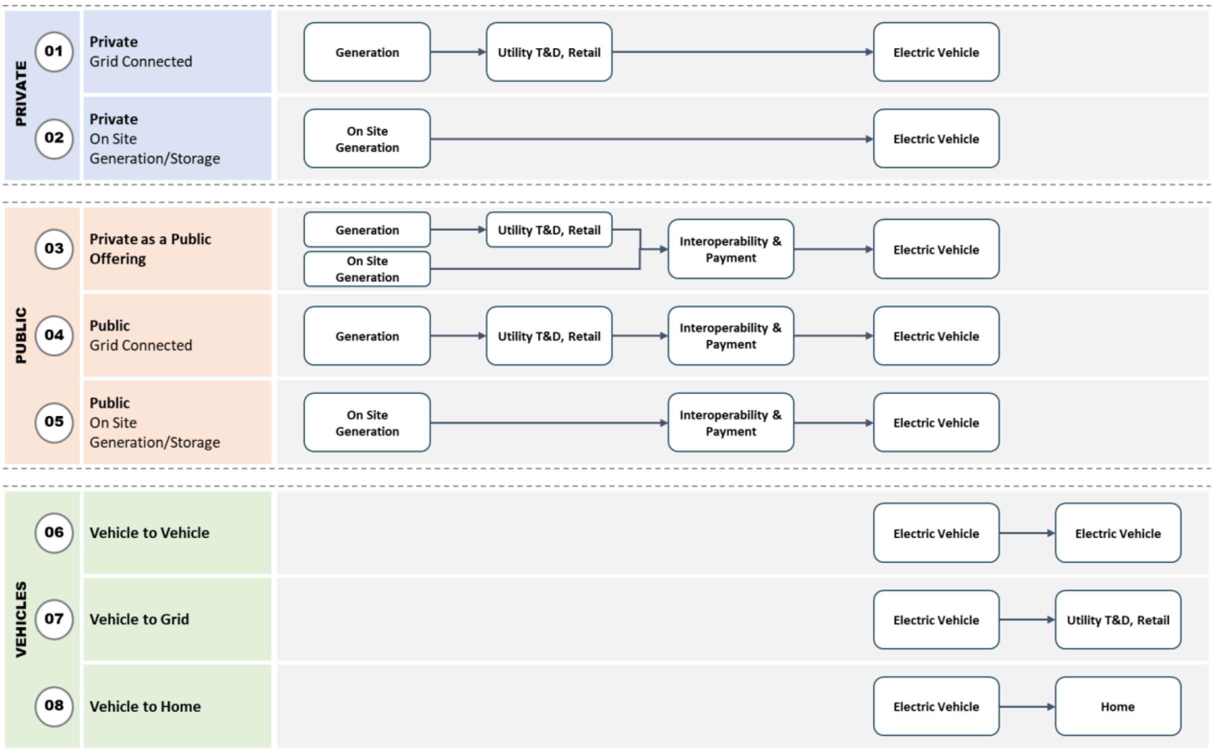

Figure 1 The electric vehicle value chain across charging types

Each of the stakeholders in the value chain has various requirements which can vary depending on the charging model. At a high level, the main parties involved in a charging transaction can be consumers who are charging their electric vehicle, utilities who can be generators or manage the distribution network, and asset owners who own charging equipment or other related assets such battery storage. Interoperability and payment services are often present in public transactions, where identification of the consumer is required for payment processing or billing.

Table 1: The range of stakeholder preferences and requirements across the value chain

		Consumer Preferences	Utility Preferences	Charge Point or Asset Owner Preferences
Private	01 Private Grid Connected	• Determine real-time demand levels and the cost to charge their electric vehicle	• Mitigate localised feeder level stress • Manage charging scheduling and speed • Incentivise off-peak demand	
	02 Private on Site Generation/Storage			• Determine optimal use of generation/ storage e.g. charge vehicle or use for other purposes
Public	03 Private as a Public Offering	• Determine real-time demand levels and potential returns for making a private charger available publicly		• Understand the competitive landscape and supply side charging availability
	04 Public Grid Connected	• Accessible and readily available public charging infrastructure • Availability and clear pricing information	• Mitigate peak demand events • Deploy demand response mechanisms as required	• Maximise charger utilisation in low demand • Maximise revenue in high demand • Minimize cost base
	05 Public on Site Generation/Storage			• Determine optimal use of generation/ storage e.g. charge vehicle or use for other purposes
Vehicles	06 Vehicle to Vehicle	• Determine real-time demand levels and potential returns for making a vehicle directly available to other vehicles		• Understand the competitive landscape and supply side charging availability
	07 Vehicle to Grid	• Determine real-time demand levels and returns for making a vehicle available in the supply market	• Mitigate and minimize peak demand. • Increase supply of distributable energy at call	• Understand the competitive landscape and supply side charging availability
	08 Vehicle to Home	• Determine real-time demand levels and arbitrage opportunities for using vehicle as a home energy source		• Determine real-time demand levels and arbitrage opportunities by charging stationary storage from the vehicle

2.1 Common stakeholder requirements

Although the interests, needs and wants are not linear across the various types of charging models, there are overarching requirements from key stakeholders;

Overarching Stakeholder Requirements	
Utilities	• Utilities must protect the grid by managing demand whilst endeavouring to maintain and protect the equipment distributed across the network.
Charge Point Operators	• Charge point operators are looking to maximise returns, this requires them to both manage costs and try to drive increased revenues by matching supply with demand.
Consumers	• Consumers require charging availability, and easy to understand pricing information to make purchase decisions. These decisions could be made by software acting on behalf of the consumer who has set specific preferences.
Distributed Energy Resource Owners	• Owners of distributed generation or storage want to maximise the value of their asset through time-shifting energy, therefore enabling arbitrage of low-cost supply with high yield demand.

3 Currently, consumer pricing models for EV charging aren't optimal

3.1 Rate structures for the underlying electricity cost are not designed for e-mobility

Public and private electric vehicle charging typically uses the same tariffs available to the building or premises. In some jurisdictions, Utilities are designing new tariffs that specifically are designed to support charging operators. Two examples of these EV specific tariffs are Time of Use Tariffs and Demand Charge Holidays.

Time of Use tariffs are normally a variation of on-peak or off-peak charges, where costs are lower in off-peak periods. These tariffs indicate to consumers the lower price periods per day, however, they are not truly cost reflective. As discussed by Anderson (2014) [2], these time of use rates are useful to mitigate the worst-case impacts of overall increases in system peak demand, but they are inadequate to describe pricing for the marginal value of electricity. This means that while consumers can pay less in off-peak times the true cost impact from consumption is not visible. If pricing was more granular customers could benefit by switching consumption to cheaper periods, and grid operators could benefit from reduced grid stress in extreme peaks.

Demand Charges are a capacity charge to electricity users. Normally a part of commercial tariffs these charges are intended to reduce a user's peak demand. Demand charge holidays eliminate these payments while electric vehicle adoption is still growing [3]. While demand charge holidays will reduce consumer cost in the near term, the suitability of demand charges for electric vehicle charging is questionable. For commercial electric vehicle charging these costs are incorporated and passed on to consumers in the rates set by the charge point operator. As the driver who is charging their vehicle may not be contributing to a period where the charging site reaches a new peak demand, there is a cross subsidisation impact. Drivers charging when the site is not busy are subsidising drivers who contributed to a new peak in busy periods. As there is no visibility of the impact to site peak load, the customer has no ability to influence the overall cost component from demand charges and must pay a distributed rate spread across all users.

3.2 The pricing mechanism for customer charging sessions is not flexible enough

Customers at commercial charging sites normally pay one of three types of pricing mechanisms, cost per session, per minute pricing, or kilowatt-hour pricing.

Cost per session pricing is the least flexible where the customer pays a flat rate per charging event irrelevant of the time the charger was occupied, or the amount of power consumed. This pricing mechanism is highly variable for charging operators. It is unlikely that this pricing mechanism will be used long term due to customers with larger battery sizes effectively paying much lower rates.

Per minute pricing similarly is a pricing mechanism that is not flexible, reducing transparency, and predictability of the actual cost to the operator due to the variables from the vehicle side. Drivers with a car that can charge at higher power pay less for the electricity consumed than cars that have constrained charging capabilities. Similarly, the battery state of charge will determine how much power the battery can draw from the charger, resulting in a wide range of cost per unit of electricity. Per minute pricing is a mechanism to rent the use of equipment from the operator, where the underlying cost of electricity is not transparent.

Kilowatt-hour pricing is the most transparent pricing mechanism, and the most likely mechanism to become the norm. Regulators, such as weights and measures boards are already beginning to set kilowatt-hour pricing as the required pricing mechanism due to its standardisation and transparency of cost to consumers and vendors [4].

Common across the typical pricing mechanisms is linearity. Costs to the consumer are set at a flat rate, potentially with some variation for time of use during peak periods. This is sub-optimal for both consumers, and charge point operators for two reasons. Firstly, as Faruqui and Aydin (2017) [5] point out "Customers cannot react to the high production and investment costs of electricity during peak demand periods if they are shielded from observing these costs at the point of consumption". Meaning, consumers have less ability to reduce their cost of charging by consuming in lower cost times of the day. Secondly, charge point operators have less ability to extract higher value from their assets when charging demand is high or place an equivalent surge price on their equipment when charging demand rises.

3.3 Both the underlying cost drivers and pricing mechanisms are not currently optimal and do not meet the requirements of EV charging stakeholders

As discussed, the needs and wants across stakeholders are varied, however, the current pricing approach for electric vehicle charging is sub-optimal in four main ways;

The pricing approach for electric vehicle charging is sub-optimal	
Costs are not reflective	• The underlying energy costs and peak demand externalities are spread across users and are not tied to the actual costs at any one time.
Low transparency of end customer costs	• Commercial charging operators should maximise their revenues through price changes. Without clear underlying energy cost visibility operator margins are invisible to the end consumer inhibiting clear purchase decisions.
No granularity of price signals	• Pricing mechanisms don't constrain demand or signal new supply to meet market requirements which could be supplied via Vehicle to Grid, or other forms of storage.
Cross subsidisation of consumer prices	• Demand charges are a blunt instrument not well suited for EV charging as they create cross subsidisation effect where actual demand impacts are spread and applied to customer rates as a fixed cost.

4 Rethinking EV charging pricing to be more transparent

Developing a more efficient pricing mechanism requires we think through how to balance the requirements and needs of the stakeholders in the electric vehicle charging value chain.

4.1 Surge pricing for electric vehicle charging could provide some overall benefit

The first option to improve price signals for electric vehicle charging would be to use a dynamic surge price. An example of surge pricing is the ride sharing industry. Uber uses surge pricing when demand increases to attract new supply to the market.

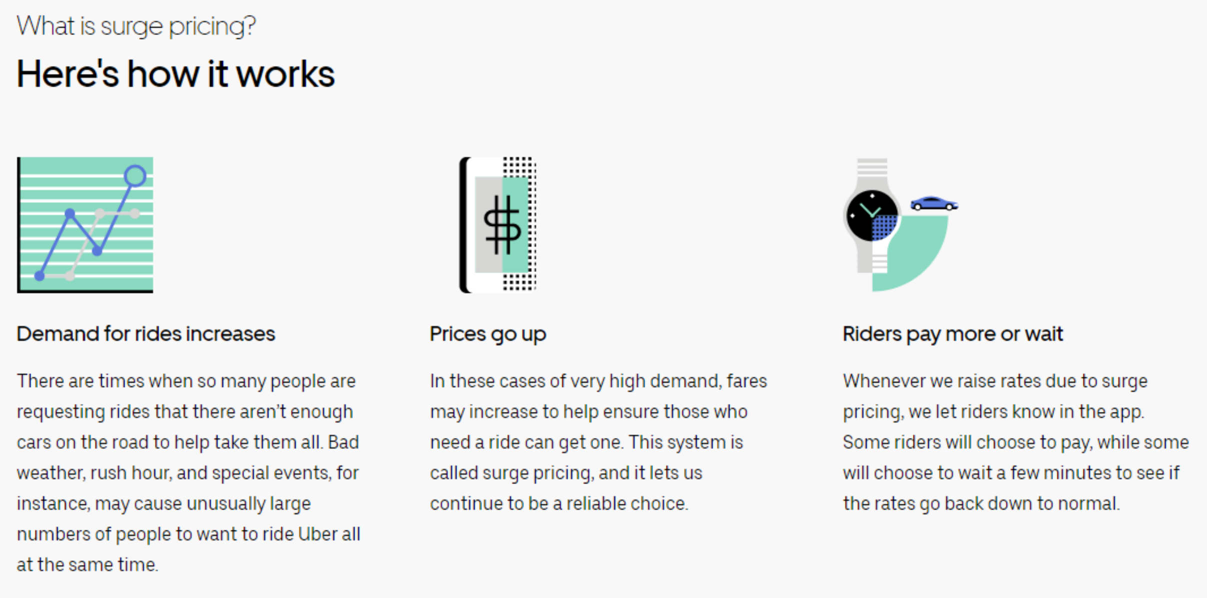

Figure 2 Surge Pricing Overview – Uber [6]

Using a variant of surge pricing for electric vehicle charging could help address the varying stakeholder challenges. For private charging, the Utility could send clear signals to the market through a surge price to alleviate negative externalities from charging demand. At the local level, the negative externality is typically localised grid stress, where local capacity or equipment such as local feeder transformers risk shorter lifetimes due to repeated stress.

A surge price to alleviate stress could reduce the load, causing charging sessions to be delayed or postponed to cheaper periods. This surge price would reduce the need for Utility control of the actual charging equipment. As opposed to using managed charging, the end consumer could set bid limits based on price preferences in accordance with their minimum state of charge requirements at a set departure period.

In the public space, commercial fast charging equipment could also utilise surge pricing. The utility could signal system load restraints or establish a surge price based on high demand on the overall grid. Surge pricing is normally seen as a mechanism to raise prices in periods of high demand. However, real demand and supply could provide a use case for reverse-surge pricing, effectively "happy-hour" pricing when low overall demand could be bolstered by reducing prices [7]. This could have a net benefit for all electricity users as "happy hour" pricing could reduce curtailed renewable supply or fill the valleys of overall generation supply increasing generation asset utilisation.

While these approaches could increase overall utilisation and reduce negative impacts at both extremes of high and low demand, their use would be sporadic, the underlying technology to enable surge pricing could be better utilised by having prices linked to the real cost of electricity all the time.

4.2 Real-time pricing could be the best fit for pricing electric vehicle charging

Real-time pricing would set a true cost reflective price for the cost of charging a vehicle at any one time. By providing a transparent cost of charging, consumers are given the control to make accurate purchase decisions.

In a real-time pricing market, overall supply availability and externalities across the value chain could be considered. The available prices could vary from system wide impacts, or from localised impacts down to the street or distribution feeder level. This real-time pricing model could be extended to a two-sided buy and sell market when V2G (Vehicle to Grid) services are more common. A buy and sell price would provide clear market pricing for vehicle owners to decide when to provide their stored energy to the grid.

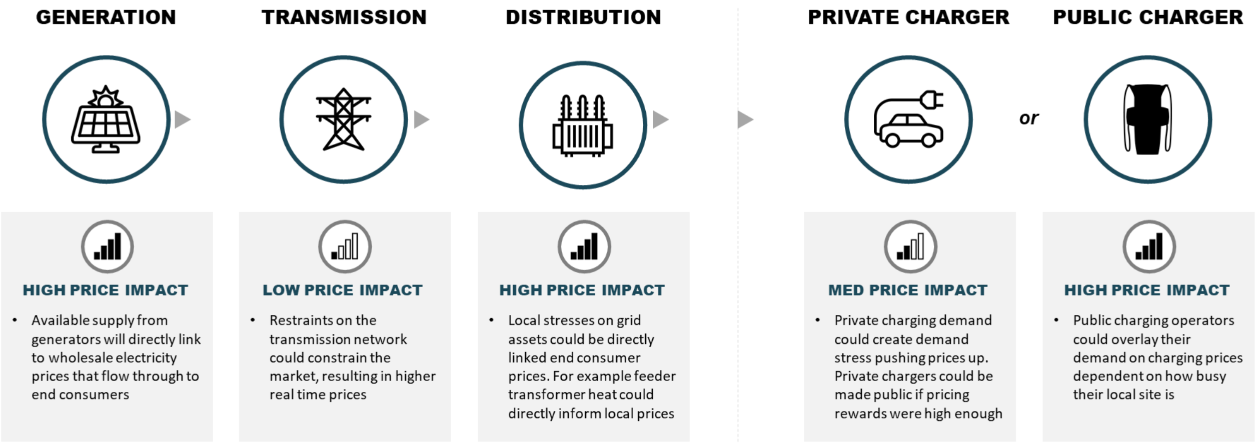

Figure 3 Price impacts across the electric vehicle value chain

There is a range of benefits arising from a real-time model across the stakeholder landscape for private and public charging. These benefits are predominantly rooted in increased transparency and true cost reflection of electricity pricing.

Real-Time Priceing Benefits for Private Charging	
True cost reflection	• Tying actual prices to externalities and the underlying cost to generate electricity provides the network operator clearer signals to reduce grid stress. Real-time pricing can also reduce electricity prices by signalling for the market to pick up slack when assets are underutilised, increasing equilibrium in demand and supply. • Using a price-based mechanism reduces the burden on Utilities to manage electric vehicle charging as price signals provide consumers the information to make choices or set charging preferences based on price.
Attracts new supply by providing a V2G or V2V price	• A market price for charging provides clear incentives to vehicles for feeding electricity back to the grid. This market price will enable consumers to determine if the reward for providing supply is high enough of an incentive for V2G. This pricing mechanism also provides an indicative market price that could be used in a vehicle to vehicle context, or for mobile charging operators.
Provides a market price to offer a charger in public	• Real-time pricing could potentially set a market price for private electric vehicle charging owners to make their charger available to the public. Dependent on regulation this private to public offering could help private equipment owners maximise the utilisation of their equipment investment.

Real-Time Pricing Benefits for Public Charging	
True cost reflection	• As with private charging, Real-time pricing will enable charging prices to reflect the actual underlying costs to generate electricity and real-time stress on the overall network. Assuming charge point operators align their pricing with these costs, consumers will receive real signals for when electricity charging is, relative to normal conditions expensive or cheap. The result of this cost reflection is stronger demand side management incentives. In peak periods the Utility can act to reduce demand, and in periods of low demand, pricing can be used to attract or incentivise demand.
Removes cross subsidisation	• Real-time pricing will remove cross subsidisation predominately through removing the requirement for demand charges. If the real-time price incorporates the impact on peak demand, customers have a choice to charge in peak periods and pay for the externality caused. Consumers with more flexibility to delay their charging time to a lower demand period, will not subsidise customers charging in peak times, ultimately paying a lower price.
Supply attraction from distributed sources	• A real-time price for EV charging could attract new sources of supply into the ecosystem. Parties who own energy storage or other distributed energy sources could feed these to the grid, or if they own charging equipment make this supply available to the market. With a visible price, it may make sense for a supply owner to reduce their normal consumption in favour of supply to the market.
Clearer consumer price transparency	• Overall consumers will receive clearer price signals that incorporate the actual cost of generation, their demand externalities, and the margin or service fee that a public provider is charging. This increased transparency may lead to a fairer market where customers and vendors both can make choices around their incentives to supply and consume within a marketplace environment.

5 How can the industry establish real-time pricing?

To deliver real-time pricing as the standard pricing mechanism across public and private charging the industry would need to converge on standard practices, determine the common technology platform and set up the relevant regulatory oversight.

Establishing Real-Time Pricing	
Standard Practices	• Standard practices would be required to establish the interconnections of information across stakeholder groups. Utilities, charge point operators, and private charging owners would require clear real-time information. A range of information sets and the protocols to share this information would need to be established. For example, the real-time pricing period length could be set at the second, minute or hourly level.
Determine a common technology platform	• A relevant technology platform would need to be established to communicate pricing to stakeholders across the market. Further work would be required to understand what communications mechanism could be used, and if there are pre-requisites to a real-time pricing market such as smart meters at the grid connection.
Set up regulatory oversight	• Oversight and management of the market would be required, like wholesale electricity market operators, an entity in each geography would be required to ensure that the market is transparent, and pricing between parties is not being unfairly manipulated.

6 Challenges to establishing real-time pricing

Further consideration of the barriers to implementing real-time pricing need to be assessed, however, six barriers are immediately obvious.

<table>
<tr><th colspan="2">Challenges to establishing real-time pricing</th></tr>
<tr><td>Consumer Preferences and Behaviour</td><td>Consumer Preferences
End customers may not want real-time pricing. Electricity price certainty may be valued higher than potentially lower costs that require increased customer effort or planning. However, Zethmayr and Kolata (2019) [8] have shown that financially, customers are likely to be better off, using ComEd Chicago, USA real-time pricing rates, EV drivers would have saved between 52-59% of their charging costs compared to flat rate pricing. The scale of these benefits may be enough to outweigh customer uncertainty, however, there may be a challenge to convince customers to switch to a new unfamiliar pricing model.
Further research would be required to ensure that vulnerable customers are not unfairly disadvantaged by any changes to the charging pricing mechanism.
Variation of Price Expectations
Further assessment of unintended consequences and second order effects of real-time pricing for electric vehicle charging is required. An immediate issue to address could be a lack of variation in customer price preferences. For example, if price preferences across customers are too similar, price peaks similar to timer peaks could emerge.</td></tr>
<tr><td>Changing Standard Industry Practices</td><td>Coordination Challenges
Agreement across the various stakeholders within the industry would need to be acquired and managed. Establishing this agreement and managing coordination and information flows across groups would require significant effort.
Business Impacts
To establish clear real-time pricing, trade-offs would need to be made, established businesses who have made investments into charging infrastructure may not be incentivised to move to a new pricing mechanism.
Regulatory Approval
Regulators would need to approve changes to electricity pricing. New pricing paradigms are difficult to establish due to historical embeddedness.</td></tr>
<tr><td>Funding the Transition</td><td>Funding
Establishing the platforms, data interconnections and overall system to share information will require funding. Return on investment for individual stakeholders may not be clear reducing the ability to fund research.</td></tr>
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7 Conclusions

The pricing structures for electric vehicle charging operate in a complex stakeholder landscape. The mechanism for charging our vehicles in the future will look different from the liquid fuel paradigm we live in today due to the electricity market being more volatile than oil-based fuels on a day to day basis. This volatility from consumer demand can have significant impacts on the underlying supply infrastructure and will be impacted by how electric vehicles are charged.

This paper set out to understand if there can be mutual benefits across the stakeholder landscape by rethinking how we price electric vehicle charging across modes, times, and locations.

Initial coverage of the stakeholder landscape and how dynamic real-time pricing could create mutual benefits has been put forward. Real-time pricing has the potential to make electric vehicle charging prices more aligned to the underlying cost base, more flexible and more transparent. This combination has the potential to enable all stakeholders to make a more informed purchase or business decisions.

Further research is required to understand to what extent consumers want this level of transparency. Secondly, more analysis is required to determine how to overcome the challenges to both align all stakeholders in established energy markets and provide the underlying systems to operate a real-time pricing system at scale across all modes of electric vehicle charging.

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Tritium designs and manufactures DC fast charging infrastructure for electric vehicles to hasten the transition to e-mobility, ultimately leading to clean, healthy and convenient cities. Our electric vehicle charging stations support the adoption and growth of low-emission e-mobility in over 25 countries around the world.