

Managed Charging for Electric Vehicles

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Managed Charging for Electric Vehicles

White Paper

Prepared for:

New York State Energy Research and Development Authority

Albany, NY

Adam Ruder
Assistant Director

Richard Mai
Project Manager

Prepared by:

The Cadmus Group LLC

Waltham, MA

and

World Resources Institute

Washington, DC

Michelle Levinson
Manager, eMobility Financial Solutions

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Abstract

This white paper analyzes managed charging measures for electric vehicles, the current market penetration of various technologies and solutions, and discusses potential load implications of those managed charging measures.

Keywords

Electric vehicles, vehicle grid integration, managed charging, charging infrastructure, charging load, load profiles, utilities, grid infrastructure, tariffs, take-up rates

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Acronyms and Abbreviations

DCFC	direct current fast charging
DER	distributed energy resources
DLC	direct load control
EV	electric vehicle
EVSE	electric vehicle supply equipment
MHDV	medium-and-heavy duty vehicle
NYISO	New York Independent System Operator
OCPI	Open Chargepoint Interface
OCPP	Open Chargepoint Protocol
OEM	original equipment manufacturer
OpenADR	Open Automated Demand Response
PEV	plug-in electric vehicle
TE	transportation electrification
TOU	time-of-use
V2G	vehicle-to-grid
VGI	vehicle grid interaction

Executive Summary

This white paper summarizes the Cadmus Group LLC and World Resources Institute's investigation of (1) electric vehicle (EV) charge management technologies, (2) vehicle grid integration (VGI) measures, (3) their EV current market penetration in the United States and worldwide, and (4) expected load shifting due to the implementation of VGI programs and policies.

The EV managed charging section provides a high-level landscape of EV managed charging measures that can be implemented for VGI, recommended communication protocols for hardware and software interoperability to enable efficient, cost-effective integration, currently available and future-looking technologies, and a summary of current market penetration. The load implication section investigates the effects of active and passive managed charging measures to illustrate the potential impact of their application to vehicle-related electric load in New York State. First, evidence of take-up rates for different program types was summarized. Next, there was a review of the load-shifting effects of active and passive measures—as documented in the literature and as theorized based on duty cycles and economic principles. The team utilized this foundation to define expected effectiveness of given measures under various conditions, providing predictions based on target year, assumed program take-up, and charger type (e.g., residential Level 1). These estimated program impacts are then scaled to size of the EV market under a decarbonization scenario aligned with the goals stated in New York State's Climate Leadership and Community Protection Act. These are presented in comparison to the baseline unmanaged scenario to illustrate the potential impact of managed charging measures.

As technologies and policies continue to develop over the next 30 years, it is likely that additional tools for managing EV load will become available that will further enable the flattening of EV electricity demand. Examples include real-time rates or dynamic pricing, low-cost energy storage, and direct load control through grid-integrated technologies.

This report provides insight into the set of measures proposed and in use to promote smart management of EV charging load. Among key findings, policies and programs should emphasize the need for communication protocol standards across EV and EVSE hardware and software for successful VGI. The market is starting to coalesce around OCPP in combination with either ISO/IEC 15118 or OpenADR. In the U.S., there is a need for widespread standardization to simplify VGI for utilities and encourage EV adoption.

Existing pilot programs have demonstrated the feasibility of VGI programs through successful implementation of EV driver incentives, networked chargers, and plug-in devices. Program administrators and analysts should consider factors such as the accuracy of EVSE integral meters versus revenue-grade meters, as EVSE accuracy can vary by service provider. However, higher cost solutions may have an impact on consumer up-take. As technology improves and new business models emerge, more research may be needed to further explore any tradeoffs that may exist between different solutions.

This study models the effects of managed charging measures to illustrate the potential impact of their application to vehicle-related electric load in New York State. The research indicates that program design decisions are central to enabling flexible load and maximizing the effect of these measures.

Key components are:

- Applying the default principle to nudge EV owners towards charging behaviors preferred by the electricity grid.
- Embracing alternative sub-metering techniques to avoid installation of a secondary meter.

This analysis suggests that if New York State were to implement proven managed charging measures, the electricity grid could avoid substantial demand that would otherwise coincide with the system peak. Even today, when EV penetrations are quite low, the magnitude of this potential flexible load is estimated to be at least 10 megawatts (MW) during the summer system peak of 5:00 p.m. to 6:00 p.m.

As the number of EVs increases in the State, the available flexible load is also expected to increase. The team estimates that TE load in an unmanaged charging case is 38 MW in 2020 and increases to 26.9 GW by 2050, with the peak TE load occurring between 7:00–8:00 p.m. for all years. This load includes all on-road electric vehicles but does not include other electrified equipment, such as aircraft, lawn equipment, forklifts, marine vessels, etc. With managed charging of TE load, the grid has an estimated 14 GW of avoided peak by 2050, equivalent to roughly 23% of New York State's expected peak demand.

1 EV Managed Charging

This white paper summarizes the Cadmus Group LLC and World Resources Institute’s investigation of (1) electric vehicle (EV) charge management technologies, (2) vehicle grid integration (VGI) measures, (3) EV current market penetration in the United States as well as worldwide, and (4) expected load shifting due to the implementation of VGI programs and policies.

1.1 EV Managed Charging Measures and Market Penetration

This section provides a high-level landscape of EV managed charging measures that can be implemented for VGI, recommended communication protocols for hardware and software interoperability to enable efficient, cost-effective integration, currently available and future-looking technologies, and a summary of current market penetration.

1.1.1 EV Charging Management Communication Standards and Interoperability Standards

There are many complex layers of communication protocols between the electric utility and an electric vehicle, as shown in Figure 1. Interoperability standards between different hardware manufacturers and software providers are key factors in product selection and ease of use, owing to the large array of options that customers have for EVs, charging infrastructure, charge management software, and renewable energy system interconnection. Open standards are vital to facilitating interoperability, allowing for different products from different original equipment manufacturers (OEMs) to work in the same network and to reduce the customer’s risk for stranded assets.

A California Vehicle Grid Integration Working Group subcommittee developed recommended messaging protocol standards for managed charging in late 2017 as shown in Table 1. Until that point, most charging equipment manufacturers were using proprietary, non-standardized protocols, which caused confusion for EV drivers and created inconsistency for electricity grid operators.

- The charge management system to EV supply equipment (EVSE) OpenADR and IEEE 2030.5 standards are listed in the NIST/SGIP catalog of standards. Open automated demand response (OpenADR) is an open-source protocol for system operators to reliably communicate demand response and distributed energy resource (DER) events over the internet or any IP-based communications network. IEEE 2030.5 uses IoT plug-and-play concepts for a range of smart applications beyond EVs such as thermostats, meters, inverters, and appliances.

Table 1. Examples of Communication Protocol Standards to Enable Vehicle Grid Integration

See endnotes for more information ^{1,2}

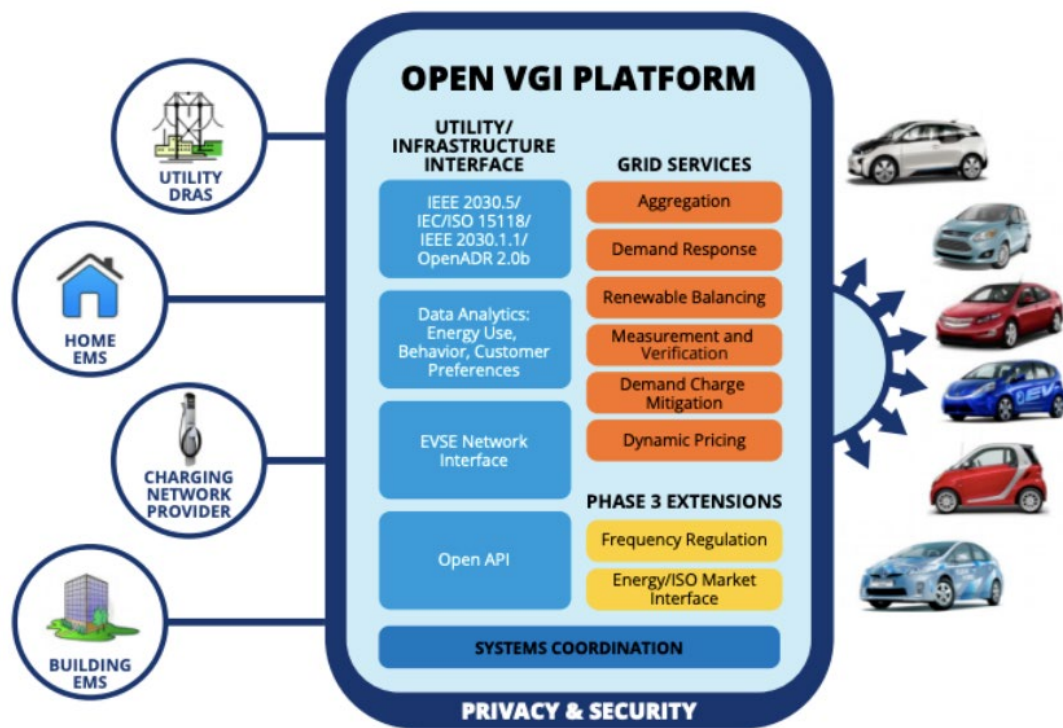
Domain of Communication	Currently Available Communication Protocol Standards	Maturity	Market Adoption
Charge Management System to EVSE	OpenADR 2.0b	High	Medium/High
	IEEE 2030.5	High	Low (limited use with EVs outside R&D)
	OCPP 1.6	High	High (implemented by many vendors in EU and U.S.)
	IEC 63110	Low	Low (at early stage of development)
EVSE to EV	ISO/IEC 15118 v1	Medium	Low (limited use with EVs outside R&D)
	IEEE 2030.5	High	Low (limited use with EVs outside R&D)
Vehicle OEM to EV	Telematics ³ using proprietary protocols or IEEE 2030.5	Low	Low (proprietary protocols lead to disjointed charging control strategies, underutilizing charging demand flexibility)
Electric Grid to EV	EPRI's Open Vehicle-Grid Integration Platform (OVGIP)	Low	Low (OVGIP is in phase 3 of development)

The Electric Power Research Institute's (EPRI) Open Vehicle-Grid Integration Platform (OVGIP)⁴ is a software application that aims to connect various nodes to enable utilities to manage charging activity for a variety of grid needs. Using the OVGIP, a utility can communicate with the EV OEM's data center, which then uses the EV telematics to control charging. EPRI's OVGIP approach allows the use of default EV and charging station communication technologies with utility standard interface protocols. The OVGIP architecture is shown in Figure 2. The OVGIP is currently being piloted in Xcel Energy's "Charging Perks" smart charging program in Colorado.

Figure 2. Electric Power Research Institute’s Open Vehicle-Grid Integration Platform Architecture

See endnotes for more information⁵

Source: EPRI



Charging hardware and plug equipment standards are also a key part of effective VGI. Hardware compatibility is important because it will allow for greater flexibility around which EVs can plug in to different chargers, increasing VGI opportunities and decreasing range anxiety and refueling concerns for EV drivers. Table 2 summarizes the current EV plug and charging hardware standards. Most EV OEMs are moving toward the J1772 plug standard.

Table 2. EV Charging Plug Hardware Standards

Charger Type	Market Sector	Electrical Requirements	EV Plug Compatibility
Level 1	Residential	110 V/240 V; 12 to 16 A	J1772
Level 2	Residential, public, workplace	240 V; 16 to 40 A	J1772
Level 3	Public, workplace, heavy-duty	480 V; 100+ A (50 to 350 kW)	<ul style="list-style-type: none"> • CHAdeMO • CCS (J1772 improved) • Tesla

1.1.2 Vehicle Grid Integration Methods

There are multiple methods by which an EV can be connected to grid communication networks. With the appropriate communication protocols in place, VGI can be achieved through direct communication with the EVSE, communication with the EV’s OEM-operated telematics, or communication through a third-party smart device.

EV Supply Equipment Control: Currently, the most common approach is through a networked EVSE. Once an EV is plugged into a networked charger, it has the potential to be controlled by the grid like other battery energy storage systems with features such as frequency and voltage regulation, load shifting and peak reduction, and automated optimization based on use. Examples of EVSE manufacturers with networked chargers are shown in Table 3.

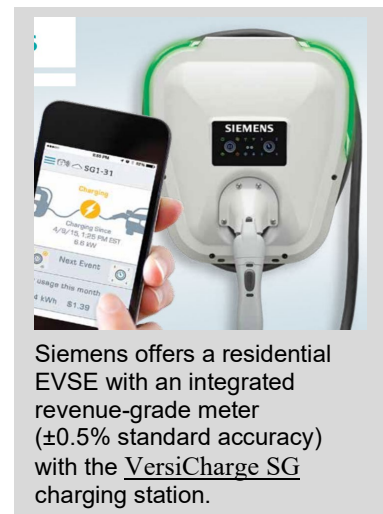
Table 3. Examples of EV Supply Equipment Manufacturers with Networked Chargers

Charger OEM		
ChargePoint	Offers networked and non-networked chargers	Networked AC home charging: https://www.chargepoint.com/drivers/home/ DC: https://www.chargepoint.com/files/datasheets/ds-cpe250.pdf
Enel X	Offers networked home chargers only	https://evcharging.enelx.com/store/residential
Siemens	Offers networked and non-networked chargers	https://new.siemens.com/us/en/products/energy/topics/transportation-electrification/versicharge-solutions/versicharge-residential-ev-charging.html
		https://new.siemens.com/us/en/products/energy/topics/transportation-electrification/versicharge-solutions/versicharge-sg-residential.html

In addition to a networked charger, implementing many of the managed charging measures such as EV-specific time-of-use (TOU) rates has historically relied on collecting data from dedicated utility-owned, revenue-grade meters, which are expensive and limit program enrollment. New York State Energy Research and Development Authority (NYSERDA) has expressed interest in investigating the use of non-revenue-grade meters for EV programs to reduce costs and simplify VGI implementation in New York State. Below are examples of how other utilities and energy agencies have implemented VGI with networked chargers, but without revenue-grade meters.

- Baltimore Gas & Electric's (BGE) EVsmart TOU program will collect charging data from their customers' residential networked Level 2 EVSE via EnergyHub's Mercury distributed energy resource management system (DERMS) to bill customers. To implement the EVsmart program, BGE installed, operates, and maintains a public network of EV chargers throughout their service territory. BGE obtained a regulatory waiver from the Public Service Commission to allow them to use the internal metrology of residential Level 2 EVSE as revenue-grade metering. This allowed them to implement an EV-only TOU rate without needing to install secondary meters. BGE noted that the waiver was vital as installing a second meter would have been cost prohibitive.⁶
- The 2014 EV Innovators Pilot load impact evaluation performed by the Sacramento Municipal Utility District (SMUD) implemented direct EV load control using networked EVSE with Zigbee (IEEE 802.15.4-based specification for high-level communication protocols used to create personal area networks) radios which could receive load-control signals to reduce the maximum charging demand to 1.4 kilowatts (kW) during peak periods.⁷ Tesla owners were unable to participate in this control option due to issues with demand limiting.

While workarounds do exist, there is concern over the current accuracy and reliability of non-revenue grade meters. Phases 1 and 2 of the California Public Utilities Commission (CPUC)'s California Statewide Plug-In Electric Vehicle (PEV) Submetering Pilot compared the accuracy of various residential submeter options. Most of the Phase 1 participants used eMW's WattBox™ (stand-alone and Wi-Fi enabled to transmit recorded usage data from the submeter to the utility), while Phase 2 allowed the use of both stand-alone submeters and submeters integrated with Level 2 EVSE. The study compared usage data from a sample of submeters to measurements from data loggers, which were installed on electrical panels directly upstream of the submeters. The evaluation showed that only 5% of the submeters met required standards for accuracy on a 15-minute interval level. On a daily level, less than 10% of the submeters passed within a $\pm 2\%$ threshold.⁸ One of the study's key findings is that using third-party submetering technology to generate utility bills is not yet viable for full-scale deployment. However, the EVSE market appears to be trending toward improving the accuracy of integral meters to avoid the need for secondary, revenue-grade meters.

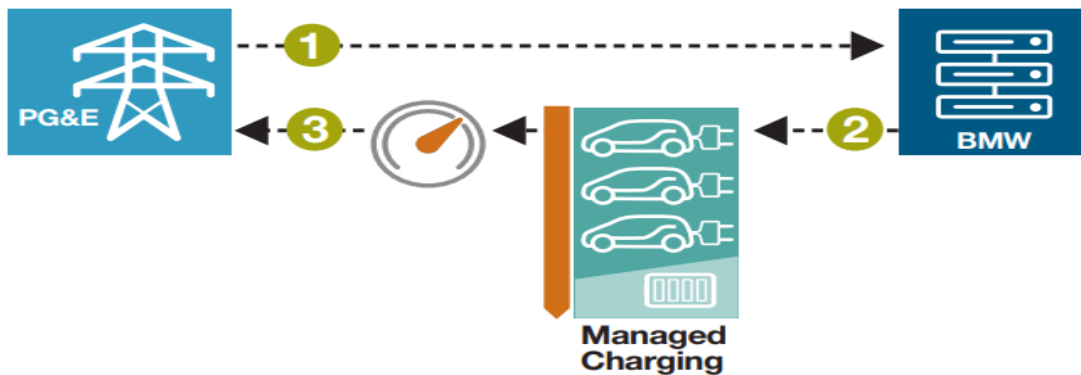


Siemens offers a residential EVSE with an integrated revenue-grade meter ($\pm 0.5\%$ standard accuracy) with the VersiCharge SG charging station.

Telematics Control: A less common method of managed charging is through an EV’s internal telematics system, such as OnStar or Geotab. Telematics software defaults are usually set by the vehicle OEM and can be proprietary. However, more EV OEMs are adopting the communication standards described above and there have been VGI pilot projects that have utilized this method. BMW’s i ChargeForward pilot operated in collaboration with PG&E in 2014 and utilized the EV OEM’s proprietary aggregation software to delay charging via embedded vehicle telematics to reduce load on the electric grid during peak demand events.⁹

Figure 3. BMW i ChargeForward System Architecture

PG&E initiates a Demand Response (DR) event to BMW (via Olivine) by sending a signal via a standard communication protocol (OpenADR 2.0b) similar to how PG&E communicates with other DR providers. Once the event has been triggered, BMW’s aggregation software determines how much of the 100-kW load drop will be met by managed charging and how much by stationary storage resources made of used EV batteries, or a combination of both.¹⁰



In-Vehicle Smart Device: Building in popularity are third-party in-vehicle smart device networking tools, such as Fleetcarma’s C2 OBD II device. This device is a data-tracking card inserted into the EV’s OBD II port, shown in Figure 3. The C2 card can collect and organize EV charging, driving, and location information, although location information is only gathered when the car is charging in order to maintain customer privacy.¹¹ The C2 allows charging to be tracked and managed outside of the home to include non-networked public or workplace charging stations.

Figure 4. Fleetcarma's C2 OBD II Device



1.1.3 Managed Charging Measure Categories

When the requisite communication protocols, hardware, and software tools are implemented, there are several managed charging measures that can be used to achieve a variety of utility grid goals, such as reducing loads during peak periods and smoothing demand spikes during off-peak periods. These measures are grouped into behavioral and direct load control (DLC) managed charging categories, as defined below. As of October 2021, of the 40 managed charging programs currently offered by utilities in the country, 25 are DLC programs while 15 take a behavioral approach.¹²

1.1.3.1 Behavioral EV Managed Charging Measures

Behavioral EV charge management measures are less direct and can be less intrusive on customer experience. Such measures are currently being piloted in many residential programs throughout the country, including tariff structures, alternative Time-of-Use (TOU) rate structures, and incentives and/or reminders to encourage scheduled EV charging or charging during off-peak hours.

1.1.3.2 Direct Load Control EV Managed Charging Measures

DLC EV managed charging measures are implemented by a utility or a third-party aggregator and usually require an opt-in by the EV driver. DLC measures can include automatic charge scheduling during off-peak periods, dynamic load control, and customer notifications of reduced charging power levels due to an upcoming peak demand period. According to a January 2020 ScienceDirect—Energy Policy article:

With smart [DLC] charging, Plug-In Electric Vehicles (PEVs) usually participate in a demand response program whereby an aggregator (utility or third-party) remotely controls active charging to be on or off through the charger or vehicle software.¹³

Grid-responsive DLC measures can be implemented by an operator or their staff through a dashboard interface or API, or through an automation controller programmed by utility staff. A third-party in some cases can implement DLC measures, typically through an automated system built by the third-party. In most cases, an EV driver still needs to enroll in a DLC managed charging measure.

While the automated aspects of DLC measures are appealing to utilities, like other networked systems there is a potential cyber security risk to the EV driver that will need to be considered and addressed as new communication protocols and managed charging programs are implemented.

Table 4 summarizes potential behavioral and DLC EV managed charging measures that could be used to meet various utility goals and includes examples of measure implementation.

Table 4. Behavioral and Direct Load Control Measures for Enabling and Incentivizing Responsible EV Charging

See endnotes for more information¹⁴

Utility Goal	Utility Benefit	Charge Management Measure	Type*	Example
Avoid Charging at Peak	Reduces peak load on grid—generation at peak load has the highest cost per kWh.	Time-based energy rates	B	Con Edison’s SmartCharge Rewards Program ¹⁵
		Time-based demand rates	B	
		Charge scheduling	DLC	Eversource’s ConnectedSolutions ¹⁶
Avoid Synchronized (Multiple EV) Charging	Reduces peak load on grid—generation at peak load has the highest cost per kWh.	Staggered peak rates	B	
		Customer notification of rate increase.	B	
		Charge scheduling	DLC	
Encourage Lower-Power Charging	Reduces demand spikes, which can place strain on grid infrastructure.	Time-based demand rates with customer chosen kW threshold.	B	
		... with utility chosen thresholds.	B	PG&E & SCE’s Business EV Rates ^{17,18}
		... with choice of charging level	B	
Avoid High-power Charging	Reduces demand spikes, which can place strain on grid infrastructure.	Demand limiting	DLC	Eversource’s ConnectedSolutions ¹⁹
		Monthly demand rates	B	
		Real-time demand notification	B	
Avoid Critical Peaks	Reduces peak load on grid—generation at peak load has the highest cost per kWh.	Customer notification of reduced power levels due to upcoming peak period.	DLC	<ul style="list-style-type: none"> PG&E EV Charge Network Load Management Plan²⁰ PG&E + BMW iChargeForward pilot²¹
		Dynamic energy rates	B	
		Dynamic demand charges	B	
		Dynamic load control	DLC	<ul style="list-style-type: none"> Green Mountain Power Unlimited EV charging Rate²² Eversource’s ConnectedSolutions²³ SMUD EV Innovators TG3²⁴
		Communicating charger with end-of use-charging, choice of charging level, high price avoidance, managed charging.	B	
Increase Consumption of Renewables	Reduces curtailment of renewable generation by deploying flexible demand to coincide with instances of high renewables penetration.	Time-based energy rates	B	PG&E & SCE’s Business EV Rates ^{25,26}
		Dynamic load control	DLC	

* Behavioral (B) or Direct Load Control (DLC) measure type.

Networked charging and user incentives are key factors for unlocking the flexibility of EVs, which will be required for their successful grid integration in the future.²⁷

1.1.4 Deployment of EV Managed Charging Measures

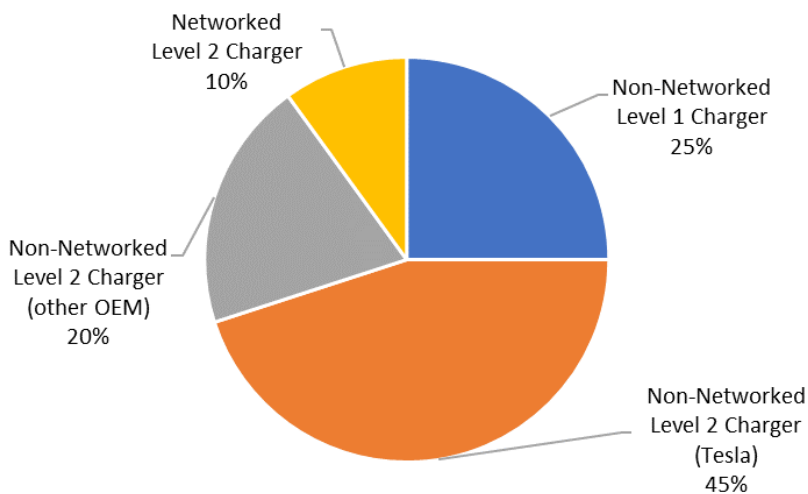
This section describes various EV charge management measures that are currently in use across the country in residential, public and workplace, and commercial and heavy-duty fleet market segments.

1.1.4.1 Residential Managed Charging Measures

Residential charging patterns are driven by cost and vehicle operating behaviors. For residential managed charging programs, ease of use, data security, and compatibility with multiple types of EVs and EVSEs are important for success. Additionally, proposed managed charging programs will likely need to provide incentives to convince residential customers at least initially to sign up, because those customers may be skeptical about a utility remotely utilizing the battery in their EVs.

The Tennessee Valley Authority (TVA) is currently conducting a study of EV managed charging and behavioral measure impacts in a pilot program called SmartCharge Nashville.²⁸ The study found that of the program participants, only 10% of residential customers have networked Level 2 chargers, as shown in Figure 4. Managed charging for most of the participants in the study was performed using Fleetcarma’s C2 OBD II port cards, described above. Cadmus expects that the nationwide home charger type distribution is reflective of these findings; therefore, utilities should not depend on using existing networked chargers to implement widespread residential VGI programs.

Figure 5. Tennessee Valley Authority SmartCharge Pilot Program Home Charger Population Types



The SmartCharge Nashville program was broken into three phases to develop a baseline and test various load management and incentive strategies.

- **Phase 1—EV Charging Data Collection:** EV drivers receive financial incentives to share their EV charging data with their utility.
- **Phase 2—Customer-Controlled Charging:** EV drivers receive financial incentives to program their vehicles to charge at desirable time periods.
- **Phase 3—Utility-Controlled Charging:** EV drivers receive financial incentives to allow the utility to control EV charging load at their homes (applicable to networked L2s).

The program is still in Phase 2 and results have not been released but the financial incentives have proven effective so far and the program has over 200 participants.

More utilities have created specific residential EV rates to make home charging more manageable:

- **PG&E** has two residential EV charging rates, one for consumers who want to meter their EV charging separately from their household energy use (EV-B), and one for households that have everything measured on one meter (EV2-A).²⁹ Both rates are TOU and incentivize charging during super off-peak hours when energy is cheaper. The rates are non-tiered and therefore do not change based on expected demand. An important note is that consumers on this rate have a limited allowance and high-energy use consumers are not eligible.
- **Con Edison** also has a residential rate for electric vehicle chargers that operate on a dedicated meter.³⁰ This rate has both a TOU component and a seasonal component. For residents charging without a dedicated meter, they have a price guarantee program. If consumers switch their entire residence to a TOU rate, after 12 months Con Edison will compare what they paid under TOU rates with their standard residential rate. If consumers paid more under TOU, Con Edison credits the difference to their account.
- **Green Mountain Power (GMP)** in Vermont created the EV Unlimited pilot program to incentivize residential EV adoption and encourage VGI. Participants received a free Level 2 charger (ChargePoint or Flo chargers with meter-grade data) and could charge their EVs as often as needed for a flat monthly rate. In exchange, GMP dynamically accessed their EV charging data and limited charging during peak demand events. Customers could opt-out of events but then had to pay an additional \$0.60 per kilowatt-hours (kWh) consumed during the event. Between October 2018 and mid-January 2019, the average opt-out rate was only 1.1%.³¹ The success of this approach was codified in the EV rates approved by regulators in September 2020.³²

In the CPUC California Statewide PEV Submetering Pilot discussed above, the Phase 2 report found that of the residential customers enrolled and surveyed, the top two decision factors for enrollment were the ability to pay a lower rate for EV charging (97%) and the availability of an incentive for an EV submeter (94%).³³ Table 5 summarizes additional examples of residential EV charging utility rates.

Table 5. Examples of Residential Managed Charging Utility Rates and Plans

See endnotes for more information³⁴

Utility	Rate Description
Pacific Gas and Electric (PG&E)	Rate: TOU DR: Flexible grid resource for CAISO—storage + EV
San Diego Gas and Electric (SDG&E)	Rate: TOU rates with multiple price ratios
Xcel (Colorado)	Rate: TOU (not EV-specific) DR: avoid system peak load
Pepco (Maryland)	Rate: TOU rate DR: curtail demand by 80%
Toronto Hydro (Toronto, CA)	DR: automated participation with option for manual opt-out
Eversource (Massachusetts)	Managed charging, through speed of charging. Shaping load profile.

1.1.4.2 Public and Workplace Managed Charging Measures

Charging network companies and charging site hosts have no direct control over the utilization patterns of their equipment. Nevertheless, through price signals, operators of these systems can incentivize alignment of charger utilization with the needs of the electricity grid.

As with residential applications, ease of use, reliability, data security, and compatibility with multiple types of vehicles are important for public and workplace charging and charge management. However, charging speed is more important in public than residential charging. Additionally, the scope of payment options for chargers is important for wider access, such as multiple credit card and smart phone payment options.

A few utilities across the U.S. have developed progressive commercial EV electric rates that make managing the energy costs of operating EVSE more manageable for commercial building managers and public entities. These utilities have tended to shift the bulk of the costs from demand (kW) to energy consumption (kWh) charges and have TOU pricing signals that incentivize charging during off-peak hours.

Southern California Edison, for example, has three non-residential EV rate options.³⁵ All three options leverage TOU pricing and are based on different levels of demand. Option 1 is available to customers with charging demands of 20 kW or less; Option 2 is for customers with 20 kW to 500 kW of charging demand; and Option 3 is for customers with more than 500 kW of demand. All three rates are currently

in an introductory period (March 1, 2019 to March 1, 2024) and do not levy additional demand charges. Demand charges are expected to be added in after the five-year introductory period unless otherwise authorized by the Commission.

As large commercial buildings and campuses require building management systems to visualize and control energy use across multiple complex interior lighting and HVAC systems, they also need a centralized control system for their on-site charging stations. ChargePoint's Enterprise Charging Optimization (ECO) Site is one of the first EV charging optimization platforms for large businesses. ECO is designed to help organizations implement EV charging strategies that best fit their business and local grid requirements.³⁶

1.1.4.3 Commercial Fleet and Heavy-Duty Managed Charging Measures

Fleet operators in the commercial and industrial sectors will prioritize charge management characteristics that allow them to minimize energy costs while accommodating vehicle use duty cycles. A managed charging program targeted at commercial and industrial customers will require a significantly different feature set than a residential program, with features for:

- System integration with fleet schedules that considers daily, weekly, and seasonal variations.
- Increasing resilience of fleet operations.
- Integration with on-site renewables energy generation.
- Customizable, automated control with easily adjustable set points.
- Compatibility with multiple EV and EVSE hardware options.
- Potentially the use of EV batteries as grid-energy storage for backup power, frequency and voltage regulation, and peak shaving (V2G).

Similar to residential and public managed charging measures, electric utilities have implemented specific commercial EV rates to encourage making the switch to electric fleets and off-peak charging. Pacific Gas and Electric (PG&E's) commercial EV rates, BEV-1 and BEV-2 are now available to low-use commercial customers (less than 100 kW) and high-use customers (greater than or equal to 100 kW) on a voluntary basis. These rates encourage the growth of electric fleets by charging the lowest rate during the "Super Off-Peak Period" of 9 a.m. to 2 p.m. during the lull between morning and afternoon commutes when most commercial fleet vehicles would be recharging. The peak period is 4 p.m. to 9 p.m., during which time most commercial fleet vehicles would be enroute and not charging.³⁷

There is also a growing number of energy management systems for commercial and transit fleets. For example, ChargePoint, Electriphi, GreenFlux, Driivz, and many others offer software solutions to dynamically optimize charging rates and reduce costs across multiple vehicles, while accounting for operational needs. Electriphi's Command Center utilizes machine learning to account for driver behavior, weather conditions, and route topology—and can be directly integrating into utility demand signaling using OpenADR.³⁸

1.1.5 Future Opportunities

The EV and VGI industry is progressing quickly and predicting future trends is challenging. Many technologies are in development and are likely to enter the market very soon, including a broader range of EV models from more automakers with greater networking capabilities and communications standards adoption.

Europe continues to be a pioneer in EV and managed charging technology development. Many of the charge management communications protocols, including Open Charge Point Protocol (OCPP) and Open Charge Point Interface (OCPI), were invented in the Netherlands. Europe and the Netherlands approached VGI policy and program structure in fundamentally different ways from the U.S. by the government taking the initiative to install EV charging stations and mandating that all public charging stations utilize open standards from day one.³⁹ Due in part to these initiatives, EV ownership and EVSE are much more prevalent.

There are many examples of charge management software facilitating VGI in Europe. One such example is NTT DATA's Open Charging Station Controller (OCC) charge point management system, which has been implemented in Austria and Germany. The OCC system enables EV charging using an open, vendor-neutral administration platform and handles reservations, evaluations, and load management.⁴⁰

China's Shanghai Electric Company just completed a six-month VGI pilot program, the first of its kind in China to use EVs as energy resources for the electric grid. The pilot was conducting based on signals from the utility to the EV driver about when they should charge their vehicles, taking advantage of excess renewable energy.⁴¹

Vehicle-to-Grid (V2G) systems are beginning to enter the market, taking advantage of internet communications between EVs and grid infrastructure. Nissan is piloting V2G tests in Denmark, Italy, and Chili⁴² and San Diego-based Nuvve is deploying 50 V2G charging platforms at UC San Diego.⁴³

With V2G systems, once an EV is plugged into a V2G charger, it can potentially function as a battery on the grid and can be dispatched freely by the controller/utility. The only condition is that EV batteries must gain or maintain a certain charge level after a given time. The impacts on battery life due to frequent cycling (charging and discharging) are still under research.

While networked EV chargers (which can integrate with V2G infrastructure) already exist, networked V2G in cars is less common. Tesla was skeptical on V2G in cars until very recently, and it is unclear whether Tesla vehicles sold now are compatible with V2G integration.⁴⁴ Meanwhile, Honda's upcoming "Honda e" EV for its European markets is being released with a V2G-enabled charger called the "Honda Power Manager," a Level 2 AC charger.⁴⁵

In Japan, Nissan has also been exploring vehicle-to-home (V2H) technologies to allow EV owners to power their homes using their EV battery during periods of peak electric grid demand or during power outages and other emergencies, increasing resilience and reducing electric costs.⁴⁶

1.2 EV Managed Charging Load Implications

This section of the white paper investigates the effects of these active and passive managed charging measures to illustrate the potential impact of their application to vehicle-related electric load in New York State. The approach is distinct from prior efforts to assess the impact of managed charging measures on the charging behavior and resulting electric load profiles of EVs in that (a) there is no blanket assumption of 100% compliance with managed charging protocols and (b), where feasible, the team draws upon the (limited) set of post hoc studies that have evaluated the effects of these measures when applied in real-world contexts.

First, evidence of take-up rates for different program types was summarized. Next, there was a review of the load-shifting effects of active and passive measures—as documented in the literature, where available, and otherwise as theorized based on duty cycles and economic principles. The team utilized this foundation to define expected effectiveness of given measures under various conditions, providing predictions based on target year, assumed program take-up, and charger type (e.g., residential Level 1). These estimated program impacts are then scaled to size of the EV market under a decarbonization scenario aligned with the goals stated in New York State's Climate Leadership and Community Protection Act. These are presented in comparison to the baseline unmanaged scenario to illustrate the potential impact of managed charging measures.

1.2.1 Take-Up Rates of Managed Charging Measures

The breadth of a program’s reach is a critical aspect of its total impact; programs that are highly effective at shaping participant behavior may have very limited total impacts if adoption is not widespread.

1.2.1.1 Residential Customers

There are several factors that affect take-up rates of managed charging measures, but principle among these is the influence of the default set by the program administrator. The most effective way to ensure optimal charging behavior is to default participants into a managed charging program, providing them the choice to opt-out. The power of the default is extremely well documented throughout behavioral science literature, and specifically in the context of consumer responses to electricity choices.^{47,48} Such patterns are observed in the take-up rates of residential TOU tariffs in the State of New York in Table 6, which illustrates given a default of a traditional flat rate, there is negligible up-take of TOU rates under an opt-in paradigm.⁴⁹

Table 6. Take-up of Opt-in Residential Time-of-Use Rates in New York State

Utility	Residential TOU Customers	Total Residential Customers	% TOU
National Grid	5,624	1,475,271	0.40%
Con Edison	1,720	2,896,029	0.10%
Central Hudson	1,000	266,061	0.40%
RG&E	1,273	334,750	0.40%
NYSEG	4,016	766,954	0.50%
O&R	3,399	198,331	1.70%

These numbers are not unique to New York State. The vast majority of IOUs in the U.S. have offered voluntary opt-in time-based rates (e.g., time-of-use) for over forty years, yet most see fewer than 2% of their residential customers taking this service.⁵⁰ We also see this default effect at play in the voluntary take-up of EV-specific rates. In both California and Minnesota, utilities report that most EV owners in their territories remain on the default tariff, rather than switching to a whole-house TOU or EV-specific tariff that is designed to be more cost-effective for EV owners.^{51, 52,53}

Meanwhile, the nationwide Consumer Behavior Studies found robust evidence that opt-out programs produce substantially higher enrollment rates (93–98%), without affecting program retention patterns.⁵⁴ Among the pilots reviewed, the increased scale of the program and reduced recruitment costs were documented to drive favorable cost-effectiveness results for opt-out protocols. For example, Sacramento

Municipal Utility District's TOU rate offering was found to be more cost-effective under a default enrollment approach than a voluntary one by almost 3 to 1, when considering benefits such as deferred grid infrastructure upgrades and peak shaving.

It is worth noting that if early EV adopters do not represent the general population, then the effectiveness of a measure may be lessened somewhat when it is introduced as the default for all. Extensive education and/or automated charge management should accompany implementation of an opt-out program to avoid the potential that, when transferred to a TOU rate, complacent consumers might not be aware of or take action to shift their behavior. In the absence of widespread understanding of the TOU program and/or automated implementation, introduction of an opt-out regime could result in some customers being made worse off unnecessarily.

Other lesser factors that have been documented to influence participant decisions to enroll in managed charging measures are predicted bill savings (and their scale), the approach to metering—whether the consumer can avoid installation of a secondary meter or there are incentives available to cover the cost of one, and clear messaging that the program is a utility-sponsored initiative, which has a positive effect on recruitment.^{55, 56}

Another variable that has been tracked across early studies of managed EV charging is whether tariffs are offered as whole-house or EV-specific. Recent data from California suggests that 95% of EV-owning households do not have a dedicated EV meter.⁵⁷ The same study reports that, of households on an *EV-specific rate*, 96% did not have a dedicated EV meter, likely because of the cost associated with installing a separate meter. However, participation trends suggest consumers prefer a separate EV tariff over whole-house EV tariffs if the cost of the separate meter is subsidized. In the SMUD EV Innovators pilot, where an EV submeter was installed at no cost to the customer, the likelihood that a participant would choose the separately metered rate was more than two times the likelihood they would choose the whole-house rate.^{58 59} However, it seems that the effect of a given metering approach on customer participation rates is a function of the cost of that approach and whether that cost is to be borne by the customer. It is also useful to understand whether and how take-up rates might differ depending on the type of managed charging measure applied. The preponderance of managed charging measures that have been implemented thus far in the U.S. rely on behavioral mechanisms, whether time-of-use tariffs or critical peak pricing. Thus, we supplement the limited evidence available on program take-up for direct control measures in the vehicle charging context with evidence on other technologies to ascertain expected consumer behavior.

The SMUD EV Innovators pilot also included a treatment group where direct load control was applied. Uptake for this segment of the program was set to 60% of study participants with an EV-specific meter and it is possible this take-up rate is further inflated because this was the only treatment group whose incentive included a free L2 EVSE. Similarly, the BMW iChargeForward program offered significant monetary incentives to participants in its direct load control program—\$1,000 up front and ongoing rewards for each day they did not choose to opt-out, up to a maximum \$540 over the 18-month pilot.⁶⁰

One EV pilot program that features a hybrid of the behavioral and direct control approaches is Green Mountain Power’s EV Unlimited pilot program. The charging activity of program participants is limited when peak events are called, though they can choose to manually opt-out of these events and pay a premium for electricity delivered during the event window. Green Mountain Power boasts an event opt-out rate of 1.1% during this initial pilot. While opting out of an event and opting out of a program are distinct, this very low opt-out rate suggests that the power of the default may carry through to direct control measures in the EV space. This is further supported by findings from the Consumer Behavior Studies, where researchers observed that in the cases of programmable communicating thermostats and load controllers for air conditioners, water heaters, and swimming pool pumps, the inclusion of programmable control technologies in a utility program offer did not alter retention rates.⁶¹

Factors that can affect uptake of direct load control (DLC) programs include:

- Size and type of incentives—up-front versus small recurring payments; loss aversion tendencies play out as awards enhance initial uptake, while penalties enhance ongoing compliance.
- Program emphasis on environmental benefits.
- Preservation of some driver control—participants in DLC programs favor the ability to opt-out for an event that is called and value the ability to set a minimum guaranteed charge-level.⁶²
- DLC programs require scale—viable trading of EV power on the wholesale market requires the aggregation of at least around 500 charging points or EVs.⁶³

Table 7 provides examples of take-up rates observed across a variety of programs that implement managed charging measures and characterizes each according to these key influencing factors: measure type, charger level, metering structure, and enrollment approach.

Table 7. Summary of Take-Up Rates of Managed Charging Measures

Utility/Program	Measure Type	Charger Level	Metering Approach	Enrollment Approach	Program Take-up Rate (%)	Event Approach	Event Participation (%)
Xcel MN ⁶⁴	Behavioral	L1 or L2	Single or separate	Opt-in	19.0%	N/A	N/A
PG&E ⁶⁵	Behavioral	L2	Separate	Opt-in	0.02%	N/A	N/A
PG&E ¹⁶	Behavioral	L1 or L2	Single	Opt-in	2.80%	N/A	N/A
SCE ¹⁶	Behavioral	L2	Separate	Opt-in	0.03%	N/A	N/A
SDG&E ¹⁶	Behavioral	L2	Separate	Opt-in	0.14%	N/A	N/A
SDG&E ¹⁶	Behavioral	L1 or L2	Single	Opt-in	3.97%	N/A	N/A
Consumer Behavior Studies ⁶⁶	Behavioral & DLC	Not EVs	Single	Default-in	93-97%	N/A	N/A
PG&E ⁶⁷	DLC	L2	Separate	Opt-in	Unknown	Default-in	94.0%*
GMP ⁶⁸	DLC	L2	Separate (virtual)	Opt-in	Unknown	Default-in	98.9%*
HECO ⁶⁹	DLC	L2	Separate (virtual)	Opt-in	Unknown	Default-in	92.0%*

* These participation rates are event participation rates, not program participation rates.

1.2.1.2 Commercial Customers

Take-up of managed charging measures likely varies across medium and heavy-duty vehicles (MHDV) categories and measure types. Generally, MHDV fleet managers are anticipated to be rational actors that will cost optimize. Unlike in the light-duty context, measure take-up decisions are not bounded by metering structure, but rather by the constraints of operational duty cycles.

There is limited evidence from real-world applications that allows us to characterize the take-up of managed charging measures in the Public L2 and direct current fast charging (DCFC) contexts. Some considerations that might differentiate adoption of managed charging measures in public contexts include:

- Public charging managers are likely to be more sophisticated consumers than residential EV owners, especially if EV load accounts for a significant portion of their total bill.
- Public charging managers that actively manage site energy costs are more likely to behave as rational actors and can be expected to select the best available tariff even if not defaulted on.
- To the extent public charging facilities are managed by EVSE network companies, e.g., Greenlots or ChargePoint, these facilities are well-positioned to aggregate EV load in response to real-time prices.

1.2.2 Market Elasticities of EV Managed Charging Measures

As described in the section Deployment of EV Managed Charging Measures, there are now more active than passive managed charging programs on offer. Nevertheless, the preponderance of programs for which empirical data is available, applied behavior-based managed charging measures in residential contexts. We draw on analyses that studied the implementation of these measures to understand how EV charging behavior responds. Because we have limited evidence on the effects of programs in public DCFC, public level-2 chargers (L2), commercial fleet, or medium- and heavy-duty vehicle (MHDV) settings, we are limited to insights gleaned from observed charging activity, stated user preference surveys, and theoretical modeling of consumer decisions.

1.2.2.1 Residential Customers

Behavioral managed charging measures applied in residential contexts, such as time-of-use rates, have consistently been found to result in a lower proportion of load coinciding with the system peak, relative to the usage patterns of general residential customers.^{70, 71, 72, 73} Evidence suggests that sensitivity to managed charging measures holds across charging power levels and in both single-family (SFH) and multifamily (MUD) residential settings. Table 1 provides a summary of the observed changes in EV charging load compared to baseline residential consumption patterns, and the associated price differentials between time periods. The On:Off Price Ratio indicates the price differential embedded in each program design.

Table 8. Effect Sizes of Behavioral Charge Management Measures

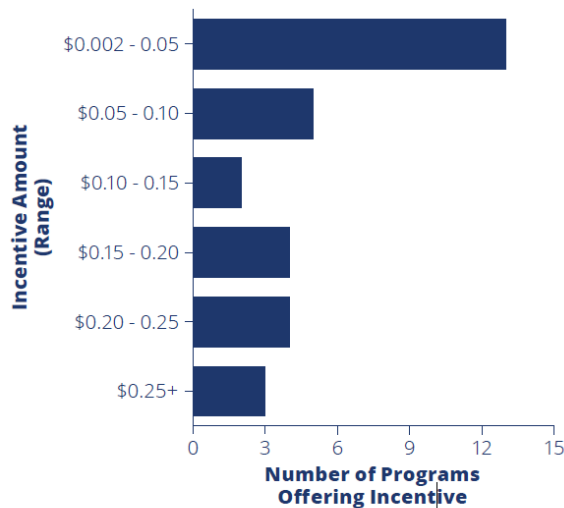
Study	Level	Setting	Meter	On:Off Price Ratio	Δ On-Peak Load (%)	Partial:Off Price Ratio	Δ Partial-Peak Load (%)
CECJI--PG&E	Mix	SFH	Single	3.24	-8.00%	1.87	-6.00%
CECJI--PG&E	Mix	SFH	Separate	3.21	-22.00%	1.84	-20.00%
CECJI--PG&E	L2	MUD	Single	3.24	-8.00%	1.87	-7.00%
CECJI--PG&E	L2	MUD	Separate	3.21	-22.00%	1.84	-21.00%
CECJI--SCE	Mix	SFH	Single	2.90	-5.29%	1.75	-7.21%
CECJI--SCE	Mix	SFH	Separate	2.35	-9.29%	N/A	N/A
CECJI--SCE	L2	MUD	Single	2.90	-5.79%	1.75	-8.18%
EVInn—SMUD T1	L1	SFH	Single	3.29	-21.00%	1.76	-5.75%
EVInn—SMUD T2	L2	SFH	Separate	7.10	-24.00%	3.58	-26.25%

Note: Partial-Peak periods are TOU windows designed to appropriately price shoulder periods when the electric system load is neither in a peak nor a trough. Sources: CECJI (Vehicle Load Research–7th, 2019); EVInn (SMUD EV Innovators Pilot–2014).

The size of the effect of managed charging measures depends, in part, upon the price differential (the price ratios in Table 1) that consumers face between incentivized and disincentivized charging periods. Figure 5 summarizes ranges of the price differential within a TOU rate observed across a variety of programs. This effect can be conceived of as the price elasticity of charging demand.

Figure 6. Difference in On- and Off-Peak Price per Kilowatt-Hours within EV-Specific TOU Rates

See endnotes for more information.⁷⁴



Source: Smart Electric Power Alliance, 2021.

Another key insight is the dampened effect of charging measures in the single-metered contexts compared to the separately metered contexts. This reinforces findings from other studies, where incremental load of EV owners on a single whole-house meter was slightly lower than the incremental load of EV owners with a separately metered charger.⁷⁵ This may indicate that heavier users of EVs look to EV-specific rates to optimize energy costs, even though these rates necessitate a separate meter. However, technology readiness and regulatory acceptance of alternative metering approaches may eliminate the need for installation of a secondary EV-specific meter. Such advances would enable all metering contexts to exhibit the levels of price elasticity measured in separately metered contexts. In this analysis, we assume that the average effect of managed charging measures on residential chargers reflects the average effect found in separately metered contexts.

Both behavioral and DLC methods have been utilized for the purpose of reducing load during critical peak periods. The BMW iChargeForward program provided proof-of-concept that vehicles can serve effectively as grid resources for this purpose.⁷⁶ Preliminary evidence from SMUD of the effect of direct control managed charging measures suggests that there is no measurable difference between the effect

on critical peak consumption of DLC measures versus scheduled charging tools (behavioral).⁷⁷ A limitation of this preliminary conclusion is that critical peaks were uniformly aligned with peak periods, so all participants, with scheduled charging enabled, avoided consumption during these peak periods.

No charge management measure covered in this analysis has attempted to apply signals representing dynamic, instantaneous, location-based grid prices to electric vehicle charging load. Illinois is the only state where such rates are available to consumers.⁷⁸ This aligns with research finding that consumer energy consumption decisions are more likely based on average price than marginal price; the relevance of this principle in the context of EV charging behavior is somewhat suspect, but it is likely the case that fewer, simpler choice sets improve the speed and quality of consumers' EV charging decisions.^{79, 80} As direct load control technologies and automated virtual charge management tools become more prevalent, it will be critical to parse out their real-world effects.

Recent work out of Lawrence Berkeley Laboratory (LBNL) models this opportunity.⁸¹ The principal difference between the effect of the overnight TOU rate and the DLC measure modeled was that the DLC measure allowed for deployment of EV load coincident with high-renewables generation. Because more cars than might be expected are located at home midday, under a DLC protocol these can be dynamically dispatched on the days when such excess midday generation is available. This functionality cannot be achieved by an overnight TOU rate because consumers require a consistent timetable for price signals to schedule charging activity. In sum, the researchers found that unmanaged charging coincides with peak loads and yields higher prices, while the total utility system cost savings from managed charging measures average about \$120/PEV per year with the DLC measure and about \$90/PEV per year with TOU charging.

1.2.2.2 Commercial Customers

There is also limited empirical evidence on the effect of either behavioral or DLC managed charging tools in public charging settings, whether workplace, public, or DCFC. Evidence from users of public chargers in the Netherlands suggests that they have some flexibility in their expectations of charging duration and session energy. If managed charging measures were implemented, it is possible that this observed flexibility could be translated to a measurable effect.⁸² Evidence from the U.S. suggests that behavioral measures can be used to reduce charge times. One study found that applying a time-based

fee reduced charge times; another study looking at the effect of flat prices found these correlated with longer charge sessions relative to free charging, potentially indicating that users over-consume when they are charged a flat fee. Stated choice studies have found that 80% of users express at least some price sensitivity in their public charging decisions.⁸³

Academic analyses suggest several approaches to apply dynamic pricing in public charging settings, such as using predicted location-based marginal prices to calculate the price of a charging session for a given kilowatt-hour and charging end time.⁸⁴ Relying upon simulations of individual travel behavior, the LBNL researchers identified that, across a vehicle's duty cycle, the greatest share of flexible load occurs at residential chargers. In a sensitivity scenario with eight times more workplace chargers, researchers still determined that the load and grid flexibility available were still dwarfed by that of the residential load. On the flip side, even with a 20-fold increase in DCFC charging sessions, the number of charging-hours that can be shifted only decreases by 3%. Our understanding of the character of charging at work and public locations aligns with these findings. Such sessions tend to be shorter, concentrated in the mid-morning hours, and have much less flexibility because queues require unplugging immediately after active charging. In dense environments where fewer EV drivers have access to home charging, the scale of this flexible residential EV load would be proportionately lower.

A review of the cost of electricity for DCFC on available tariffs identified low-station utilization as the principal driver of cost.⁸⁵ Other key design factors include preferential pricing during off-peak hours and limiting concurrent charging activity by throttling charger load to avoid peak demand charges. The effect sizes of these policies in real-world contexts are unknown.

Implementation of managed charging measures is increasingly common in the commercial fleet and medium- and heavy-duty segments. Nonetheless, there is limited real-world evidence on the effect sizes achieved by managed charging measures that have been implemented at scale in the medium- and heavy-duty segments.

Fleet managers are understood to be rational actors that will adopt managed charging measures whenever feasible for their vehicle use case. To that end, 24-hour load curves based on vehicle fleet duty cycles can be used to determine when the vehicle will be in the yard and available to charge.

As daily vehicle miles traveled (VMT) requirements decrease and dwell times at the depot increase, fleet managers have a greater opportunity to shift demand temporally and/or reduce peak demand to minimize charging costs.⁸⁶

Managed charging measures are designed to shift EV charging activity to address system-level concerns. A principal method entails managing EV load around New York Independent System Operator (NYISO) system net load after integration of renewables—referred to as “system-peak avoidance.” Additionally, measures can address site-level peak demand, referred to as “demand management,” to reduce a site’s demand charges. As renewables continue to scale up in New York State, managed charging protocols can also shape behaviors to take advantage of daytime solar or late-night wind resources, maximizing integration of renewables, but this approach is outside the scope of this study.

In this study, managed charging is implemented through TOU periods that are designed around system peaks to enable system-peak avoidance. Duty cycles are shifted in response to signals from a TOU rate, and operational constraints will limit some fleet’s ability to adjust their charging schedule. Additionally, we apply site-specific demand management designed to avoid demand spikes. When applied, energy is disbursed to the vehicle evenly over the entire time the vehicle is in the yard. This method requires consistent and predictable charging patterns within a fleet. Within the operational constraints of a given vehicle category, we apply an expectation of full compliance with the managed charging signal for those fleets that take-up the measure.

1.2.3 Estimated Opportunity for Managed Charging Measures in New York State

In this section we present modeling to assess the potential of managed charging measures to reduce grid impacts. Appendix C details the effects of charge management interventions for each charging context studied, illustrated by the unmanaged and managed load shapes.

1.2.3.1 Assumed Take-Up and Effects of Charge Management Measures on Residential EV Load

A valuable contribution of this analysis, and how it differs from other similar projects, is that we do not apply a broad assumption of economically rational behavior. Both regarding decisions to participate in measures likely to provide cost-savings to EV owners as well as in the scale of users’ responses to price signals, we draw from real-world data and thus incorporate some of the idiosyncrasies that characterize charging behavior. For this analysis we apply take-up rates of up to 92%, akin to those documented for single-metered charge management measures where participants are defaulted into participation (Table 3). Again, this reflects the assumption that technology readiness and regulatory acceptance of virtual submetering or internal EVSE metering will eliminate the need for installation of a secondary

EV-specific meter. Participation rates for programs that require a separate meter for the EV are dampened due to the burden of initial installation costs, but without the requirement for a second meter we would expect take-up more akin to that of the single-metered measures. Table 9 shows the take-up rates of the managed charging protocols in benchmark years. These are applied in both the Reference and Mitigation Cases.

Table 9. Residential Managed Charging Modeling Assumptions: Take-Up Rates

Vehicle Category	TOU Take-Up Rate 2020	TOU Take-Up Rate 2030	TOU Take-Up Rate 2040	TOU Take-Up Rate 2050
RLevel1	20%	80%	92%	92%
RLevel2	20%	80%	92%	92%

As described above, early analyses indicate that EV charging load is elastic to price. However, the price regimes consumers face, whether TOU tariffs or critical peak pricing, are not continuous distributions, so we do not employ actual elasticities to model measure effects. Rather, we focus on the change in charging behavior relative to baseline activity during the period and the associated price ratio between the peak, partial-peak, and off-peak periods to ascertain generalizable relationships.

Table 10 provides the effect sizes of charge management measures applied in the modeling. For consistency across the analysis, these more closely reflect the documented effect sizes of the separately metered measures described above. These are the most appropriate effect sizes to apply to our baseline charging behavior because the baseline load shapes are from separately metered vehicles. Additionally, this enables us to carry through the assumption that EV owners will not require an EV-specific secondary meter to participate in EV-specific managed charging programs.

Table 10. Residential Managed Charging Modeling Assumptions: Measure Effects

Setting	On: Off Price Ratio	On-Peak Load Reduction (%)	Partial: Off Price Ratio	Partial-Peak Load Reduction (%)
Residential L1	3.1427	0.7557	1.7947	0.8621
Residential L2	5.1526	0.5068	2.7093	0.4963

These modeled effect sizes are based on evidence from past programs, thus presenting some limitations to their application in a new context. Most of the studies revealing consumer charging behavior that we utilize to formulate our take-up rates and effects were undertaken in California. There are fundamental geographic and demographic factors that could mean the California studies provide an imperfect

representation of the relationships that would be observed in New York State. Most programs report the activity of early adopters that have opted into the program, so their sensitivity to the measures applied may not be representative of the effectiveness of such measures as the population of EV adopters change. Nearly all of these programs implement behavioral measures, so the effect sizes have may be a poor representation of the potential effects of DLC measures. However, based upon the insights garnered from the limited DLC cases described above, it is likely that the effects of DLC measures would be greater than or similar to the behavioral measures modeled here.

1.2.3.2 Assumed Take-Up and Effects of Charge Management Measures on Commercial EV Load

Due to the lack of empirical evidence on managed charging measures in the Public L2 and DCFC contexts, we do not model any take-up of managed charging measures applied to public chargers.

The MHDV segment is considerably varied; as such, take-up varies substantially across the vehicle categories. In all cases, due to operational requirements, fewer than 100 percent of the State’s MHDV fleets are anticipated to adopt managed charging measures. Table 11 presents assumptions of measure take-up over time.

Table 11. MHDV Managed Charging Modeling Assumptions: Take-Up Rates

Vehicle Category	TOU Take-Up Rate 2020	TOU Take-Up Rate 2030	TOU Take-Up Rate 2040	TOU Take-Up Rate 2050
Light Commercial Trucks	20%	40%	60%	60%
Transit Buses	50%	80%	95%	95%
School Buses	50%	80%	95%	95%
Refuse Trucks	50%	80%	95%	95%
Single Unit Short Haul Truck	N/A	20%	40%	60%
Combination Unit Short Haul truck	N/A	20%	40%	60%
Single Unit Long Haul Truck	N/A	20%	40%	60%
Combination Unit Long Haul truck	N/A	20%	40%	60%

The measure take-up rates are considered conservative, which is appropriate given how the effects of managed charging measures are modeled for the MHDV segment. As discussed above, for those fleets that do take-up measure, we assume complete responsiveness to the managed charging signal within the operational constraints of that vehicle category.

1.2.3.3 EV Charging Load Shapes with Interventions

This section illustrates the effect of transportation electrification (TE) load on the magnitude and timing of the system peak in New York State out to 2050. All values discussed in this section relate to the M1 Scenario described in the New York Clean Transportation Roadmap. The M1 Scenario is the “high EV use” scenario in which nearly all on-road vehicles are battery electric vehicles by 2050. Vehicle miles traveled in the M1 Scenario rise by an average of 0.84% per year for all on-road vehicles, although the exact change differs by vehicle category (e.g., transit bus VMT rises by 2.2% per year whereas light-duty vehicle VMT rises by 0.8% per year).

To assess the cumulative potential for managed charging measures to mitigate EV-related grid impacts, the team identified the energy demand associated with each charger category in the years 2020, 2030, 2040, and 2050 under an economy-wide decarbonization scenario. Using the unmanaged load shapes detailed in appendix C, this load was integrated with the economy-wide peak day- profiles in each target year, indicated by the blue line in the figures below. This process was repeated for the managed charging scenario, but the load associated with the portion of each charger category that is anticipated to take up the managed charging measures was shifted to the managed charging load shape. The resulting economy-wide peak day, load profile, indicated by the orange line in the figures, illustrates the potential reduction in system peak that EV managed charging measures could achieve under the given assumptions. Notably, in 2020, when the scale of EV deployment and take-up of measures are assumed to be low, the effect is imperceptible; however, as the assumed deployment and take-up increase over the intervening decades, the magnitude of the effect of these measures is anticipated to become very meaningful for the electricity system, reaching 14 gigawatts (GW) in avoided peak load by 2050.

Figure 7. Effect of Managed Charging on 2020 Winter Peak Day Profiles

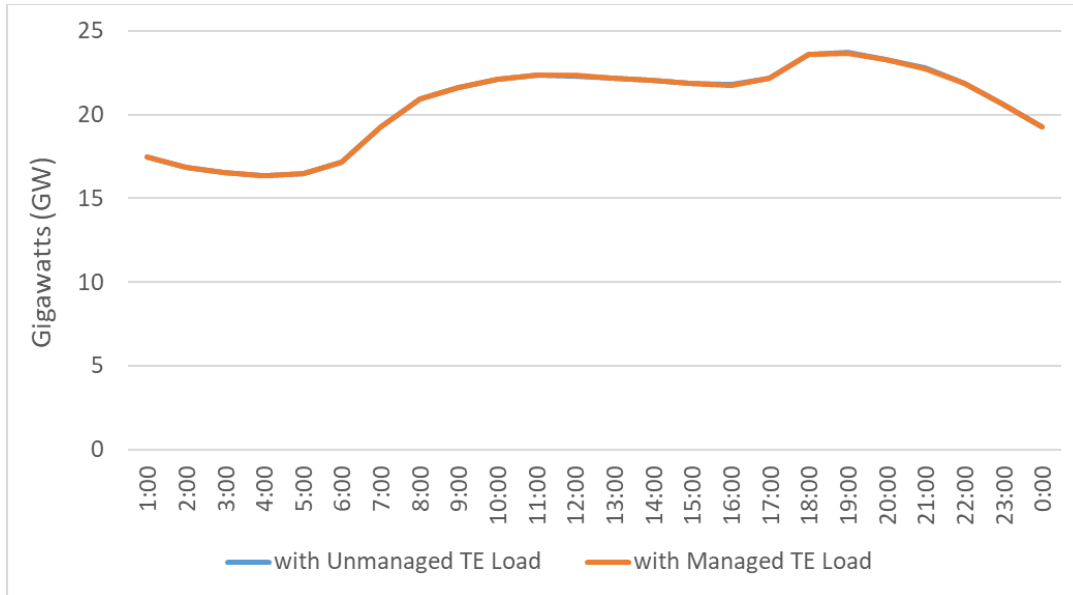


Figure 8. Effect of Managed Charging on 2030 Winter Peak Day Profiles

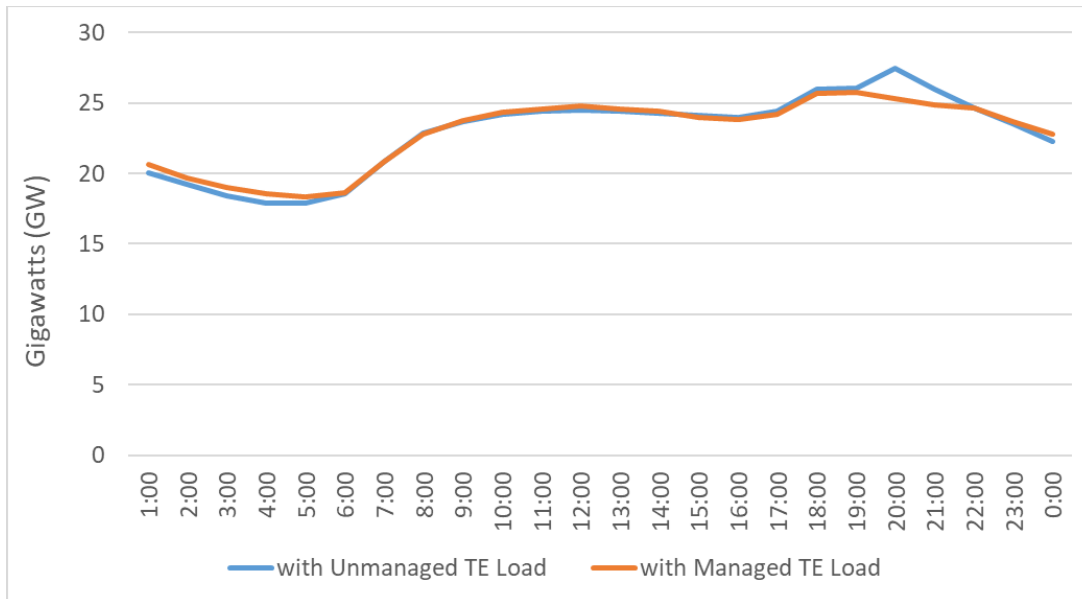


Figure 9. Effect of Managed Charging on 2040 Winter Peak Day Profiles

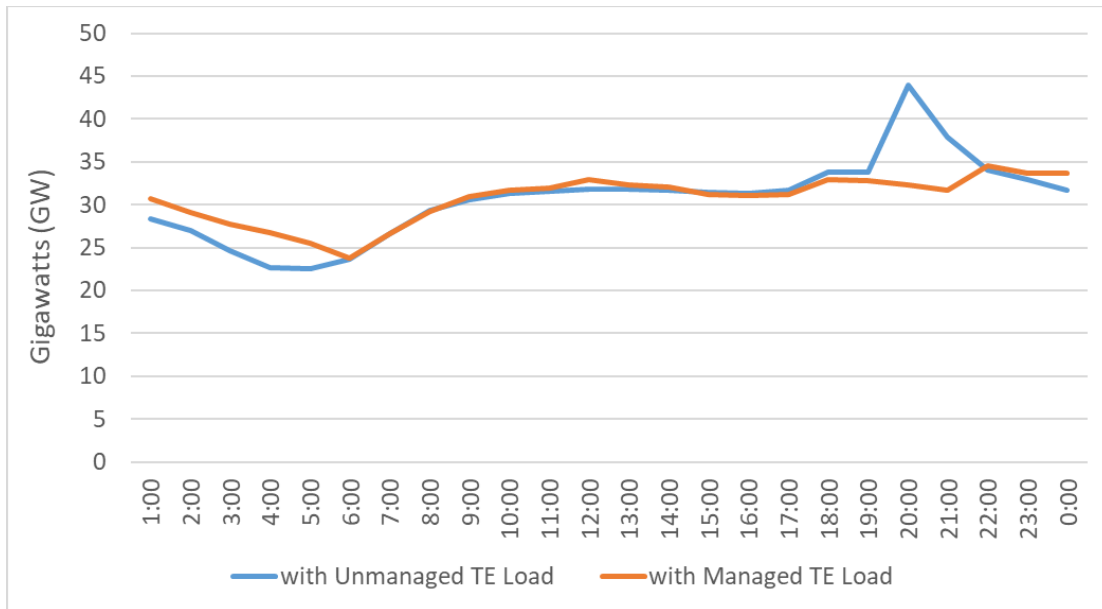
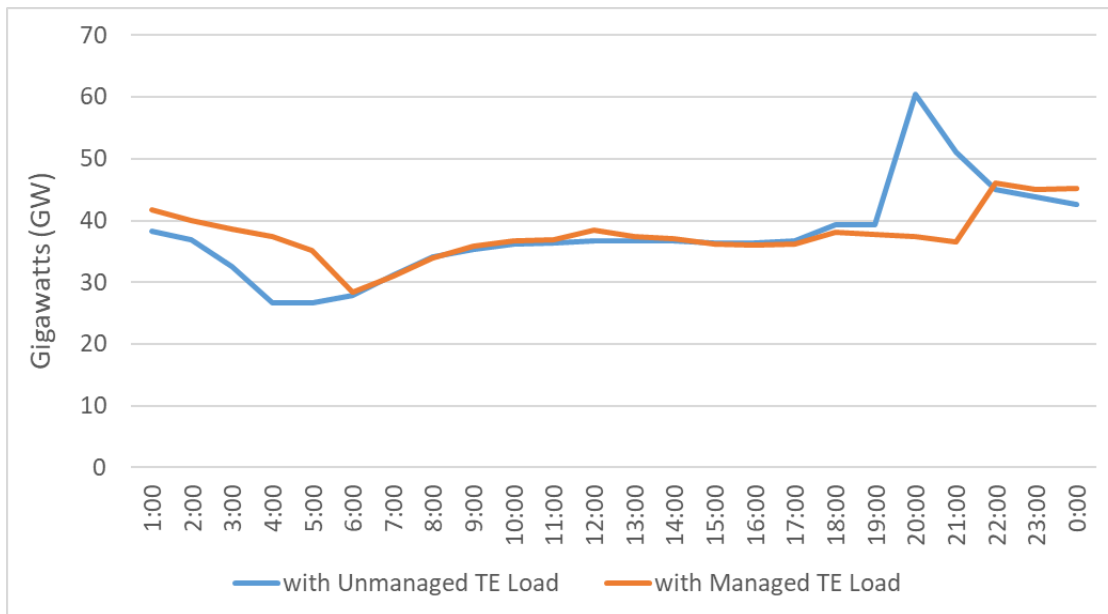


Figure 10. Effect of Managed Charging on 2050 Winter Peak Day Profiles



Not only does managed charging reduce the total system peak, but it also moderates the slope of the system ramp. The system peak with unmanaged transportation load, represented by the blue line, includes a 20 GW surge in electricity demand between 7:00 and 8:00 p.m. When the managed charging measures are applied, the challenge of the achieving the system ramp is doubly reduced—not only is the magnitude of the ramp is smaller, but it occurs more gradually, as indicated by the more moderate rise of the orange

line over the two-hour period between 9:00 and 11:00 p.m. Note that despite their distinct forms, both load shapes illustrated by the blue lines provide the same total energy over the course of the day. The lower and later peak can lessen the need for additional electrical capacity and infrastructure upgrades, resulting in cost-savings.

1.3 Discussion and Conclusions

As technologies and policies continue to develop over the next 30 years, it is likely that additional tools for managing EV load will become available that will further enable the flattening of EV electricity demand. Examples include real-time rates or dynamic pricing, low-cost energy storage, and direct load control through grid-integrated technologies.

1.3.1 EV Managed Charging Measures and Market Penetration

This report provides insight into the set of measures proposed and in use to promote smart management of EV charging load. Among our key findings, we note that policies and programs should emphasize the need for communication protocol standards across EV and EVSE hardware and software for successful VGI. The market is starting to coalesce around OCPP in combination with either ISO/IEC 15118 or Open ADR.⁸⁷ In the U.S., there is a need for widespread standardization to simplify VGI for utilities and encourage EV adoption.

Existing pilot programs have demonstrated the feasibility of VGI programs through successful implementation of EV driver incentives, networked chargers, and plug-in devices. Program administrators and analysts should consider factors such as the accuracy of EVSE integral meters versus revenue-grade meters, as EVSE accuracy can vary by service provider. However, higher cost solutions may have an impact on consumer up-take. As technology improves and new business models emerge, more research may be needed to further explore any tradeoffs that may exist between different solutions.

In this quickly evolving space, it is useful to keep an eye toward the global market. European countries, especially the Netherlands, have been strong leaders in VGI, but the U.S. has unique size, infrastructure, and cultural challenges. Forward-thinking policy and program design should account for upcoming V2G and V2H market applications.

1.3.2 EV Managed Charging Load Implications

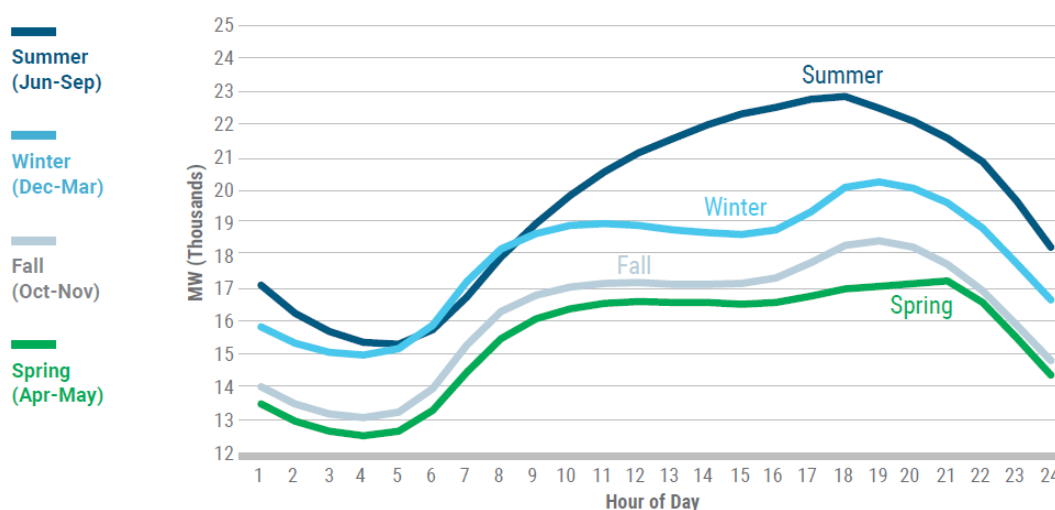
This study models the effects of managed charging measures to illustrate the potential impact of their application to vehicle-related electric load in New York State. Our research indicates that program design decisions are central to enabling flexible load and maximizing the effect of these measures.

Key components are:

- Applying the default principle to nudge EV owners toward charging behaviors preferred by the electricity grid.
- Embracing alternative sub-metering techniques to avoid installation of a secondary meter.

This analysis suggests that if New York State were to implement proven managed charging measures, the electricity grid could avoid substantial demand that would otherwise coincide with the system peak. Even today, when EV penetrations are quite low, the magnitude of this potential flexible load is estimated to be at least 10 megawatts (MW) during the summer system peak of 5:00 p.m. to 6:00 p.m., as illustrated in Figure 10. For context, this is 0.15% of the State’s required reserve margin of 6,674 MW.⁸⁸

Figure 11. Seasonal Hourly Demand Patterns: 2019 (NYISO)⁸⁹



As the number of EVs increases in the State, the available flexible load is also expected to increase. The team estimates that TE load in an unmanaged charging case is 38 MW in 2020 and increases to 26.9 GW by 2050, with the peak TE load occurring between 7:00–8:00 p.m. for all years. This load includes all on-road electric vehicles but does not include other electrified equipment, such as aircraft, lawn equipment, forklifts, marine vessels, etc. With managed charging of TE load, the grid has an estimated 14 GW of avoided peak by 2050, equivalent to roughly 23% of New York State’s expected peak demand.

1.3.3 Opportunities for Future Work

One key area for further research is the collection and analysis of empirical data on the take-up and effects of managed charging measures in MHDV fleet settings. This is stymied by the nascent nature of electrification in many of these vehicle segments. Study of rates of adoption of managed charging measures by light-duty commercial vehicle fleets and insights from stated preference surveys of MHDV fleet managers are a few avenues for near-term research that could inform future analyses.

A second area of interest for future inquiry is the opportunity for managed charging at public chargers, especially in urban areas like the New York City metropolitan area. In contexts where access to residential charging is limited, public charging will become more prevalent and mechanisms to manage that load will need to be developed. It is possible public chargers could be sited in multipurpose lots and be occupied consistently throughout night and day by consumers. In this scenario, these public chargers would have a much flatter load shape than residential load shapes that peak at night or public load shapes that peak during the day. Therefore, the impact of a charger intervention measure might look significantly different than the analysis currently conducted on residential and commercial MHDV chargers.

Appendix A. Additional Data: Managed Charging Measures

The studies summarized in Table 12 do not have a clear set of data points to serve as the baseline or counterfactual, against which the effect of the pricing structure that was applied can be assessed. Nonetheless, the studies illustrate the distribution of charging load over different periods of the day and reflect the same patterns and trends as would be expected.

Table A-1. Incidence of EV Load by TOU Period and Price Ratio

Study	Level	Setting	Meter	On: Off Price Ratio	Share On-Peak Load (%)	Partial: Off Price Ratio	Share Partial-Peak Load (%)
CECJI--SDG&E	?	?	Single	1.71	23.78%	1.15	36.36%
CECJI--SDG&E	?	?	Separate	1.71	7.42%	1.15	13.78%
TOU+Tech - SDG&E	L2	SFH	Separate	1.63	7.50%	1.21	7.00%
TOU+Tech - SDG&E	L2	SFH	Separate	3.43	6.00%	2.22	5.50%
TOU+Tech - SDG&E	L2	SFH	Separate	5.27	4.50%	2.11	5.00%

Note: Partial-peak periods are TOU windows designed to appropriately price shoulder periods when the electric system load is neither in a peak nor a trough.

Appendix B. EV Growing Pains Load Curves

Figure 11 and Figure 12 below are the load profiles from the EV Growing Pains report.^{90,91} The load shapes created were customized based on the changes in peaks the figures depicted.

Figure B-1. Winter Load Profile

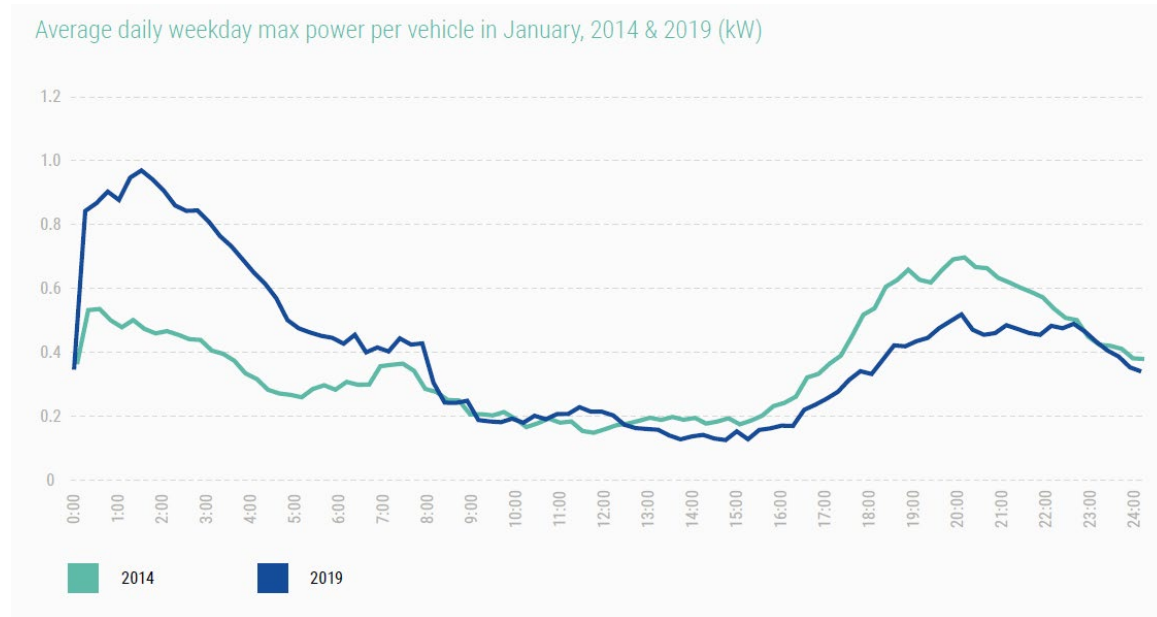
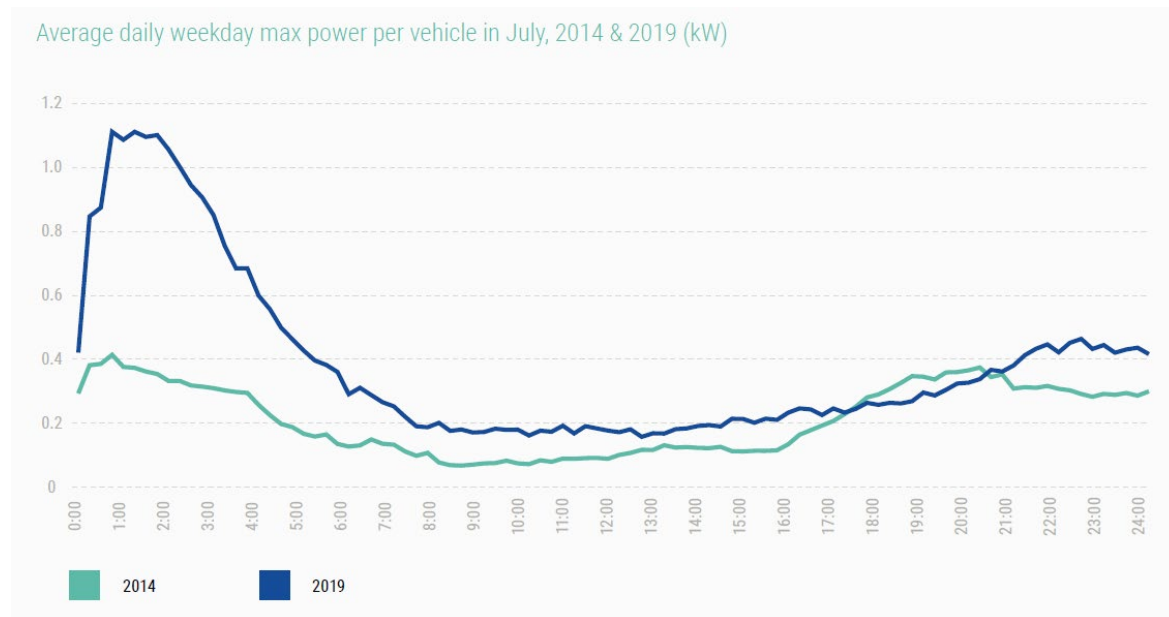


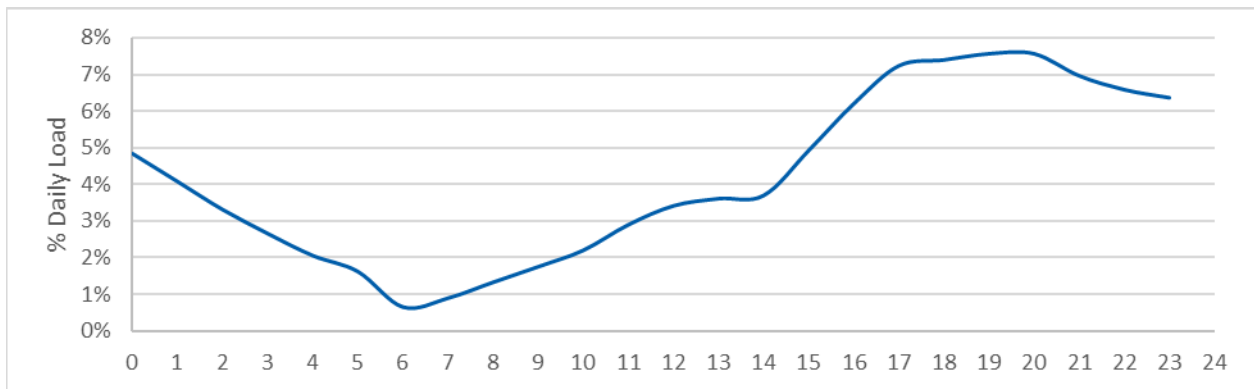
Figure B-2. Summer Load Profile



Appendix C. EV Charging Load Shapes

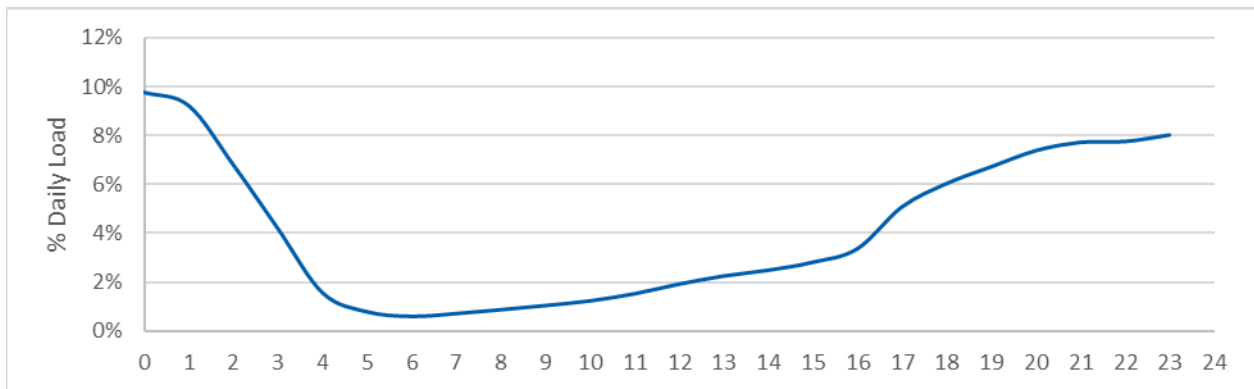
The residential and public unmanaged load shapes are derived from empirical data obtained from the Idaho National Lab’s (INL) Advanced Vehicles Project and from supporting data that the National Renewable Energy Lab (NREL) provided for their Impact of Uncoordinated Plug-In Electric Vehicle Charging on Residential Power Demand Research Paper.^{92, 93} The daily load shapes are calculated in terms of Percent Daily Load, indicating the share of daily load occurring in each hour.

Figure C-1. Residential Level 1 Charger: Daily Load Shape



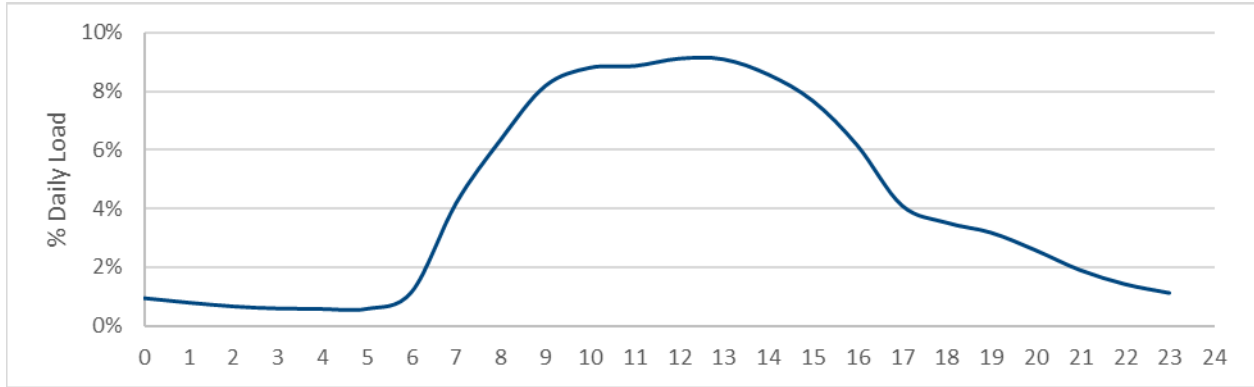
The residential Level 2 load data does not differentiate between single- and multifamily homes but is assumed to include both. Note that because these load shapes are based on a limited number of EV models, they likely understate the natural staggering of EV load that occurs when a diverse set of vehicle models with varied battery capacities and daily energy needs are managed to unique target end times.

Figure C-2. Residential Level 2 Charger: Daily Load Shape



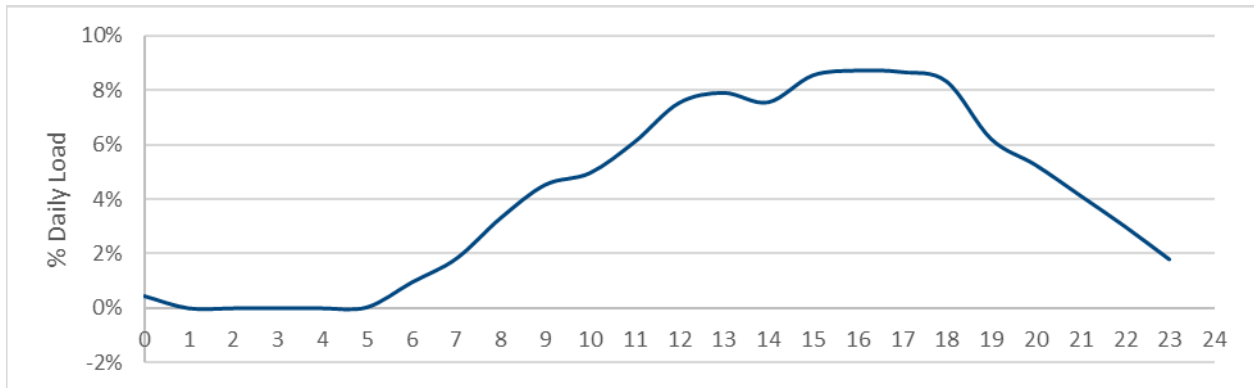
The public Level 2 load shape depicted below represents chargers both on public land, such as in the right-of-way or on municipal lots, and at workplaces.

Figure C-3. Public Level 2 Charger: Daily Load Shape



The DCFC included in this data set are rated at 50 kW. To account for DCFC that are rated higher than 50 kW, the slope of the curve was increased to reflect a higher power rating when charging starts in the morning, and when it tapers off in the evening.

Figure C-4. Public Direct Current Fast Charging: Daily Load Shape



MHDV unmanaged and managed daily load shapes present the average charger profile as a percentage of total daily load. These load shapes assume take-up of managed charging measures vary across MHDV categories and measure types, and MHDV fleet managers act rationally and will cost optimize. Unlike the above light-duty vehicle (LDV) load shapes where metering structure bounds measure take-up decisions, MHDV measure adoption decisions are constrained by vehicles' 24-hour duty cycles.

Figure C-5. Light Commercial Truck Charger: Daily Load Shape

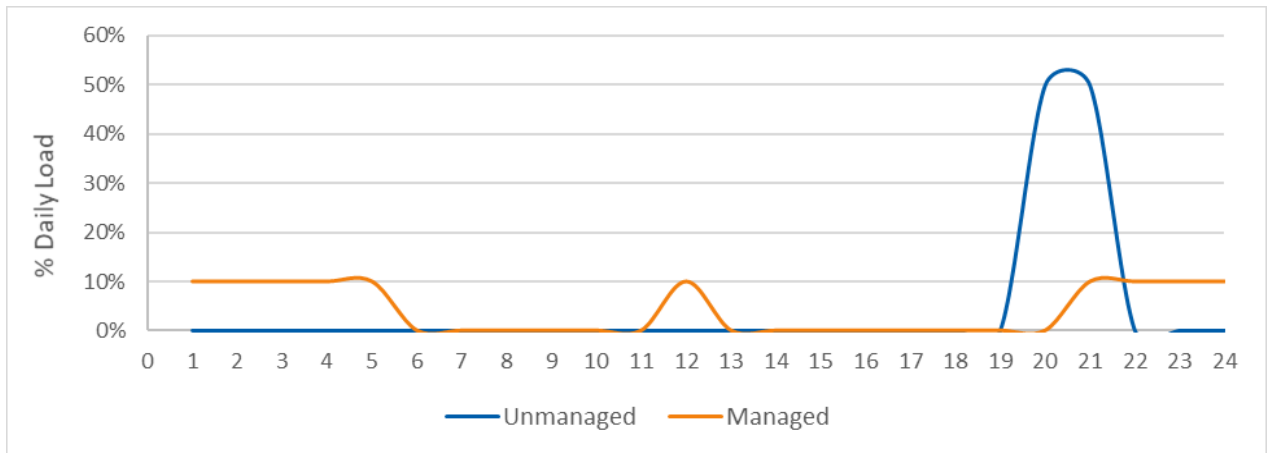


Figure C-6. School Bus Charger: Daily Load Shape

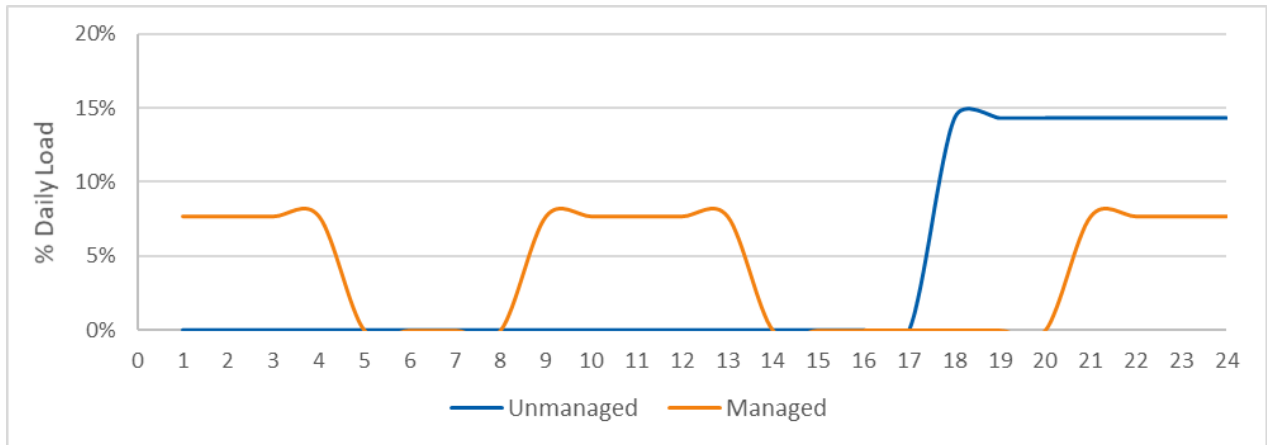


Figure C-7. Transit Bus Charger: Daily Load Shape

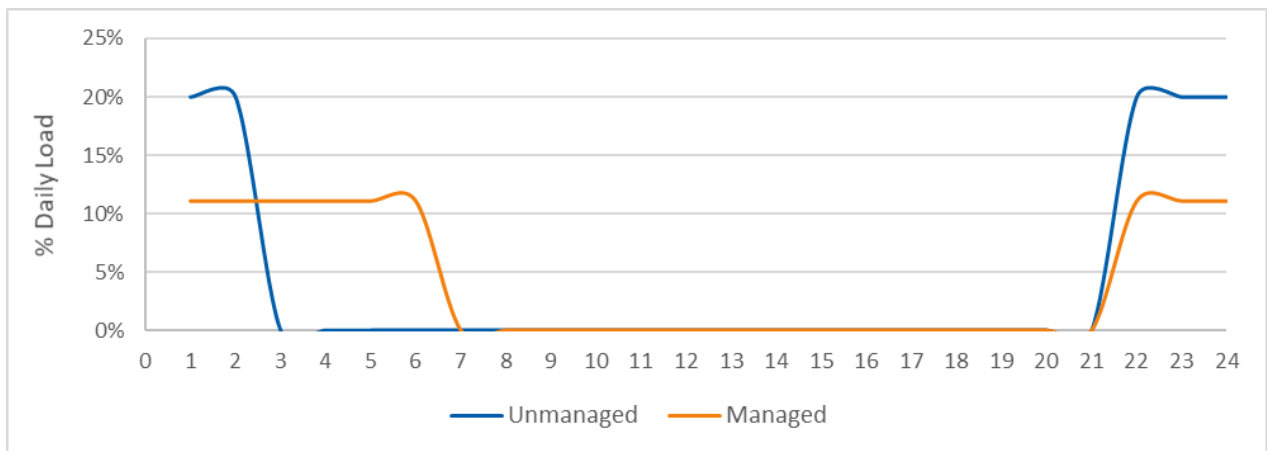


Figure C-8. Refuse Truck Charger: Daily Load Shape

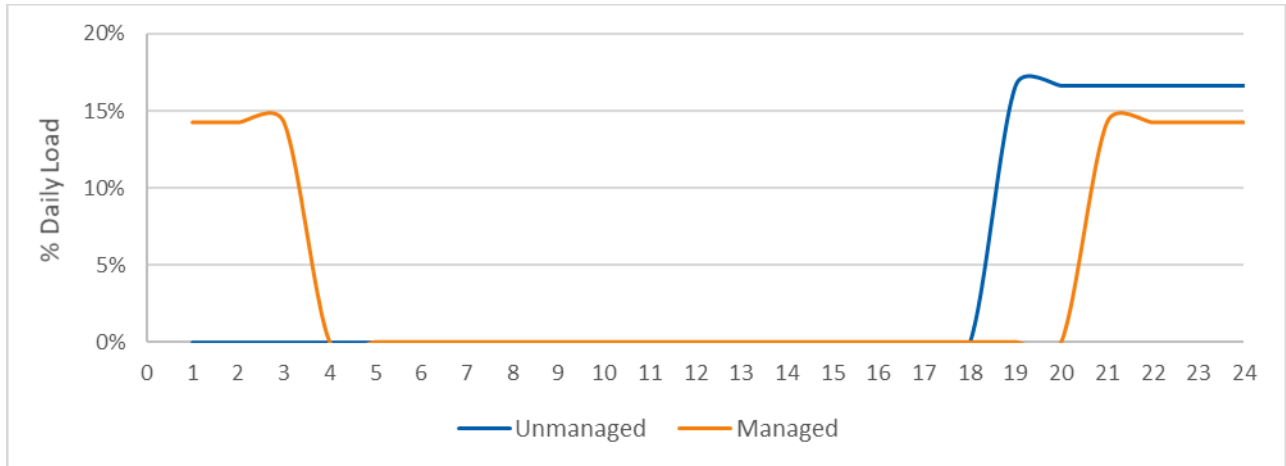


Figure C-9. Single Unit Short-Haul Truck Charger: Daily Load Shape

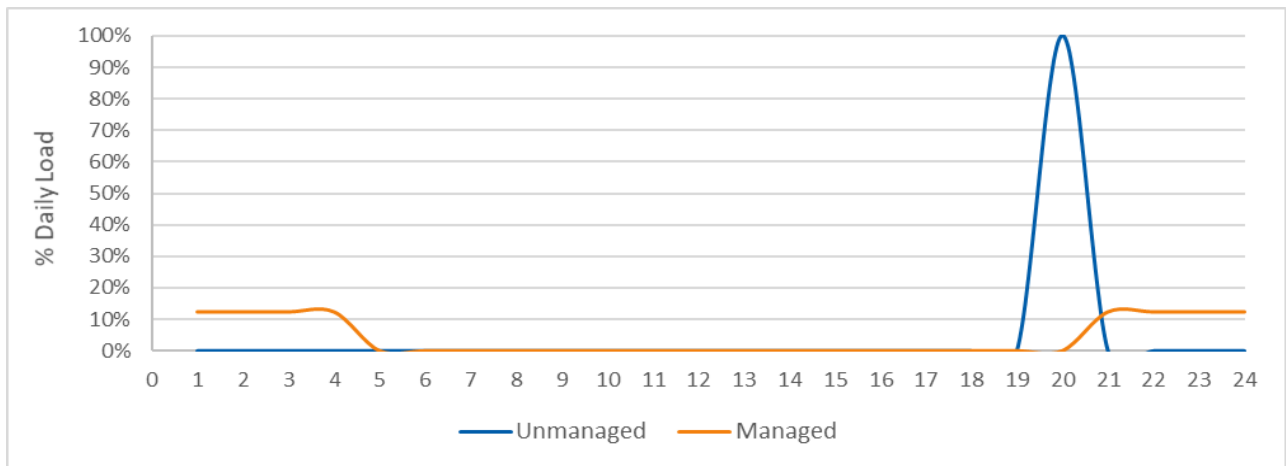


Figure C-10. Single Unit Long-Haul Truck Charger: Daily Load Shape

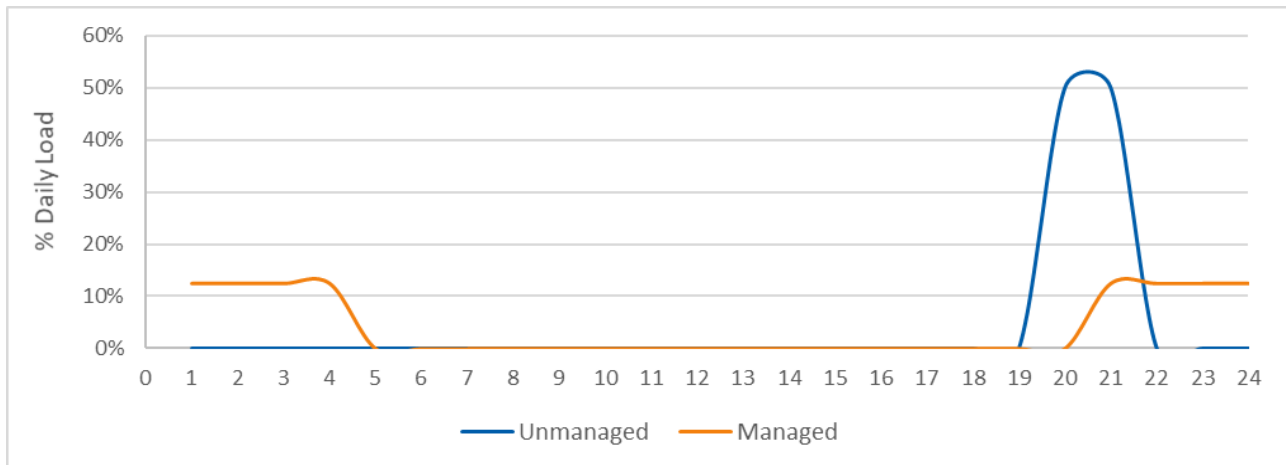


Figure C-11. Combination Short-Haul Truck Charger: Daily Load Shape

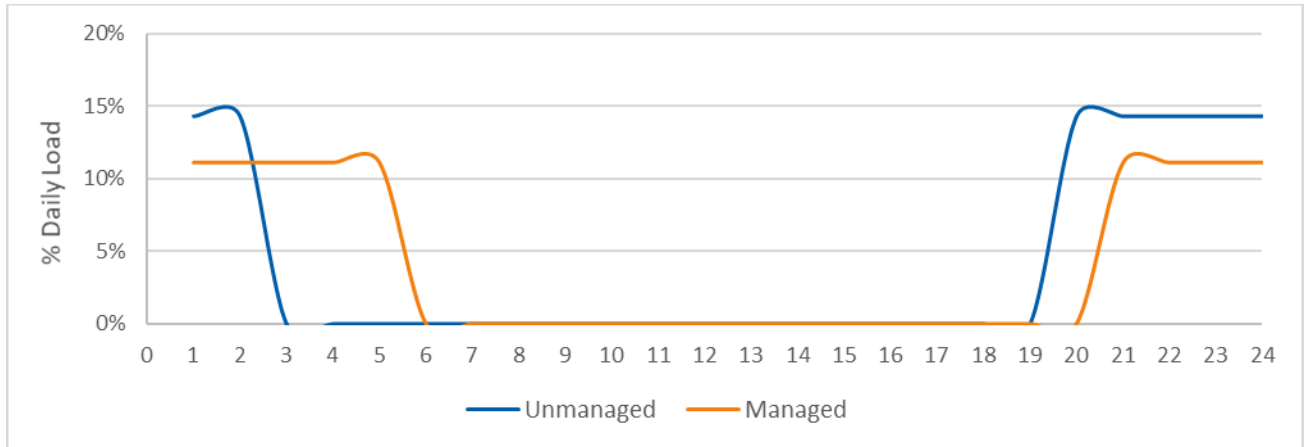
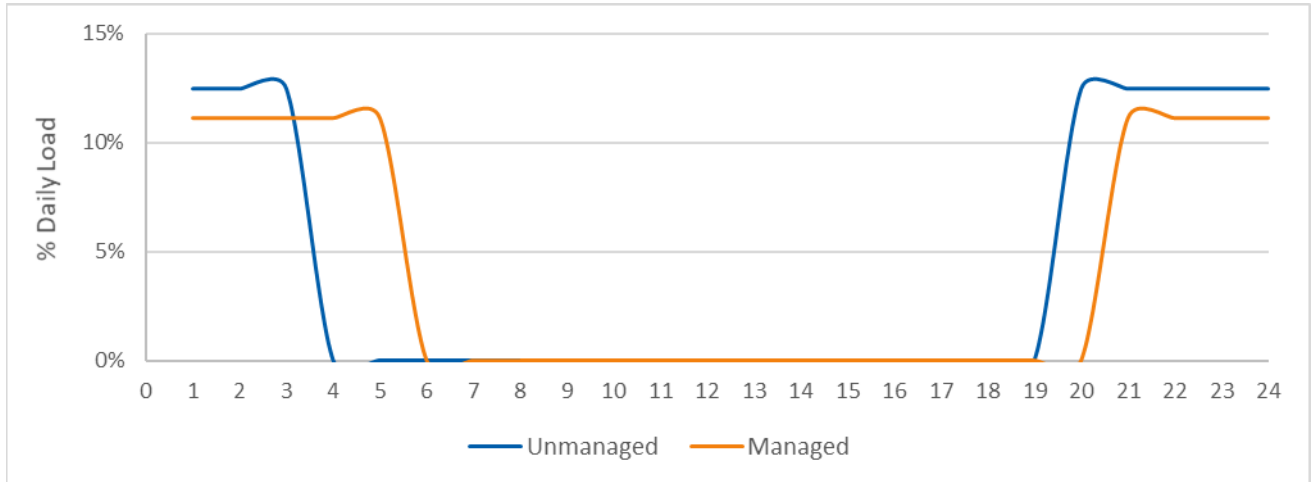


Figure C-12. Combination Long-Haul Truck Charger: Daily Load Shape



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**New York State
Energy Research and
Development Authority**

17 Columbia Circle
Albany, NY 12203-6399

toll free: 866-NYSERDA
local: 518-862-1090
fax: 518-862-1091

info@nyserdera.ny.gov
nyserdera.ny.gov



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