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Solar Power + Electric Vehicle Charging

CAPTURING SYNERGIES IN MINNESOTA

PREPARED BY THE GREAT PLAINS INSTITUTE

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Acknowledgements

MINNESOTA SOLAR ENERGY INNOVATION NETWORK (SEIN) TEAM

Led by the Great Plains Institute (GPI), a Minnesota team of agencies, nongovernmental organizations (NGOs), utilities, cities, and solar and EV stakeholders (the Minnesota SEIN Team) investigated the market potential, both opportunities and barriers, of EV charging infrastructure synchronized with solar energy production as a means of accelerating the EV market and expanding solar deployment. The initiative was part of the Solar Energy Innovation Network (SEIN), a national effort led by the National Renewable Energy Laboratory (NREL) that works with multi-stakeholder teams to research solutions to challenges associated with solar energy adoption. This project would not have been possible without the substantial contribution of the following organizations and individuals:

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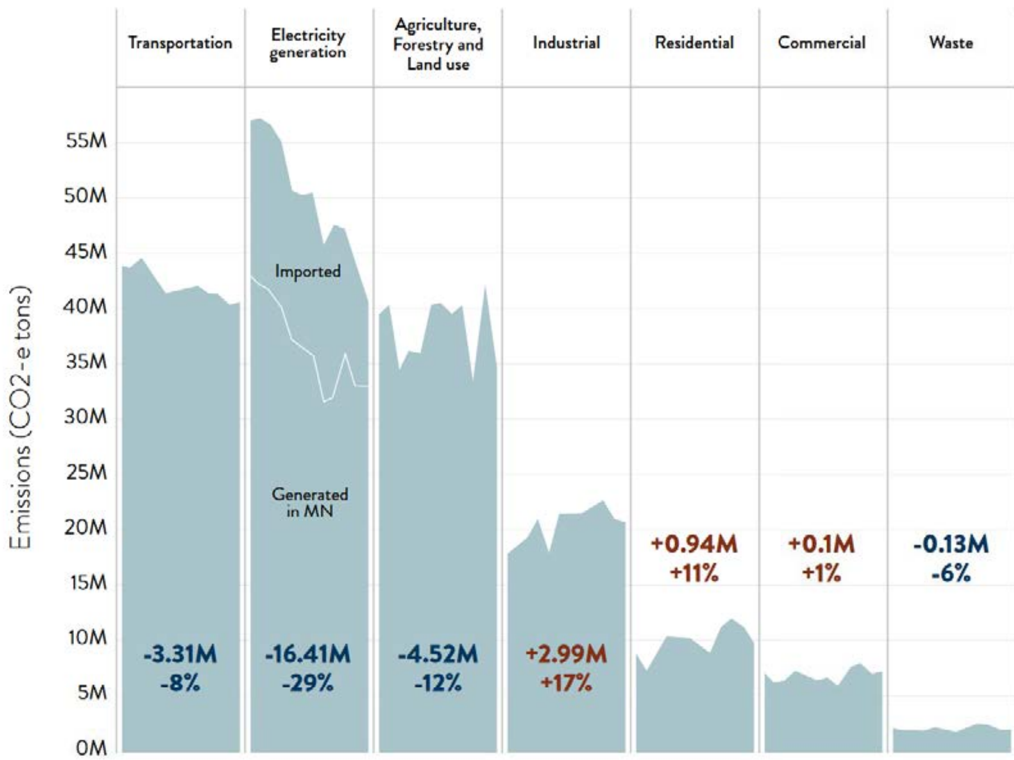
Executive Summary

In 2007, Minnesota enacted one of the most aggressive climate action commitments in the nation, setting a mandatory goal of reducing statewide greenhouse gas (GHG) emissions by 80 percent from a 2005 baseline by 2050. In 2013, Minnesota passed additional solar energy deployment commitments and set goals that sought to capture the opportunity created by rapidly declining costs and recognized solar resources as the state's most abundant and ubiquitous energy resource.

After 13 years, Minnesota's efforts to reduce emissions in the power sector have been largely successful, with a 29 percent decline in power sector emissions and renewable energy deployment rising rapidly (Figure 1).

Figure 1. Minnesota emissions by sector 2005-2016



Source: Pathways to Decarbonizing Transportation, MnDOT, 2019, 15. Source data from 2016 MPCA Greenhouse Gas Inventory.

Emission reductions in other sectors, however, are well behind interim targets. In 2018, the largest source of GHG emissions shifted from electric generation to transportation. State policy and administrative action has now moved to addressing transportation emissions, including linking the state's success in clean electric power to the electrification of transportation. This refocusing has manifested in several specific actions by the state:

- The adoption of electric grid modernization principles by the Minnesota Public Utilities Commission (PUC) that support the evolution of the state's electric grid from being designed for centralized power generation to a grid that accommodates distributed generation and management of flexible loads, such as solar energy and electric vehicle (EV) charging.
- Developing transportation electrification goals of 20 percent EV penetration for passenger vehicles by 2030.
- Conducting stakeholder engagement and detailed modeling to identify Minnesota Department of Transportation priority pathways to decarbonizing transportation systems across the state.
- Launching an administrative action to adopt "clean car" standards for the state, joining 14 other states in adopting low-emission vehicle standards (LEV) and/or zero-emission vehicle standards (ZEV) for auto sales within the state.

Minnesota Grid Modernization Principles

1. Ensure continued safe, reliable, and resilient utility network operations.
2. Enable Minnesota to meet its energy policy goals, including the integration of variable renewable electricity sources and distributed energy resources (DERs).
3. Provide for greater system efficiency and greater utilization of grid assets.
4. Enable the development of new products and services.
5. Provide customers with necessary information and tools to enable more informed control and choice regarding their energy use.
6. Support a standards-based and interoperable utility network.

THE SOLAR + ELECTRIC VEHICLE OPPORTUNITY

Despite the state policy support, significant market barriers to decarbonization of transportation remain. Analysis conducted by the National Renewable Energy Laboratory (NREL) and others confirm that without routine access to charging infrastructure, both at home and in non-residential locations, bullish market forecasts are unlikely to materialize. Similarly, the expansion of EV charging and variable renewable energy deployment each have potentially disruptive and costly effects on the distribution grid. Finally, electrification of passenger vehicles is not enough to decarbonize transportation *without pathways to carbon-free electrification*, linking EV charging and clean energy generation.

This document examines the opportunity to jointly deploy solar energy and EV charging infrastructure to capture synergistic value, mitigate for risks associated with integrating and scaling both solar and EV charging, and accelerate their mutual deployment.

SOLAR ENERGY INNOVATION NETWORK

Led by the Great Plains Institute (GPI), a Minnesota team of agencies, nongovernmental organizations (NGOs), utilities, cities, and solar and EV stakeholders (the Minnesota SEIN Team) investigated the market potential, both opportunities and barriers, of EV charging infrastructure synchronized with solar energy production as a means of accelerating the EV market and expanding solar deployment. The initiative was part of the Solar Energy Innovation Network (SEIN), a national effort led by the National Renewable Energy Laboratory (NREL) that works with multi-stakeholder teams to research solutions to challenges associated with solar energy adoption. The Minnesota SEIN project focused on the following:

- ✓ examining the value propositions offered by different solar+EV technologies and applications
- ✓ identifying and understanding the different use cases for solar+EV applications, and prioritizing uses cases with the most opportune pathways to scaled deployment and impact on carbon reductions
- ✓ analyzing data from solar+EV pilot and demonstration projects

KEY FINDINGS

The project reviewed published literature and studies of solar+EV, incorporated findings and stakeholder input from ongoing regulatory and program initiatives in Minnesota, directly engaged specific market actors and participants on solar+EV opportunities and barriers, conducted a review of solar+EV pilots, and modeled the value of solar+EV under various use cases.

Some key takeaways for understanding market transformation opportunities and barriers include:

1. **The patterns of solar production and unmanaged EV charging have, at best, a mediocre overlap**. Even focusing on daytime charging use cases, there is a timing mismatch of several hours between peak solar production and peak EV charging. However, pairing managed charging with use cases such as workplace charging or public parking has the potential to bridge the mismatch and improve the economics of both EV charging and distributed solar.
2. **Aligning or synchronizing solar production and EV charging can create value for the site-owner, the distribution grid, and the bulk power system**. The primary economic benefit for the solar+EV site host is in lowering demand charges associated with unmanaged daytime charging (where applicable, such as at commercial building hosting workplace charging paired with on-site solar), for the distribution grid in reducing local or component peaks and preventing overload or degradation, and for the bulk power system in enabling the integration of higher amounts of renewable energy.
3. **Some solar+EV use cases present substantially better opportunities than others**. The most promising use cases have four characteristics:
    a. Large enough sites to capture economies of scale for both EV and solar installations.
    b. Electric rate schedules and metering to allow the site owner to capture value, particularly to reduce demand charges.
    c. Consistent, long, daytime parking tenure to allow economic tradeoff between solar generation, flexible EV charging, and battery storage and use.
    d. Opportunities for widespread deployment in order to be able to meaningfully grow the market and decrease GHG emissions.
4. **Daytime EV charging is critical to achieving transportation electrification goals**. Current and forecast patterns of charging behavior show that 80-85 percent of EV charging will occur at night or in the evening. But the 15-20 percent

of charging that will occur during the day is critical to transportation electrification goals. Workplace, destination, and corridor fast charging are necessary to enable deep penetration of EVs into the passenger vehicle fleet.

5. **Site owners or managers need an understanding of the economic potential of solar+EV applications, an approach to considering use cases, and clear pathways for implementation.** The site owner is the deployment decision maker. Other market actors (utilities, grid operators, and state and local government) can influence the value proposition and the decision, but the site owner value is key.
6. **Distribution system impacts and costs with solar+EV charging need to be better understood**. Charging multiple EVs simultaneously on the same distribution grid component can create over-capacity issues or power quality issues. Coupling EV loads to on-site generation or generation on the same distribution subsystem can remove or limit the risks. But few best practices for valuing and programmatically capturing this benefit can be found in literature or program designs. Grid value clearly has potential to be positive, but assigning value to it within program design and managing the dispatch of synchronized charging needs more testing and research.
7. **A variety of solar+EV technologies are now available in the market, which can result in different values for the EV customer, site owner, and grid operator, depending on the EV charging use case.** This review found that the applications of solar+EV charging that provide the greatest value for customers, the distribution grid, and the bulk power are the grid-tied technologies that enable synchronization of solar production and EV charging. These promising use cases can include managing charging so that it is timed with solar production or using battery storage to manage EV charging loads and solar production.

RECOMMENDATIONS FOR MARKET TRANSFORMATION

Market transformation requires an integrated effort among participants in order to create an economically self-sustaining market. Critical market participants include state and local governments, utilities, property owners/managers of workplace charging and public parking, and the solar and EV charging industries. Key recommendations are summarized below by the entity that would need to lead the action, though all require on partnerships across stakeholders. The four categories of activities are private sector initiatives, local government policies and programs, utility rate design and programs, and state government policies and programs.

> *Market Transformation*
>
> The strategic process of intervening in a market to create lasting change in market behavior by removing identified barriers and/or exploiting opportunities to accelerate the adoption of all cost-effective energy efficiency as a matter of standard practice.
>
> Source: conduitnw.org/Pages/Article.aspx?rid=910

Private Sector Initiatives

The private sector actors (solar and EV industries in particular)) can create initiatives to capture solar+EV value in its products and services.

Recommendation—Create solar+EV market products to notify the market of the value-added opportunity of pairing the technologies.

- Co-market solar products with an EV charging option and vice versa.
- Capture construction and design economies of scale with pre-engineered solar carport products.
- Ensure that commercial solar installations are EV-ready with synchronization hardware and communications systems.
- Develop financing options specific to solar+EV products.
- Promote use cases for combined solar, energy storage, and managed charging.
- Identify opportunities to incorporate solar+EV into new commercial and mixed-use development.

Local Government Actions

Local governments, through such actions as setting development priorities, land use regulations, and building codes, can ensure the development of needed infrastructure and set incentives for beneficial infrastructure while removing inadvertent barriers to solar+EV applications.

Recommendation—Incorporate EV charging-ready infrastructure into local ordinances, codes, and development programs, similar to solar-ready buildings requirements and standards.

- Modify development regulations (e.g., parking standards, zoning) to enable or require EV charging or to prioritize solar+EV land uses.
- Support code changes or stretch codes that require EV charging infrastructure and incentivize solar-synchronized charging.
- Link city development incentives (financial or regulatory), city grants, and sustainability programs with EV infrastructure and solar+EV outcomes.
- Create local government collaborations with the electric utility to expand the market for solar+EV and ensure distribution grid benefits.
- Develop an EV-ready city certification program to supplement existing city certification or technical assistance programs, such as Minnesota's GreenStep Cities program and the national SolSmart solar designation program for local governments.

Utility Programs and Rates

Participants in the research, design, and regulation of utility programs and rates include the electric utilities, state regulators, universities, national laboratories, and non-governmental organizations (NGOs).

Recommendation—Identify and measure predictable grid value from solar+EV applications; design programs to capture solar+EV value.

- Identify and document distribution grid benefits and costs, anticipating the expansion of EV charging as a significant end use with potentially significant consequences on the distribution grid.
- Identify and document bulk power system benefits and costs, determining the potential for managed load with distributed solar to provide bulk power system services.

Recommendation—Develop EV charging utility rates and incentives that enable potential demand charge savings, grid benefits, and bulk power benefits.

- Enable customers to manage EV charging with building loads and synchronize EV charging with on-site solar generation for peak load reduction.
- Invest in utility grid infrastructure that is ready for third parties to build out solar+EV charging.
- Evaluate potential distribution grid benefits from solar+EV applications (e.g., manage system peak capacity; provide frequency regulation, ramping, and balancing capability)
- Consider rates or incentives that encourage EV charging at times that are beneficial for managing bulk power challenges associated with EV charging or solar production growth (e.g., avoiding charging that exacerbates evening ramp ups associated with solar generation declining) .

Recommendation—Integrate equity consideration into solar+EV applications.

- Mitigate potential rate impacts to low-income customers of solar and EV charging in programs and rate designs, and ensure that low- to moderate-income households can successfully participate in solar and EV incentive programs.
- Create financeable EV deployment in multi-family buildings.
- Develop public charging mobility hubs (shared vehicles, public charging, electric bikes/scooters, ride share centers) with solar charging.

State Policy and Programs

State public policy and programs can support clean fuel standards, implement grid modernization principles, and create public investment that links EV charging to renewable energy.

Recommendation—Create supportive policy and standards for development of solar+EV markets.

- Incorporate solar into Minnesota's EV charging installation code to enable their optimal co-location and use
- Develop a low-carbon or clean fuel standard in Minnesota that emphasizes the importance of coupling clean energy, particularly solar and wind energy generation, with EV charging.

Recommendation—Develop program or regulatory initiatives to increase the opportunities for solar+EV deployment.

- Recognize and prioritize solar+EV value in state grant programs.
- Support research into grid or bulk power benefits.
- Incorporate solar+EV benefits in state infrastructure planning or regulation.
- Implement the Minnesota PUC's grid modernization principles in resource and distribution system planning, utility business model alternatives, and other regulatory processes.

Introduction

Led by the Great Plains Institute (GPI), a Minnesota team of agencies, NGOs, utilities, cities, and solar and EV stakeholders, investigated the market potential (both opportunities and barriers) of synchronizing EV charging with solar energy production. As part of the Solar Energy Innovation Network (SEIN), a program that assembles diverse teams of stakeholders to research solutions to real-world challenges associated with solar energy adoption, the Minnesota team assessed technologies for combining EV charging with solar energy (solar+EV). The solar+EV project also investigated the interest in and attitudes of market participants for solar+EV applications, modeled economics, and investigated market transformation vectors that result in a self-sustaining solar+EV market.

More specifically, the project

- examined the value propositions offered by different solar+EV technologies;
- identified and defined the different use cases for solar+EV applications and prioritized uses cases with the most opportune pathways to scaled deployment; and
- developed and initiated solar+EV pilot and demonstration projects in several market segments.

The Minnesota SEIN team project documented a business case and identified pathways to a creating a self-sustaining market for solar+EV charging applications. Supported by the National Renewable Energy Laboratory (NREL), the project worked with national, state, and local stakeholders to identify value propositions of solar+EV applications, market readiness and effectiveness of solar+EV technologies, and opportunities to meet Minnesota's carbon reduction goals for both the power and transportation sectors.

WHY SOLAR+EV?

Electrification of transportation is recognized as perhaps the primary opportunity to lower transportation carbon emissions both in Minnesota and nationally. Transportation emissions are now the largest source of carbon emissions in Minnesota (and in the nation). Of the transportation emissions, the light-duty fleet (the cars and light trucks driven by households and businesses to meet daily transportation needs) is the largest sector of emissions and energy use.

EVs are a much more energy efficient and lower carbon means of providing daily transportation needs than gasoline-powered vehicles, even under the current carbon footprint of the electric grid. But Minnesota's long-term goal of largely decarbonizing transportation needs to be more than simply electrification; it means finding pathways to carbon-free electrification.

Minnesota's 2019 vision for electrification, *Accelerating Electric Vehicle Adoption*, notes that meeting Minnesota's 2030 carbon emission goals requires that the State do more than merely electrify the fleet as the electric grid gets cleaner. The report notes that Minnesota's forecast renewable energy deployment falls short of what would be required to meet decarbonization goals in transport. Additional renewable energy equal to the demand of 20,000 electric vehicles will have to be added to the grid to meet Minnesota's goals.[1] Since the publication of the vision, additional commitments to renewable and carbon-free electric production have been advanced by some of the State's utilities, but the carbon-intensity of the statewide grid is still insufficient to reach 2030 transportation decarbonization goals.

Minnesota's adopted policies on the future of the electric grid also demonstrate the need for solar+EV strategies. The legislature and the Public Utilities Commission specifically prioritized the importance of designing the electric grid to accommodate an evolving market for services, increasing levels of variable renewable energy deployment, and a rapidly expanding set of distributed energy resources (DERs) that include both supply and demand-side applications behind the meter.[2]

This project examines how, as solar energy and EV charging infrastructure are being deployed across the state, these two distinct technologies can be jointly deployed to meet Minnesota's goal of carbon-free electrification, deepen deployment of renewable energy systems, and limit risks to the electric grid.

NEED FOR NON-HOME CHARGING

Nearly all market forecasts predict consistent and long-term growth of EV sales and use, and a commensurate reduction in GHG emissions. However, the barriers to high-level penetration are also acknowledged in market forecasts. One of the primary barriers cited by potential EV buyers is the lack of readily available opportunities to charge EVs.[3] Analysis conducted by NREL and others[4] confirms that, without routine access to charging infrastructure both at home and in non-residential locations, market forecasts for EV adoption are unlikely to materialize. Consumers need to feel as confident that they can charge EVs as they do that they can fuel gasoline-powered vehicles. In particular, the need for non-home charging options is critical to achieving the high-penetration EV goals needed to meet carbon reduction goals.

[1] Minnesota Department of Transportation (MnDOT), Minnesota Pollution Control Agency (MPCA), Great Plains Institute (GPI), *Accelerating Electric Vehicle Adoption: A Vision for Minnesota* (2019), http://www.dot.state.mn.us/sustainability/docs/mn-ev-vision.pdf.

[2] Minnesota Public Utilities Commission, Staff Report on Grid Modernization, Docket 15-1556 (March 2016), https://www.edockets.state.mn.us/EFiling/edockets/searchDocuments.do?method=showPoup&documentId=%7BE04F7495-01E6-49EA-965E-21E8F0DD2D2A%7D&documentTitle=20163-119406-01. Minnesota set six principles for electric grid modernization that prioritizes integration of renewable energy, improving system efficiency, and enabling new products and services.

[3] National Renewable Energy Laboratory (NREL), *The Barriers to Acceptance of Plug-in Electric Vehicles: 2017 Update* (November 2017), https://www.nrel.gov/docs/fy18osti/70371.pdf; Stefan Knupfer, Russell Hensley, Patrick Hertzke, and Patrick Schaufuss, *Electrifying insights: How automakers can drive electrified vehicle sales and profitability* (McKinsey & Company, January 2017), https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/electrifying-insights-how-automakers-can-drive-electrified-vehicle-sales-and-profitability; Elkind, Ethan, *Plugging Away: How to Boost Electric Vehicle Charging Infrastructure (Emmett Institute on Climate Change & the Environment,* June 2017), https://law.ucla.edu/centers/environmental-law/emmett-institute-on-climate-change-and-the-environment/publications/plugging-away/; Ellen Edmonds, "Why Aren't Americans Plugging in to Electric Vehicles?," *NewsRoom*, May 9, 2019, https://newsroom.aaa.com/2019/05/why-arent-americans-plugging-in-to-electric-vehicles/.

[4] Midcontinent Transportation Electrification Collaborative, Electric Utility Roles in the Electric Vehicle Market: Consensus Principles for Utility EV Program Design (GPI, April 2018), 14. https://www.betterenergy.org/wp-content/uploads/2018/04/MTEC_White_Paper_April_2018-1-1.pdf. See citations and analysis.

The non-residential Level 2 charging network is generally considered to include several use categories:[5] (1) workplace charging, (2) destination charging, and (3) other public charging.

NREL completed a detailed analysis in 2017 on how much non-home charging infrastructure would be needed by 2030 to accommodate a world in which 20 percent of the light-duty vehicles sales were electric (either completely electric or plug-in hybrids). NREL estimated that for every 1,000 EVs in a geographic area (such as a city or metropolitan area), 3-4 direct-current fast chargers (DCFC) and over 40 workplace or public Level 2 chargers are needed.

Using NREL's EVI-Pro model[6] estimates, the Minneapolis-Saint Paul metro area needs approximately 9,000 workplace or public Level 2 chargers to serve just 10 percent of the EV penetration, even if all EV owners have access to home charging.[7]

Assuming that 10 percent of EV owners live where they cannot charge their vehicle at home, the need for non-home Level 2 chargers increases to over 16,000.[8] To meet Minnesota's 20 percent market penetration goal, the metro area would likely need over 30,000 non-home chargers.

> *Finding*
>
> To meet Minnesota's climate action goals, the availability of public and workplace charging needs to increase significantly, and the rate of installation is currently insufficient to meet non-residential charging needs associated with Minnesota's vision of 20 percent EV market penetration by 2030.

The Minneapolis-Saint Paul metro area currently has about 600 workplace and public Level 2 chargers. The availability of public chargers in other areas of Minnesota is similarly substantially lower than needed to support electrification goals: the Duluth area has 16 public charging plugs but needs over 1,000 to support a 20 percent market

[5] NREL, US Dept. of Energy, *National Plug-in Electric Vehicle Infrastructure Analysis* (September 2017), https://www.nrel.gov/docs/fy17osti/69031.pdf. A number of analyses that focus on the build-out of the nation's charging infrastructure identify these or related use cases for non-home Level 2 charging. NREL's National Plug-in infrastructure analysis categorizes non-residential charging as "work and public" (numerous) and "workplace and public destinations."

[6] US Department of Energy Alternative Fuels Data Center, EVI-Pro Lite Tool, https://afdc.energy.gov/evi-pro-lite.

[7] The EVI-Pro Lite model has a maximum market penetration value of 10 percent. To reach the Minnesota goal of 20 percent market penetration needed to keep Minnesota on track to achieve GHG reduction goals, a significantly greater number of public chargers would be needs, although the relationship is probably not linear.

[8] The US Census (2010) reports that 27 percent of households in the Minneapolis/Saint Paul metro area are renters. Renters in multi-family building generally don't have access to charging facilities, and renters in townhomes or single-family buildings will (in the near term) have home access to only Level 1 charging.

penetration goal, Rochester has 20 and needs 1,000, and St. Cloud only has one but needs 900.[9]

> *Finding*
>
> Daytime charging (workplaces, commuter public parking, some destinations) is an essential part of the needed charging infrastructure to achieve Minnesota's electrification—and therefore GHG reduction—goals.

This SEIN solar+EV project, working with a variety of stakeholders and market participants, identified priority use cases that have the greatest solar+EV market transformation opportunities.

The Potential Solar Energy Contribution

Minnesota's largest renewable energy resource potential is solar energy. Moreover, the solar resource is ubiquitous; every community in the state has a substantial solar energy resource. At the community scale, solar energy "reserves," solar energy resources that can be economically captured using existing technology, on rooftops and parking lots are sufficient (with today's technology) to meet 25-75 percent of many community's electric energy needs, even with the increase in electric demand resulting from meeting Minnesota's 20 percent EV goals.[10] Solar energy development has been growing rapidly and is expected to approach 10 percent of Minnesota's total electricity use by 2030. The cost of solar energy is expected to soon be the least expensive form of energy generation in both the wholesale and retail market.

Distributed solar generates electricity at or near where it will be used and thus is turning energy consumers into energy producers, or "prosumers." EVs are expected to be a substantial new load, for which new generation will likely be needed, particularly for load that cannot to shifted to off-peak times. New capacity may also be necessary on the utility's distribution grid to deliver power to EV's plugged into homes, public places, and workplaces.

This project examines the possibility of linking the growth of the EV market with the expanding rate of solar energy deployment to directly charge EVs, helping to achieve Minnesota's need for renewable energy charging, minimizing the impacts to the distribution grid of new technologies and electric demand, and eliminating the need for new centralized power plants.

[9] EVI-Pro Lite results, assuming full access to home charging. Existing charger data is from the Alternative Fuels Data Center Central Locator.

[10] GPI calculated the solar energy local "reserves" for dozens of Minnesota cities as part of the Local Government Project for Energy Planning. The rooftop reserve ranged from 30-100 percent. Accounting for the likely electrification of vehicles and building loads, the local solar resource is large enough to meet substantial portions of local energy demand.

THE SEIN SOLAR+EV PROJECT

The 18-month project had three goals: (1) to identify use cases where solar+EV can provide value for the utility customer and the grid; (2) create an action plan for solar+EV deployment market opportunities, working with the solar industry, utilities, businesses, and property owners; and (3) testing the market and technologies with pilot and demonstration projects. The SEIN project team worked with stakeholders across the solar and EV market to identify potential solar+EV "use cases" where these technologies could be combined with varying levels of efficacy and value for a variety of market participants.

Of these, the project team prioritized two use cases—workplace charging and public parking — as having the right characteristics and fewest barriers to market adoption of solar+EV applications. With the assistance of NREL, the project modeled the customer utility cost savings for workplace and public parking solar+EV charging, optimizing across dozens of scenarios that include: managed and unmanaged charging, using on-site solar production, incorporating battery storage, and integrating solar, storage, and EV charging with building loads.

> *Finding*
>
> Solar production and EV charging patterns have, at best, a mediocre overlap.
>
> - Daytime charging will account for only 10-20% of all charging under a business as usual case.
> - Most workplace charging will be daytime charging, but it occurs in the morning before solar production peaks.

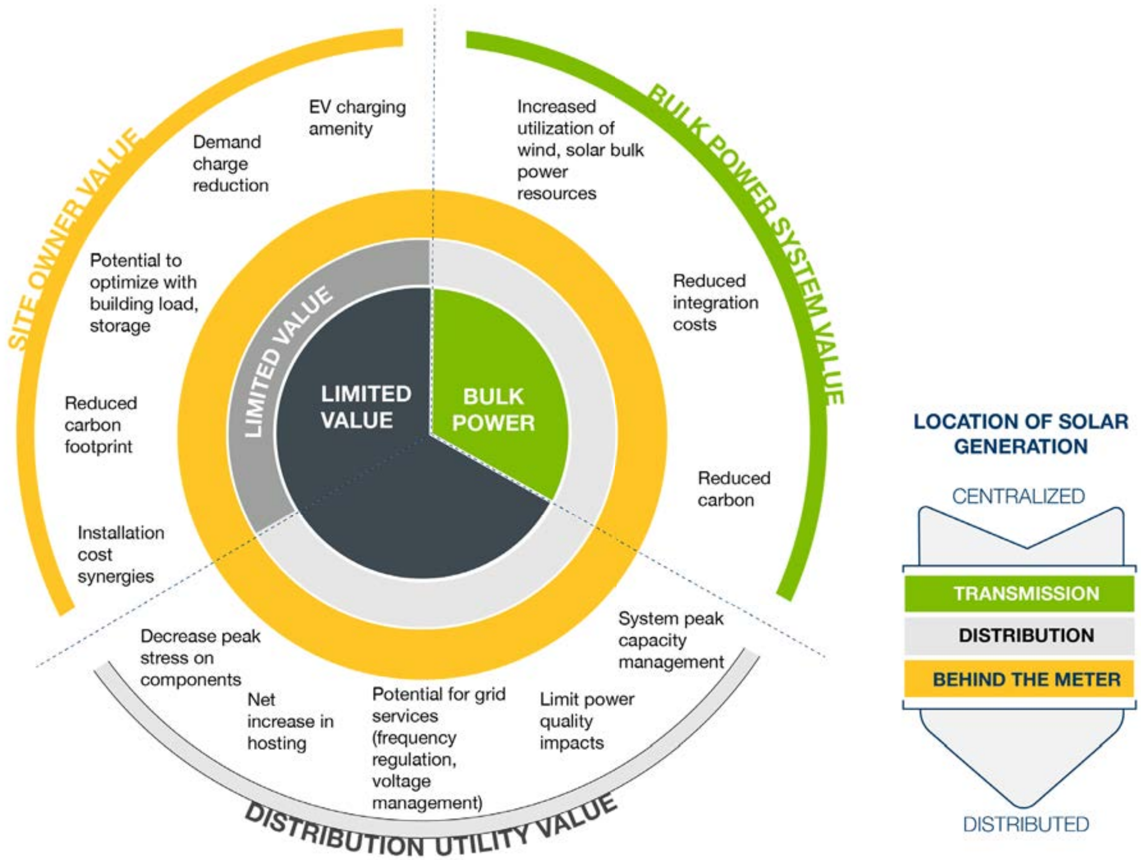
ASSESSING THE SOLAR+EV VALUE PROPOSITION

A primary hypothesis of the this project is that integrating EV charging with solar energy production creates synergies that are greater than the sum of the two technologies individually. The potential added value of integrated solar+EV applications comes in a variety of forms (quantitative and qualitative) and accrues to different market participants. The added value can be considered as a stack of values, similar to previous "value of solar," "solar+," and energy storage assessments.[11] Solar+EV applications can provide value at three different points in the electricity system:

1) Site owner value
2) Distribution grid value
3) Bulk power system value

[11] O'Shaughnessy et.al, NREL, *Solar Plus: A Holistic Approach to Distributed Solar PV* (May 2017), https://www.nrel.gov/docs/fy17osti/68371.pdf; Rocky Mountain Institute (RMI), *The Economics of Battery Energy Storage: How Multi-use, Customer-sited Batteries Deliver the Most Services and Value to Customers and the Grid* (October 2015), https://rmi.org/wp-content/uploads/2017/03/RMI-TheEconomicsOfBatteryEnergyStorage-FullReport-FINAL.pdf. The Minnesota Value of Solar calculation (also used in a number of other states) adds together distinct cost savings of using solar generation from different elements of the utility system. NREL discusses the value stack synergies of "solar+" for residential solar applications if evaluated in conjunction with other technologies.

Figure 2. Value streams for synchronizing solar production with EV charging



Source: Adapted from Fitzgerald, et al., Rocky Mountain Institute, *The Economics of Battery Energy Storage: How Multi-use, Customer-sited Batteries Deliver the Most Services and Value to Customers and the Grid* (October 2015), 6, Figure ES2, https://rmi.org/wp-content/uploads/2017/03/RMI-TheEconomicsOfBatteryEnergyStorage-FullReport-FINAL.pdf.

Note: Solar+EV can be integrated or synchronized at bulk power, distribution grid, or individual customer level, and different values are captured for each of the applications.

Each component of the value stack accrues to different market participants and at different rates or amounts depending on how the solar+EV application is designed and managed. The Minnesota SEIN Team examined the solar+EV value proposition for each of the use cases from the standpoint of each of these value stack elements. The use cases that provide value in all three segments of the value stack incentivize the greatest number of market participants to support solar+EV deployment.

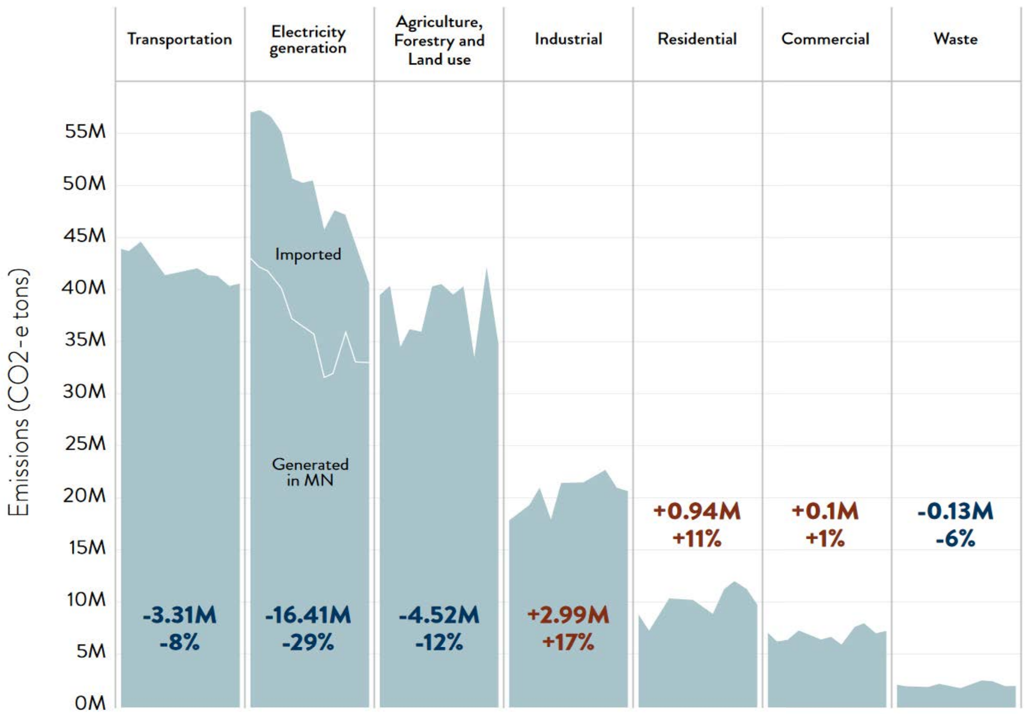
However, the key participant for market transformation is the site owner, who makes the decision to deploy solar+EV. Other market participants with an economic value proposition can attempt to influence the decision maker or set incentives to capture their value proposition, but the decision is ultimately in hands of the site owner. Thus, while this project considers all three points of value, the economic modeling prioritized assessing the value proposition for the site owner.

Minnesota Context for Solar and Electric Vehicle Deployment

In 2007, Minnesota enacted one of the most aggressive climate action commitments in the nation, setting a mandatory goal of reducing statewide greenhouse gas (GHG) emissions by 80 percent from a 2005 baseline. The Next Generation Energy Act (NGEA) included specific goals for transitioning to renewable energy (25 percent by 2025), increasing energy efficiency in the electric and natural gas utility markets, and requiring state agencies to track and report on progress.[12]

After 13 years, Minnesota's energy efficiency investments and wind energy consumption have led to a 29 percent decline in power sector emissions (from 2005 to 2016).[13]

Figure 3. Minnesota emissions by sector 2005-2016



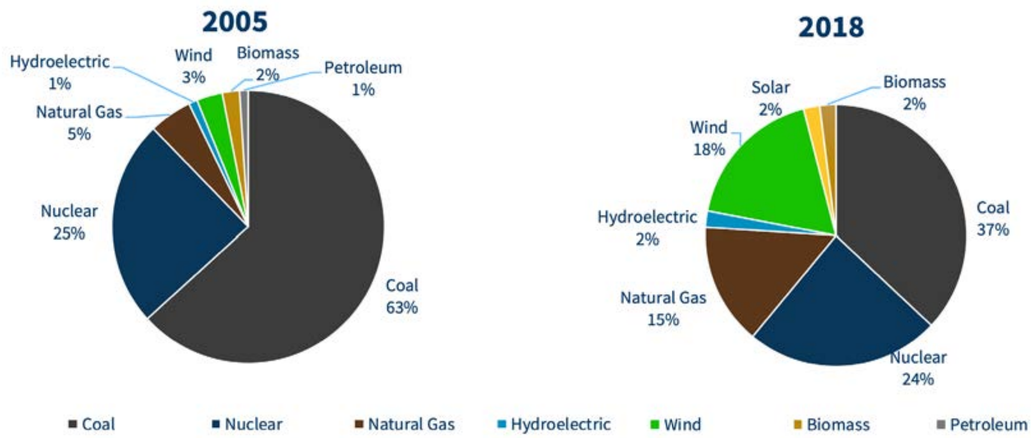
Source: Pathways to Decarbonizing Transportation, MnDOT, 2019, 15. Source data from 2016 MPCA Greenhouse Gas Inventory.

Emission reductions in other sectors, however, are well behind interim targets. In 2018, the primary sector for GHG emissions shifted from electricity generation to transportation.

[12] Next Generation Energy Act, 2007 Minn. Laws Ch. 136, https://www.revisor.mn.gov/laws/2007/0/136/.

[13] MPCA, *Greenhouse gas emissions data* (2016), distributed by the MPCA, https://www.pca.state.mn.us/air/greenhouse-gas-emissions-data.

Figure 4. Minnesota electric generation mix



MINNESOTA'S SOLAR AND EV POLICY GOALS

Minnesota has supportive policies for both solar and EV deployment. Solar deployment (both large-scale and small-scale) is explicitly supported in state statute, while EV deployment goals have been defined through administrative (agency) action in implementing the NGEA.

Solar-Specific Goals

In 2013 Minnesota added solar-specific goals to the more general GHG reduction and renewable energy goals in the NGEA. The state set a non-binding goal of meeting 10 percent of statewide retail sales with solar energy generation by 2030, and requirements for the investor-owned utilities to generate solar energy equivalent to 1.5% of retail sales by 2020.[14] The 1.5% requirement included a set aside for 10% of requirement (.15% of retail sales) to come from small-scale (on-site) PV.

EV-Specific Goals

The Minnesota legislature has not adopted EV-specific policies, but state agencies have assessed transportation-related needs for meeting NGEA goals. In 2019, the Minnesota Department of Transportation released *Accelerating Electric Vehicle Adoption: A Vision for Minnesota*, identifying goals for EV adoption and charging behavior that would lead to achieving NGEA goals.[15] The *Vision* targets 20% of the state fleet for EVs by 2025, and 20% EV penetration of all light-duty passenger vehicles (LDV) by 2030.

The *Vision* also estimates the carbon reductions from achieving a 20% market penetration by 2030 under the estimated carbon intensity of the electric system for each utility in the State. The *Vision* notes that even with an aggressive goal of 20%

[14] Minn. Stat. § 216B.1691(2)(f).

[15] MnDOT, MPCA, and GPI (2019), *Accelerating Electric Vehicle Adoption: A Vision for Minnesota,* http://www.dot.state.mn.us/sustainability/docs/mn-ev-vision.pdf.

electrification of LDV (an estimated 60% of new sales), the 2030 NGEA interim carbon reduction goal will not be met. The *Vision* document states:

> A 3.5-million-ton gap in GHG emission reductions will remain if Minnesota relies solely on CAFE [Corporate Average Fuel Economy] standards to meet NGEA interim targets for 2030. Shifting 20 percent of the light-duty vehicles in the state to PHEVs [plug-in hybrid electric vehicles] and BEVs [battery electric vehicles] is one way to close the gap. Additionally, power for at least 10% of these vehicles must come from wind or solar electricity ***beyond the renewables expected to come onto the general grid***.[16] [emphasis added]

Prioritizing renewable energy for EV charging is an essential part of meeting Minnesota's carbon reduction goals.

STAKEHOLDER/CUSTOMER CONTEXT

In order to understand market opportunities and barriers to solar+EV deployment, the project engaged market participants and key stakeholders in workshops, interviews, and surveys. The project engaged stakeholders in order to:

- gather market information on perceptions and awareness of solar+EV applications by distinct stakeholder and market participant cohorts;
- engage a variety of market participants and stakeholder cohorts on study analyses, findings, and draft recommendations; and
- set the stage for broader implementation of solar+EV applications and initiated processes for removing barriers and creating incentives for broader market activity.

The market participant/stakeholder engagement processes generated key findings that shaped the solar+EV market transformation recommendations and enabled several solar+EV demonstrations.

Project Stakeholder Engagement

Three specific stakeholder engagement initiatives were undertaken to understand market opportunities and receive feedback on draft analyses and findings.

1. A project team was formed for the SEIN solar+EV project to directly engage key market participant/stakeholder cohorts or entities with access to key cohorts. The team included:

- Great Plains Institute (GPI)
- Minnesota Department of Commerce, State Energy Office
- Minnesota Department of Administration, Office of Enterprise Sustainability
- Metropolitan Council, Community Development Division
- Metro Transit
- ZEF Energy
- Minnesota Solar Energy Industry Association
- Center for Energy and Environment

[16] MnDOT, MPCA, and GPI (2019), 14.

- Xcel Energy
- Minnesota Pollution Control Agency
- City of St. Cloud
- City of Rochester
- City of Minneapolis

2. A wide range of stakeholder organizations participated in three stakeholder workshops to engage in collaborative discussion about solar+EV use cases, market potential, feedback on technical analyses, and opportunities for demonstration projects.
3. The project specifically engaged two key private sector cohorts of market participants–the solar industry and commercial property developers–regarding their perceptions of market opportunities for incorporating solar+EV into their business operating practices and offerings among market participants.

SOLAR ENERGY INDUSTRY

The project engaged 50 stakeholders from the solar industry to better understand industry perceptions on the viability and status of integrating solar development with EV charging, including solar industry perceptions of the Minnesota market for pairing solar and EV products. Findings and perceptions were captured in the fall of 2018 in several industry surveys and interviews.

> *Finding*
>
> The solar industry acknowledges the latent solar+EV market, but has taken few steps toward developing the market. Industry participants identify that value propositions under existing rules, markets, rate structures are uncertain, or difficult for decision-makers to understand.

COMMERCIAL DEVELOPERS/MANAGERS

The Minnesota SEIN team engaged commercial, multi-family residential, and mixed-use developers to assess market interest and activity in linking solar and EV charging on the same site and for EV infrastructure alone. Developers assessed both short- and long-term market opportunities to incorporate solar+EV applications into development projects and property management activities.

> *Finding*
>
> The commercial development/ property management industry does not see demand for EV charging and has adopted a wait and see approach. Developers are not incentivized to capture operating savings such as lower electric costs with up-front capital investment unless requested by clients.

Additional Stakeholder and Market Participant Input

Several other projects and initiatives also gathered stakeholder perspectives on solar+EV that proved informative for the Minnesota SEIN team. These projects drew from stakeholder engagement on EV and solar energy market transformation efforts, and focused on three primary stakeholder cohorts for the SEIN solar+EV project: (1) cities and other local governments; (2) the EV industry (car industry stakeholders and electric vehicle supply equipment [EVSE] manufacturers); and (3) utilities, from distribution-only utilities to interstate investor-owned utilities and independent system operators of the power grid.

LOCAL GOVERNMENTS

Four initiatives contributed insights on local government perspectives on solar and EV issues at the local level:

1. The **GreenStep Cities** program, with over 140 actively participating cities and tribal nations working on climate, energy, and sustainability initiatives.
2. The **Local Government Project for Energy Planning (LoGoPEP**), where over 30 cities and counties are incorporating energy and climate goals (including solar and EV deployment goals) into comprehensive plans or energy/climate plans.
3. The **Cities Charging Ahead!** cohort, where twenty-eight cities across Minnesota worked to prepare their communities for broad adoption of EVs.
4. The national **SolSmart** program, where a three-state cohort of over 40 cities and counties worked on local solar energy market transformation, including opportunities to link solar deployment with EV charging and other flexible loads.

> *Finding*
>
> Increasing numbers of Minnesota local governments are setting climate, renewable energy and transportation electrification goals, and can use solar+EV deployment to help meet those goals.

These four programs demonstrated the widespread commitment by communities to establish goals for transportation electrification and to remove barriers and create opportunities for distributed solar installations.

ELECTRIC VEHICLE INDUSTRY AND UTILITY STAKEHOLDERS

Key stakeholder and market participant initiatives provided insights for the SEIN project: Drive Electric Minnesota, the Midcontinent Transportation Electrification Collaborative, and utility EV program planning required of Minnesota's investor-owned utilities.

> *Finding*
>
> Minnesota communities have the tools for implementing climate, energy, and transportation electrification goals (regulations, programs, public sector investment), but have limited experience adapting tools to these goals.

Drive Electric Minnesota

Drive Electric Minnesota is a coalition of stakeholders dedicated to encouraging the deployment of EVs and the establishment of EV charging infrastructure through public-private partnerships, financial incentives, education, technical support, and public policy. Drive Electric Minnesota provides a market perspective on barriers and opportunities from advocates, state agencies, utilities, businesses, and value chain industries.

Midcontinent Transportation Electrification Collaborative

> *Finding*
>
> Utilities, industry, and regulators acknowledge the synergistic relationship of matching EV charging with renewable energy production at the bulk power level.

The Midcontinent Transportation Electrification Collaborative (MTEC), a coalition of EV stakeholders working in Midcontinent Independent System Operator (MISO) territory , consists of automakers, electric utilities, EV charging companies, environmental groups, and state officials. MTEC developed consensus principles for the design of utility EV programs,[17] then created a transportation electrification road map for the MISO region.[18] The road map demonstrates the regional value of EV deployment, including the potential to optimize large variable power sources like wind and solar via load management.

Utility and Regulatory Processes

Several ongoing studies and stakeholder discussions are examining transportation electrification and grid modernization in an era of new DER markets. These processes affect both individual utility service territories and Minnesota state policy. Examples of the range of ongoing stakeholder discussions are noted below.

- Xcel Energy EV market transformation pilot programs
- Xcel Energy performance regulation investigation
- Integrated distribution planning dockets
- Grid modernization investigation

> *Finding*
>
> Minnesota utilities, regulators, advocacy organization, and other stakeholders acknowledge the potential opportunity of DERs (including distributed solar and managed EV charging) to reduce distribution grid costs and improve grid function.

MARKET STATUS

Deployment of both solar and EV are growing in Minnesota, although not at sufficient rates to meet state deployment goals or GHG reduction goals. Moreover, these two technologies are deployed separately, missing the potential synergy between joint deployment that aids the state's carbon reduction and grid modernization goals. Assessing Minnesota's EV and solar deployment markets provides context for the solar+EV action plan.

State of the EV Market

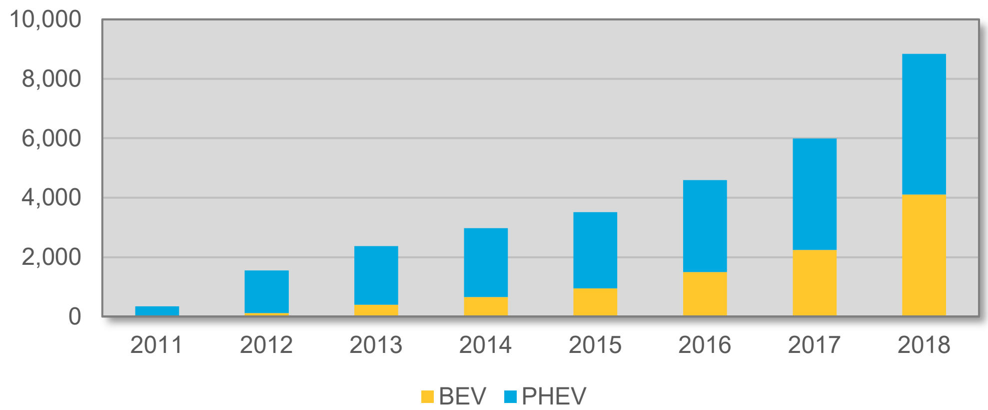
EVs have steadily gained traction in Minnesota since 2011 (Figure 5), with increasing penetration of new car sales. This growth in market share is expected to continue.

[17] Midcontinent Transportation Electrification Collaborative, *Electric Utility Roles in the Electric Vehicle Market: Consensus Principles for Utility EV Program Design* (GPI, April 2018), https://www.betterenergy.org/wp-content/uploads/2018/04/MTEC_White_Paper_April_2018-1-1.pdf.

[18] Midcontinent Transportation Electrification Collaborative, GPI, *A Road Map to Decarbonization in the Midcontinent: Transportation Electrification* (GPI, 2019), http://roadmap.betterenergy.org/wp-content/uploads/2019/02/GPI_Roadmap_Electrification_Online2.pdf.

However, future growth still faces significant barriers, and the forecast rate of growth is insufficient to meet Minnesota's goals for reducing transportation emissions.

Figure 5. Cumulative EV sales in Minnesota, 2011-2018



Source: Auto Alliance (ZEV Sales Board).

Several elements affect the growth of the EV market and the ability to achieve carbon reduction outcomes, including: vehicle availability and diversity of EV models; availability of charging infrastructure (home, non-home, fast charging); vehicle mileage range; and the carbon intensity of electric generation used for charging.

CHARGING INFRASTRUCTURE

To continue scaling Minnesota's EV market, it is key to ensure a diversity of charging infrastructure in a variety of locations.[19] Although most charging will occur at home, non-home and fast charging infrastructure is essential to limit the "range anxiety" associated with the relatively short range of many EV models compared to internal combustion engines.[20] The current level of non-home charging opportunities is appropriate for the current level of EV deployment (over 10,000 registrations in Minnesota),[21] but it needs to be substantially increased to meet Minnesota's 2030 electrification goals.[22]

As described below, several key initiatives to increase the number of charging stations are underway in Minnesota. The initiatives include developing utility EV programs and

[19] US Department of Energy, *National Plug-In Electric Vehicle Infrastructure Analysis* (September 2017), https://www.energy.gov/sites/prod/files/2017/09/f36/NationalPlugInElectricVehicleInfrastructureAnalysis_Sept2017.pdf. This analysis examined the infrastructure needed to serve a set penetration of EVs (20 percent of new market sales by 2030).

[20] Singer, Mark, NREL, *The Barriers to Acceptance of Plug-in Electric Vehicles: 2017 Update* (2017), https://www.nrel.gov/docs/fy18osti/70371.pdf.

[21] Minnesota Department of Motor Vehicles, *Vehicle Registration Data* (2019). Distributed by the Minnesota Department of Motor Vehicles.

[22] NREL, US Dept. of Energy, *National Plug-in Electric Vehicle Infrastructure Analysis* (September 2017), https://www.nrel.gov/docs/fy17osti/69031.pdf.

incentives, creating state and federal EV and clean energy policies, and creating local opportunities in public charging and EV-supportive development regulation.

UTILITY EV PROGRAMS

Utilities have an economic incentive to encourage EV adoption and, if charging is managed to avoid capacity issues, utility ratepayers can benefit from increased utilization of the existing electric distribution grid.[23] By installing charging stations, utilities can positively affect the rate of EV adoption.

Nationally, utility EV plans tend to have three common elements: deploy Level 2 and DC fast charging stations, support fleet adoption of EVs (e.g., commercial or municipal entities that own, operate, or lease a large number of vehicles), and provide education and outreach for consumers. Figure 6 shows a summary of utility filings in the Midwest as of September 2018 and highlights the potential for increased charging infrastructure.

Figure 6. Summary of utility filings in the Midwest as of September 2018

Approved	Pending/Filed	Denied/Withdrawn
5 States	4 States	3 States
5 Filings	7 Filings	4 Filings
5 Utilities	5 Utilities	3 Utilities
$14,241,200 Investment	$71,311,000 Investment	$25,295,000 Investment
75 DC Fast Charging Stations	126 DC Fast Charging Stations	42 DC Fast Charging Stations
520 Level 2 Charging Stations	8,975 Level 2 Charging Stations	792 Level 2 Charging Stations

Source: "Electric Utility Filings," EV Hub, Atlas Public Policy, accessed September 2018, https://www.atlasevhub.com/materials/electric-utility-filings/.

MINNESOTA UTILITY EV INCENTIVES

In 2018, 29 electric utilities in Minnesota offered incentives for installing EVSE and special rates for EV charging. The programs include lower electric rates for off-peak charging, charging infrastructure rebates, and green power options. Nineteen utilities (mostly Great River Energy co-ops) offer rebates of up to $500 for the installation of a Level 2 charger. Utility programs also link EV charging to "surplus" renewable energy.

[23] Illinois Citizens Utility Board, *The ABCs of EVs: A Guide for Policy Makers and Consumer Advocates* (2017), https://citizensutilityboard.org/wp-content/uploads/2017/04/2017_The-ABCs-of-EVs-Report.pdf.

For example, Great River Energy member co-ops can offer a renewable energy option for customers. All but one are linked to wind energy only, with Peoples Cooperative Service offering a solar or wind option for charging (linking renewables to charging at the bulk power level).

In the spring of 2019, the Minnesota PUC approved Xcel Energy's $25 million EV pilot program, which is the largest in the Midwest. The plan's two main components include: (1) Creating 70 community mobility hubs in the Minneapolis/Saint Paul urban core that will have four charging stations each; and (2) providing "make ready" charging infrastructure for government transportation fleets (200 charging ports). These projects will potentially be expanded as the pilot phase is completed. As more utility filings are approved, opportunities for deploying additional charging infrastructure in Minnesota will likely increase.

Examples of EV incentive rates and infrastructure programs operating in 2018 are shown below in Table 1.

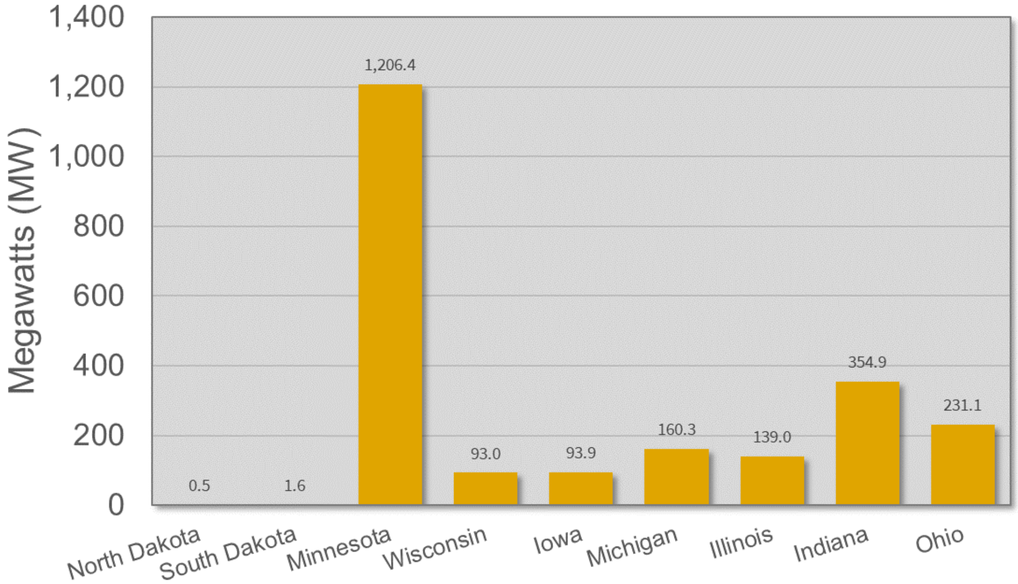
Table 1. Selection of EV rates/incentives in Minnesota

Utility	Customer class	Off-peak hours	Off-peak rate kWh	On-peak rate kWh	On-peak rate kWh	Monthly charge	Rebate	Renewable energy option
MN Power	residential	11 p.m. – 7 a.m. daily	$0.03903	$0.11763	$0.11763	$4.25		100%, $0.025/kWh
Otter Tail Power		10 p.m. – 6 a.m. daily	$0.0149 Jun-Sep $.02093 Oct-May	N/A	N/A	$3.00	$400 L2 charger	Wind (Tailwinds)
Xcel Energy	residential	9 p.m. – 9 a.m.; 7 holidays	$0.0426	$0.21096 (Jun-Sept)	$0.16968 (Oct-May)	$4.95		
Great River Energy		11 p.m. – 7 a.m. daily	100% Wind energy, rate set by dist. co-op	Set by local co-op	Set by local co-op		$500 L2 charger	Wind (ReVolt)

State of the Solar Energy Market

Minnesota is a leader in solar energy deployment in the Midwest with 1.2 GW of installed capacity that supplies roughly 2% of annual electric sales via solar generation. Minnesota is still, however, an emerging market on the national scale.

Figure 7. Solar deployment in the Midwest through Q2 2019



Source: Solar Energy Industries Association, 2019. Figure authored by GPI.[24]

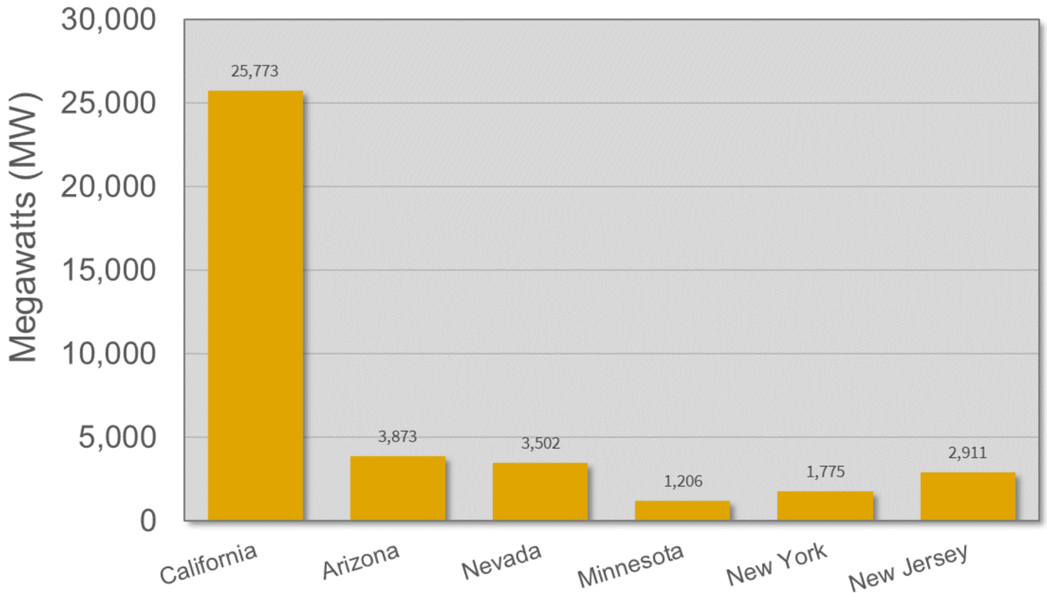
Minnesota's solar deployment has thus far been driven by the state's community solar garden program.[25] Customer-sited solar is approximately 10% of capacity, a smaller percentage than other states with equal or larger solar energy markets. Minnesota's customer-sited solar industry is still in its nascency, and residents and businesses in much of the state face difficulty deploying solar at equivalent prices to other states.[26]

[24] Solar Energy Industries Association (SEIA), *State-By-State Map*, https://www.seia.org/states-map. Accessed October 4, 2019.

[25] Minn. Stat. § 216B.1641. The CSG statute applies exclusively to Xcel Energy, and the vast majority of installed capacity is in Xcel service territory. However, a number of co-ops and municipal utilities have also created shared solar programs, with over 30 utilities having some offering to their customers.

[26] Lawrence Berkeley National Laboratory (LBNL), *Tracking the Sun: Pricing and Design Trends for Distributed Photovoltaic Systems in the US 2019 Edition* (2019), https://emp.lbl.gov/tracking-the-sun. Minnesota's average cost of customer-sited solar is significantly higher than other states, particularly for small commercial installations (less than 500 kW), which were 30 percent more costly than the national average in 2017.

Figure 8. Solar deployment in various states nationwide through Q2 2019



Source: Solar Energy Industries Association, 2019. Figure authored by GPI.[27]

DISTRIBUTED SOLAR

Minnesota's statutory solar deployment requirements support a diversity of system scales. The 1.5% solar generation requirement for all utilities includes a carve-out for systems under 40 kW.[28] However, some utilities have not been able to meet the small-scale goals, while programs and policies to support the distributed solar market are decreasing.[29]

Distributed energy capacity, including customer-sited solar, provides unique value opportunities at the customer and distribution grid scales.[30] While the majority of new solar capacity will be utility-scale (solar farms) or distributed community-scale (solar gardens), a robust and self-sustaining market for on-site solar installations provides diverse benefits to complement utility- and community-scale development.

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[27] Solar Energy Industries Association (SEIA), *State-By-State Map*, https://www.seia.org/states-map. Accessed October 4, 2019.

[28] Minn. Stat. § 216B.1691(2)(f).

[29] Minnesota no longer has a state incentive program for distributed solar (eliminated in 2016), and several co-operative and municipal utilities eliminated rebate programs and instituted fees for solar self-generation.

[30] O'Shaughnessy et.al, NREL, *Solar Plus: A Holistic Approach to Distributed Solar PV* (May 2017), https://www.nrel.gov/docs/fy17osti/68371.pdf. Connecting electric load directly to on-side generation enables both resilience benefits and opportunities to minimize distribution grid capacity issues as we electrify loads.

Distributed Energy Resources and the Distribution Grid

Minnesota has recognized the potential benefits of DERs to the distribution grid. Two related regulatory initiatives are underway to identify and capture the distribution grid benefits of DERs, including distributed solar:

1. An integrated distribution plan process that addresses DER is required for all investor-owned utilities.
2. The Minnesota Public Utilities Commission (PUC) recently completed an investigation into distribution grid modernization, including what is needed to accommodate a growing market for distributed solar.

Minnesota Statutes 216B.2425 Subd. 8. Distribution study for distributed generation

Each entity subject to this section that is operating under a multiyear rate plan approved under section 216B.16, subdivision 19, shall conduct a distribution study to identify interconnection points on its distribution system for small-scale distributed generation resources and shall identify necessary distribution upgrades to support the continued development of distributed generation resources, and shall include the study in its report required under subdivision 2.

In March 2016, the Minnesota PUC staff issued a report summarizing the findings of a year-long stakeholder engagement and research effort, the first phase of a grid modernization investigation (Docket 15-556). The effort was the first step in implementing a new statutory requirement (Biennial Distribution Grid Modernization Reports, Minn. Stat. §216B.2425) for utilities and the PUC to engage in distribution system planning.

The results of the first phase of the docket set forth principles for an integrated modernized grid:

1. Ensure continued safe, reliable, and resilient utility network operations.
2. Enable Minnesota to meet its energy policy goals, including the integration of variable renewable electricity sources and DERs.
3. Provide for greater system efficiency and greater utilization of grid assets.
4. Enable the development of new products and services.
5. Provide customers with necessary information and tools to enable more informed control and choice regarding their energy use.
6. Support a standards-based and interoperable utility network.

These principles are influencing each utility’s integrated distribution plan as those plans are filed and assessed. Solar+EV applications integrate DERs and variable renewable energy resources, enhance utilization of grid assets, and provide new products and services for customers.

Finding

Minnesota has adopted grid modernization principles that are enhanced by solar+EV deployment.

Solar+EV Use Cases

The value of a solar+EV application varies considerably depending on where and when the charging occurs, what type of vehicle is being charged, how much solar capacity is tied to the EV charger and whether the production is used on-site or sent to the grid, the needs or expectations of the EV owner, the configuration and use of the local distribution grid, and a variety of other factors.

These variables can be assembled into "use cases" that describe how different actors need to interact with a system in order to achieve desired goals. Different values can be captured by different actors at different points in the system, from EV owners wanting to charge with renewable energy, to utilities looking for enhanced grid flexibility, to states seeking to increase the capacity of the grid to add renewable energy.

To consider a variety of market applications of solar+EV systems, alternative use cases were developed based on likely EV charging behavior, potential hosts for solar+EV applications, parking and land use patterns, and availability of solar resources. In constructing the use cases, consideration was given to transportation patterns for different land uses, EV charging behavior, and how charging patterns could evolve over time as technology improves and EV market penetration increases.

Use cases define interactions between external actors and the system to attain particular goals. There are three basic elements that make up a use case:

1. **Actors**: Actors are the type of users that interact with the system.
2. **System**: Use cases capture functional requirements that specify the intended behavior of the system.
3. **Goals**: Use cases are typically initiated by a user to fulfill goals describing the activities and variants involved in attaining the goal.

Source: Techopedia, available at https://www.techopedia.com/definition/25813/use-case

UNDERSTANDING VALUE PROPOSITIONS

The concept of the solar+EV value stack recognizes that different actors benefit from solar+EV applications in different ways. The priority cases for market transformation will create value in more segments of the value stack, providing incentives for all actors to make economic decisions supporting deployment. The value propositions for each component of the solar+EV value stack are discussed below.

Finding

Managed charging and co-location of distributed generation can lower the cost and risk of transportation electrification at the customer, distribution system, and bulk power system levels.

Utility Distribution Grid Value Proposition

New technologies can have significant impacts to the utility system, both positive and negative. While there is limited modeling specific to solar+EV applications, studies have analyzed the potential value of high penetration EV deployment on the distribution grid and bulk power system, including effects on renewable energy deployment.[31] These studies and articles assess the risks of EV charging and distributed energy resources (DERs) integration to both local and regional grid infrastructure, as well as the opportunities that EVs and DERs offer to increase grid utilization, improve performance, and reduce costs. Worst-case scenarios could result in substantial costs to the system ordiminishedsystem performance. Best-case scenarios could accommodate substantial increases in transportation-related load without effect or meaningful cost.

There is general agreement that realization of risks or opportunities depends largely on how charging technology and load-shifting programs are deployed and managed. If EV charging occurs at the same time as peak demand on a distribution system component, performance of the system can be degraded, equipment will be degraded earlier, and costs will increase for all users. Moreover, for some components, enough coincident EV charging can create a new peak on the system.[32]

The value of solar+EV for the distribution system is complicated by the fact that value can be differently defined for each component of the system. For instance, mitigating the peak demand impacts of EV charging is valuable, but that value can be assessed at a variety of points between the customer meter and the transmission system interface. The demand peak on the transmission substation or a feeder may be

> *Finding*
>
> Solar+EV charging can be deployed to capture value at multiple points in the electric system and capture multiple value streams:
>
> - Behind the meter value to the host site for the solar+EV application.
> - Critical grid value as the transportation electrification comes to scale and distributed solar deployment expands.
> - Bulk power system benefits that reduce costs and enable realization of Minnesota's GHG reduction goals.

> *Finding*
>
> Daytime charging is likely to add a much smaller load to the utility system than home charging, but unmanaged charging adds to existing peak demand and may be more likely to create capacity or power quality issues.

> *Finding*
>
> Distribution grid benefits of DERs, including solar+EV, are insufficiently documented to capture value in programmatic applications.

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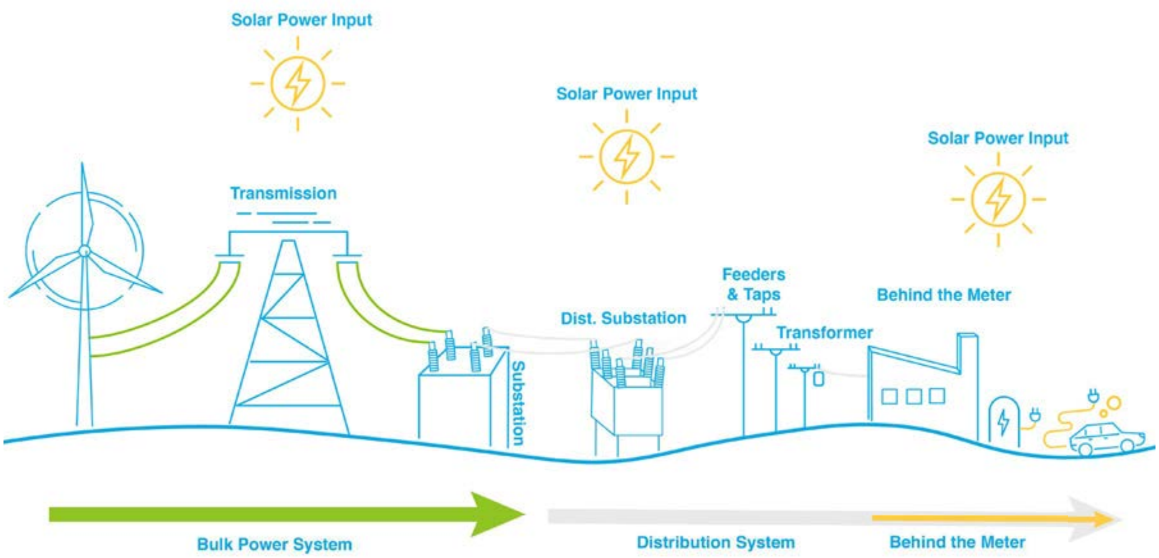
[31] GridLab, Gridworks, *The Role of Distributed Energy Resources in Today's Grid Transition* (August 2018), http://gridworks.org/wp-content/uploads/2018/09/GridLab_RoleOfDER_online-1.pdf; Muratori, Matteo, *Impact of uncoordinated plug-in electric vehicle charging on residential power demand (forthcoming)* (2018), https://dx.doi.org/10.7799/1363870; Illinois Citizens Utility Board, *The ABCs of EVs: A Guide for Policy Makers and Consumer Advocates* (2017), https://citizensutilityboard.org/wp-content/uploads/2017/04/2017_The-ABCs-of-EVs-Report.pdf.

[32] Ibid.

at a different time and have different characteristics than the peak for a line transformer or at a different tap.

Figure 9. Diagram of the electric energy system solar+EV value segments



Source: GPI. Solar+EV value can be captured at any or all of the three segments, and EV charging can be synchronized with solar inputs at each of the value segments. Because EV-charging is always a distributed energy resource, value from solar+EV applications can move upstream to create value (e.g. behind the meter synchronization can provide some benefit or value in the bulk power system).

The distribution grid benefit of distributed solar (and other DERs) is unique to distributed solar but is also the least well-documented and the least predictable portion of its value stack.[33]

Bulk Power System Value Proposition

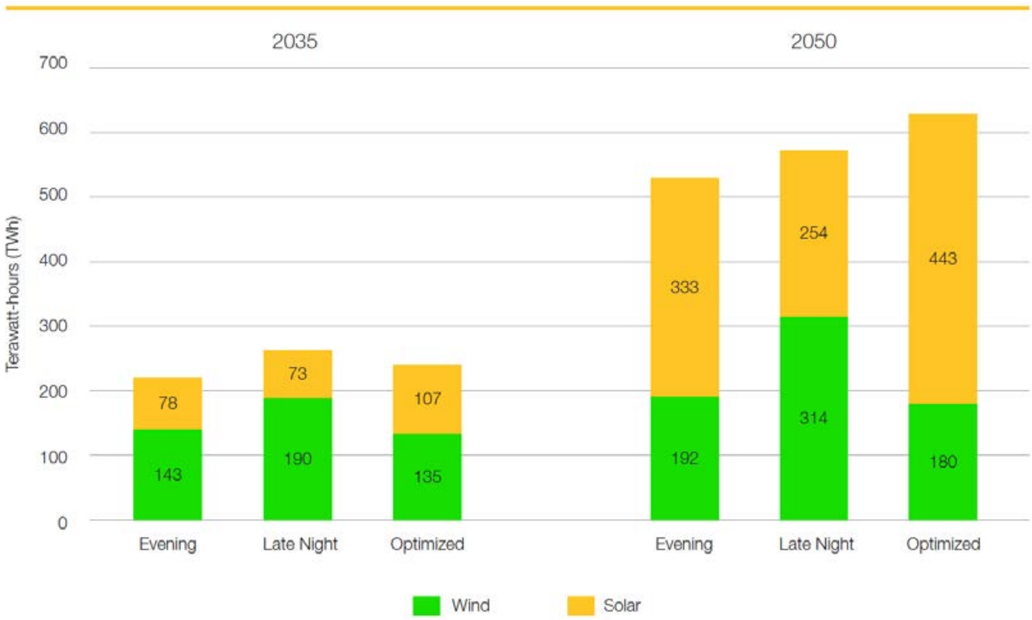
"Managed" EV charging (where charging of EVs is deliberately timed to avoid generation capacity constraints or high costs, and targeted to times with capacity surplus) enables more renewables to be deployed on the grid.[34] This has multiple benefits, including potentially supporting meeting carbon reduction goals, reducing costs (marginal costs of wind and solar energy are close to zero), or both.

[33] Herman Trabish, "Locational value of DER is essential to grid planning. So why hasn't anyone found it?", *UtilityDive*, November 13, 2018, https://www.utilitydive.com/news/locational-value-of-der-is-essential-to-grid-planning-so-why-hasnt-anyone/541946/; Clean Power Research, prepared for the Minnesota Department of Commerce Division of Energy Resources, *Minnesota Value of Solar: Methodology* (January 30, 2014), https://www.cleanpower.com/wp-content/uploads/MN-VOS-Methodology-2014-01-30-FINAL.pdf

[34] Jeffrey Greenblatt, Cong Zhang, Samveg Saxena, Lawrence Berkeley National Laboratory, Emerging Futures, *Quantifying the Potential of Electric Vehicles to Provide Electric Grid Benefits in the MISO Area* (Midcontinent Independent System Operator Inc., 2019), https://cdn.misoenergy.org/Quantifying%20the%20Potential%20of%20Electric%20Vehicles%20to%20Provide%20Electric%20Grid%20Benefits%20in%20the%20MISO%20Area354192.pdf.

Some tradeoffs or conflicts between potential values must be accounted for. EV charging that increases renewable capacity in the bulk power system may increase peak loads on distribution grids. This diminishes the distribution grid benefit of EV charging, as those local loads might otherwise be met with distributed power.[35]

Figure 10. Renewable energy in the MISO market under different charging assumptions



Source: A Road Map to Decarbonization in the Midcontinent, more renewable energy can be incorporated into the MISO market if EV charging is managed to meet the available renewable resource.

Site Owner Value Proposition

On-site solar generation and on-site EV charging provide value to the site owner. Combining the two can create economic synergies in terms of lowered total cost of installation, increased value of solar through displacing demand charges, improved utilization of on-site transformers or other electrical equipment, and potentially other economic synergies. Qualitative benefits include charging with "green" power, new employee or customer amenities, and parking shade structures.

Meeting the need for non-home charging is paramount to achieving Minnesota's EV deployment and carbon reduction goals. Home charging will likely remain the preferred choice for most EV owners. Meeting the state's need for non-home charging requires site owners at workplaces, destinations, and public parking facilities to create the needed system of charging options.

[35] Clean Power Research, *Minnesota Solar Potential Analysis Report* (November 18, 2018), http://mnsolarpathways.org/wp-content/uploads/2018/11/solar-potential-analysis-final-report-nov15-2.pdf. The analysis examined dispatching EV charging as a flexible load to improve utilization of renewables that would otherwise be idle. The bulk power benefit was important, lowering the cost of a high-penetration renewables scenario by about 10 percent, but increased daytime loading on the distribution grid.

SITE OWNER VALUE PROPOSITION AS PRIORITY

The most determinative value proposition for solar+EV adoption is the value to the deployment decision-maker: the site owner. While utility rates or programs create incentives or send price signals to encourage desired behavior, the site owner is the final decision-maker on whether to make a solar+EV investment, and how to manage that investment over time. This project thus focuses primarily on the value proposition to the site owner or manager.

SOLAR+EV METHODS AND TECHNOLOGIES

Solar+EV charging can take a number of different forms, and market participants' perception about what a "solar+EV" application is varies considerably. The most common deployment of solar+EV applications in Minnesota is simple co-location of a distributed solar array with EV charging stations under or alongside the array, without any managed charging or synchronization of solar production and charging.[36] A larger number of residential co-location examples were identified, and some public entities noted that their charging station was either powered under a green energy tariff or supported by a subscription to a community solar garden.

However, multiple solar+EV technologies and products are available in Minnesota and nationwide. Several companies actively market solar+EV products in regional markets where EV deployment is more robust than Minnesota.[37] The types or categories of solar+EV applications available in the market, and the methods of integrating solar production with charging as noted below:

Solar+EV Application Categories

1. Stand-alone, off-grid solar charging
2. Grid-tied co-located solar with EV charging
3. Integrated solar charging carports
4. Behind the meter virtual integration
5. Solar Renewable Energy Credit (SREC) charging
6. Bulk power integration

Solar+EV Integration Methods

1. DC-to-DC connection at inverter
2. Battery storage and dispatch
3. Managed or "smart" charging
4. Economic integration (SRECs)
5. Rate design (green power rates)

Each of these applications and integration methods presents a different set of costs and value propositions to the site owner and other market participants. The Minnesota SEIN team emphasized solar+EV applications that provide economic value to all three value stack elements (site owner, distribution grid, bulk power system), and prioritized

[36] No formal survey was conducted, but interviews with contractors, public charging site owners, state agencies, and utilities found only a few co-located sites and no synchronized sites. There are several known workplace charging sites with solar synchronization.

[37] Several companies do offer solar+EV products in Minnesota, such as the virtual behind the meter integration used in the GPI pilot project.

applications that provide direct economic benefit to the site owner/manager. The economic modeling described below did not quantify the distribution grid and bulk power components of the solar+EV value stack, but the literature and evidence in ongoing regulatory proceedings demonstrate that the selected applications and integrations provide value to all three components.

The most promising applications are solar+EV chargers that are physically located and synchronized at the distribution scale. These applications benefit all three value stack elements.

Finding

A variety of solar+EV technologies and products are available, but different applications capture very different value propositions. Key differences include:

1. Grid connected and not connected
2. Physically co-located and separated
3. Synchronized and not synchronized
4. Integrated with building loads and separate from all other loads
5. Incorporating storage and without storage

DEVELOPING THE USE CASES

The Minnesota SEIN team reviewed transportation patterns (origins and destinations), EV charging needs, potential market size for solar+EV applications, categories of host sites, categories of deployment decision-makers, and other variables. The team then hosted a day-long stakeholder workshop that included the solar industry, cities with land use and transportation planning authority, utilities, property developers and managers, EV advocates, state agencies, public transit operators, and public fleet managers. The stakeholders worked in large and small groups to refine the use cases, aiming to assess specific applications, benefits, value propositions, and scalability of each solar+EV use case, in addition to identifying potential pilot projects. The outcome of the workshop was a portfolio of eight use cases.

The eight use cases are the following:

1. Workplaces
2. Public parking facilities
3. Mixed-use, multi-family
4. Electric buses
5. Fleets
6. Single family home
7. Community solar gardens
8. Destination land uses

Each use case demonstrates a different system for deploying solar+EV applications and a distinct set of actors for deploying decisions. A summary of the eight use cases examined is show below in Table 2. A detailed description is provided in Appendix B, identifying:

- Users of the charging equipment
- Decision-makers for deployment
- Example projects
- Site owner value proposition

- Expected synergies or benefits with other stakeholders (non-site-owner benefits), and
- Possible barriers and limitations to realizing value.

Table 2. Summary of use cases

Use Case	Description	Customers	Owner/Decision-Maker	Examples
Workplaces	EV charging during business hours at places of employment, with opportunities for on-site solar.	Employees/visitors of business or office complex who need to charge.	Large employers who own their own buildings, property owners managing employment centers with multiple businesses.	Small office complexes, large corporate campuses, technology business parks, institutions such as hospitals, government administrative operations.
Public Parking Facilities	Drivers using public charging facilities, such as downtown lots and park & rides, stay for longer periods of time, with substantial areas for on-site solar.	Individuals using public parking facilities including employees, customers of nearby businesses, and businesses wanting to provide a charging amenity.	Local governments and transit authorities who own and manage large parking facilities such as park & rides and downtown parking ramps.	Transit park & ride lots, public or private airport parking facilities, downtown parking ramps that have solar resources.
Mixed-Use Multi-Family	Solar+EV can be incorporated into new multi-family mixed-use developments with commercial spaces on the ground floor or adjacent to shared parking lots to make it possible for more residents to own EVs.	Residents, business customers, business employees.	Commercial developers building large mixed use or multi-family buildings, commercial building owners of such facilities, property management companies.	New multi-family mixed-use developments in and around metro area downtowns and suburban master-planned developments.
Electric Buses	Many buses, especially school buses, can take advantage of a longer charge time during the day since most of the routes are performed in the	Transit authorities, school bus operators, para-transit providers.	Transit authorities, school districts, governmental or non-profit para-transit providers.	Several transit agencies in Minnesota are transitioning to electric buses and some school bus providers are also electrifying some of their fleets.

	morning and afternoon/evening to get riders to and from work or school. Electric buses could also take advantage of a longer charge time overnight, which would work well for a solar+EV+storage application.			
Fleets	Many commercial and public-sector fleets that remain parked for hours - ideal locations are where fleet operations coincide with good solar resource and daytime charging.	Commercial fleet vehicle companies, public sector authorities with fleet vehicles.	Local governments with fleets, state agencies, private sector fleet operators of light-to medium-duty delivery vehicles.	Public (city, state) and private fleets that have enough vehicles to require consistent charging.
Single Family Homes	Solar+EV is incorporated into residential homes by private EV owners and possibly new home builders, or existing solar energy systems are synchronized to new EV chargers.	Households owning EVs.	Single family homeowners, residential developers.	This is dependent on electric utilities offering a program for residential customers willing to accept a synchronized rate of charging in exchange for savings on the EV portion of their bill.
Community Solar Gardens	Commercial community solar garden (CSG) subscribers can be offered a “smart” EV charging station at their business that can be controlled during business hours to match CSG output. Added benefit if RECs go with the EV subscription.	Commercial CSG subscribers, EV owners (employees, visitors, customers) utilizing chargers.	Commercial CSG subscribers.	Any existing CSG with multiple commercial subscribers that want to link EVs.

Destination Land Uses	Places where people go to spend leisure time. Ideal destinations would include those where customers stay for sufficiently long periods of time and be interested in charging, and that have a relatively consistent daytime customer base.	Destination visitors owning EVs, destination business that are lessees and want to provide charging amenities to their customers.	Businesses that own their property or building, property managers that lease to destination businesses, public entities that own and manage destination locations.	Shopping malls, retail establishments, state parks, recreation facilities where long-term ownership of solar arrays is guaranteed.

Prioritizing Use Cases for Market Transformation

In the solar+EV value stack, benefits flow to different market participants: the site owner or manager, the distribution grid utility, and the bulk power system (owned by the utilities but managed by MISO).[38] The key participant for market transformation is the site owner; the site owner/manager is the decision-maker for solar+EV deployment. Other market participants with an economic value proposition can attempt to influence the decision-maker, but the decision is ultimately in hands of the site owner.

> *Market Transformation*
>
> The term market transformation is the strategic process of intervening in a market to create lasting change in market behavior by removing identified barriers or exploiting opportunities to accelerate the adoption of all cost-effective energy efficiency as a matter of standard practice.
>
> Source: American Council for an Energy-Efficient Economy

From the standpoint of achieving Minnesota's GHG reduction goals, the solar+EV use cases present a variety of opportunities, with some use cases having higher or more numerous barriers to market adoption than others. The project team, utilizing stakeholder input and its own analysis, identified four characteristics common to the most promising use cases:

1. Large enough sites to allow for sufficient economies of scale in solar and EV charging infrastructure.
2. Electric rate schedules that enable capture of solar+EV value, mostly notably the opportunity to reduce costs associated with both energy use (kWh) and power (kW demand) behind the same meter.
3. Consistent and predictable daytime parking patterns (parking tenure and day-to-day consistent parking times) by a sufficient number of EV owners. This allows a solar+EV system to optimize the economic tradeoff between solar generation,

[38] Additional qualitative and policy benefits flow to other market participants, including the EV owners having the opportunity to charge with solar energy, state and local governments meeting economic development or GHG reduction goals, society at large benefitting from climate action, etc.

flexible EV charging, battery storage and use, and other loads on site and behind the same meter.

4. Sufficient number of deployment opportunities (the number of potential site owners) to create a viable market and (at full scale) meaningfully affect GHG emissions.

Of the eight use cases, two stood out as having the greatest market transformation potential: (1) workplace charging, and (2) public parking facilities charging. Several other use cases had most of the appropriate characteristics and offered potential additional value to the site owner/decision-maker, in particular the “destination charging” and “mixed-use development” use cases.[39] But workplace and public parking facilities had the most straightforward decision-making pathway and the most predictable and consistent daytime parking patterns to allow for optimization of solar+EV applications.

Finding

Some use cases have significantly better potential for market transformation, particularly those having:

- large enough sites for economies of scale and deployment;
- electric rate schedules that allow the site owner to capture value, particularly reducing demand charges;
- consistent, long parking tenure during daytime hours for a large number of vehicles; and
- widespread opportunities for deployment, to be able to meaningfully affect the market and GHG emissions.

WORKPLACE AND PUBLIC PARKING CHARGING

Nearly all estimates of EV charging behavior, both currently and in assessing a high penetration EV future, show that the overwhelming preference for charging light-duty EVs is home charging.[40] EV owners can charge at either Level 1 or Level 2 rates when the vehicle is parked in a garage or driveway. Since 70% of households in Minnesota own their residence, and car ownership rates are substantially higher for owner-occupied households,[41] home charging is the most convenient method of fueling, as well as being the cheapest form of charging.[42] Figure 11 compares cost per mile estimates for

[39] The destination charging use case is called out in the literature, and by some market participants, as a necessary location for publicly available charging infrastructure to achieve transportation electrification goals. The site owner’s value proposition includes economic benefit from providing charging as an amenity for customers to choose that destination site or to stay longer at the site in order to charge. Stakeholder feedback also noted, however, that parking tenure may not be long enough to be able to shift load with solar production and still provide the charging amenity.

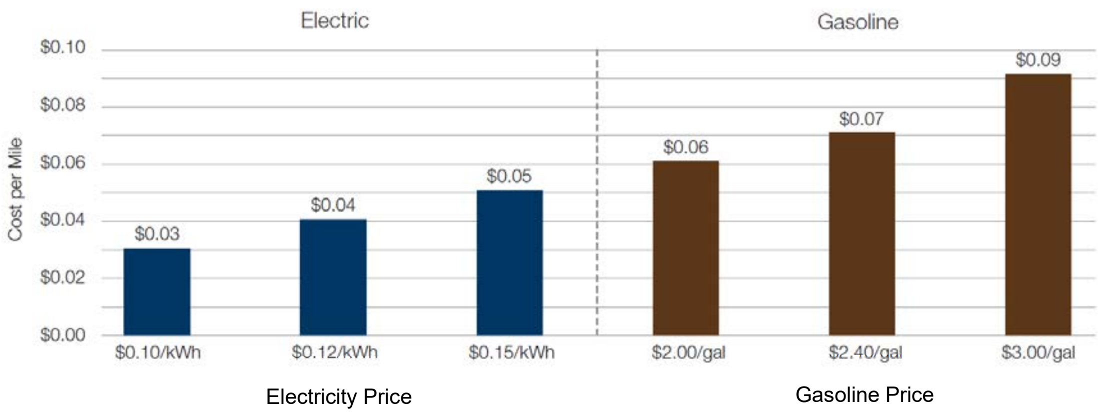
[40] US Department of Energy, *National Plug-In Electric Vehicle Infrastructure Analysis* (September 2017), https://www.energy.gov/sites/prod/files/2017/09/f36/NationalPlugInElectricVehicleInfrastructureAnalysis_Sept2017.pdf.

[41] US Census Bureau, State of Minnesota Demographic Center, “Tenure by Vehicles Available”, American Community Survey Data (2017), distributed by American FactFinder, https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_17_5YR_B25044&prodType=table.

[42] Even without considering incentive rates for night-time charging, residential electric rate schedules provide for the equivalent of $1 per gallon gasoline. Fee-for-service non-residential charging is 25 percent to 200 percent more expensive than home charging, although still more economic than an equivalent gasoline cost scenario.

electricity- and gasoline-powered vehicles under differing energy source cost assumptions (and assuming 28.2 miles per gallon for gasoline-powered vehicles based on 2012 national averages).

Figure 11. Fuel cost per mile, EV and gasoline, by fuel price



Source: Road Map for Decarbonization of the Midcontinent, Transportation Electrification, pp. 5.

Workplace Charging

Who is charging? Employees of or visitors to a business or office complex of businesses who need to charge their vehicle while at work or participating in meetings.

Who is the owner/decision-maker? Large employers who own their buildings and business/property owners managing employment centers with multiple businesses that can benefit from on-site solar production.

Description: This use case focuses on EV charging during business hours at places of employment (8:00 a.m.to 6:00 p.m., Monday through Friday). This use case requires charging at a commercial building or in a commercial parking area (lot or ramp). The buildings or parking areas offer opportunities for on-site solar in either the parking lot or on the roof of the building. The use case includes large employers who own their own facilities and employment centers in which multiple businesses lease space from a property management company.

Example sites: A large variety of sites, from small office complexes to large corporate campuses fit into this use case. Other possible sites include hospitals or medical complexes, technology business parks, and local and state government administrative operations. Within the seven-county metropolitan area there are over 4,000 acres of surface parking lots associated with office and institution land uses.[43]

[43] As a partner of the Minnesota SEIN Team, the Metropolitan Council conducted a survey and analysis of surface parking lot solar potential in the seven county Twin Cities metro. The analysis excludes areas under 20,000 square feet. Including all commercial parking could significantly increase the number of potential applications for small employment centers and office buildings.

Workplace charging in surface parking lot at Mortenson Construction headquarters. Photo credit: Brian Ross

Solar Deployment Opportunities: Commercial buildings frequently have flat, unshaded roofs with excellent solar resources, but are highly unutilized. Commercial building rooftops typically make up a disproportionate share of a city's rooftop solar resources.[44] Commercial parking lots are large enough to offer sites for solar carport development. All of these solar opportunities will offer on-site generation opportunities that significantly exceed EV charging loads and can be optimized for both EV charging and building loads with appropriate metering arrangements.

Site owner value proposition: EV charging can become a standard feature of commercial parking lots, and the solar+EV application can enable EV charging without demand charge impacts for the site (creating a demand charge benefit for on-site solar, something that typically is not a benefit of commercial solar energy systems). Managed, solar-synchronized charging also allows the site owner to install more charging units on fewer circuits, and limit risk to on-site transformers from peak EV charging. Many of these facilities could optimize on-site solar and battery storage for both building load and EV charging at a low marginal cost to the solar+EV application. Solar carports in surface parking lots serve as shade structures and weather protection to add value to the EV charging space. Providing EV charging means adopting new technologies that serve as a recruiting tool for businesses seeking millennial or high-tech employees.

Expected synergies and other benefits: Workplace charging is a critical component of meeting transportation electrification goals, as over 30 percent of Minnesota households are renters and will have less access to overnight charging (benefiting cities that have climate action goals and the state's goals for both GHG reduction and renewable energy

[44] GPI has conducted dozens of assessments of community rooftop solar "reserves." Commercial rooftops frequently account for most of the best solar development in the community.

adoption). The potential deployment size of workplace charging could mean substantial distribution grid benefit and increasing the amount of renewable energy resources on the grid. Solar+EV in workplaces can address the transportation portion of city and state GHG reduction goals.

Barriers and limitations: Barriers to realization of the customer value proposition for this use case include the following issues.

- Metering issues: In order to capture demand charge savings, the EV charger and the solar array must be on the same meter.
- EV owner value proposition: Most EV charging is done overnight at the home and is the cheapest option for EV drivers. If the property owner or manager chooses to charge a fee for use, workplace EV charging may not offer enough value for EV drivers to use.
- EV charger capacity: As EV market penetration increases, the number of charging stalls may be insufficient for demand by employees, or the electric demand from charging could overload property transformers.
- Economic benefit to the site owner and the EV owner could be diminished depending on the workplace commute-shed.[45]

Public Parking Facilities

Who is charging? Individuals using public parking facilities include employees and customers of nearby businesses, and businesses wanting to provide a charging amenity.

Who is the owner/decision maker? Local governments and transit authorities who own and manage large parking facilities such as park & ride lots and downtown parking ramps serving multiple businesses and attractions.

Description: Parking facilities are not always associated with a specific destination, business, or land use, but can be instead a part of public infrastructure supporting regional or local transit operations or a group of businesses. Examples include “park & ride” facilities owned by transit operators, city-owned parking ramps supporting commercial nodes with many businesses, and private parking ramps (serving the public) in locations such as downtown areas or the airport. Drivers using these facilities are generally staying for longer periods of time, and the number of users is sufficient to ensure EV participation or need. Such facilities tend to be publicly owned, and thus have a different value proposition (a public benefit) compared to workplace parking/charging opportunities. Such facilities could have substantial areas for on-site solar development, although parking ramps in downtowns may have little on-site solar resources.

Example sites: Transit park & ride lots,[46] public or private airport parking facilities, city-owned parking ramps or surface lots that have solar resources, and parking at government facilities or community centers.

[45] Commute shed is the area within which workers at a site are traveling from home to work.

[46] Metro Transit has 21,000 parking stalls in over 100 facilities around the metropolitan area and is developing new facilities in conjunction with light rail transit stations. Several other transit agencies in the metro area also have park & ride facilities with hundreds of stalls.

Co-located solar and EV charging facilities in city-owned surface parking lots, Austin, MN and Duluth, MN.
Photo credit: Brian Ross

Solar Deployment Opportunities: Surface parking lots typically have substantial areas on which to install solar generation, although the additional support infrastructure (compared to mounting on an existing roof) can raise installation costs. Public parking facilities may have a building on-site that can host a rooftop system (such as airport parking), but some facilities are separated from buildings.

Customer value proposition: Provides an amenity to encourage transit use or to distinguish the parking ramp from others and creating a new revenue stream from solar generation co-located with parking. The long typical parking tenure allows for greater flexibility to match charging time to solar production, resulting in a greater level of charge, even on cloudy days.

Expected synergies and other benefits: Encourages improved utilization of transit for more distant commuters and low/no carbon commuting across the region, and improves “green branding” of transit options. For surface parking areas, on-site solar could provide an additional amenity as a shade structure. Direct public control of EV+solar investment offers city/state/regional opportunities to meet GHG reduction goals for private transportation sector.

Barriers and limitations: Barriers to realization of the customer value proposition for this use case include the following issues.

- Solar resource: Parking ramps may not accommodate on-site solar or may not have a solar resource if they are in a dense commercial area.
- Size of on-site load: On-site electric energy load would be lower relative to other commercial use cases, resulting in a diminished opportunity for optimizing combined load with on-site solar and storage.
- Charging for use: Transit operators or cities may have to make a financial case that would require fees for charging and diminish use.
- Parking tenure: Long parking times at park & rides limits the ability to cycle a fully-charged car out of the charging station.

Priority Market Transformation Use Cases

The priority solar+EV use cases are workplace charging and charging at public parking facilities. Both use cases involve daytime charging locations, are an essential part of the EV charging infrastructure system, and meet the characteristics of a priority solar+EV market transformation opportunity.

This section examines the economic case for workplace and public parking solar+EV applications. The analysis considers the opportunity from the site owner's economic perspective, as the site owner is the ultimate decision-maker for solar+EV installation. Economic analysis was conducted by the National Renewable Energy Laboratory (NREL) using an optimization tool called REopt to evaluate the impact on customer utility costs of light-duty EV charging operation in Minnesota.[47] NREL used REopt to evaluate questions such as:

- How can PV and stationary storage be co-deployed with EV charging infrastructure to lower the cost of purchasing grid electricity?
- What are the potential savings of co-locating EV charging infrastructure with a commercial building (behind the meter)?
- What savings can be gained from optimizing the times at which the EVs are charged?

The following use case assessment first looks at the size of the potential market for workplace charging and then examines the site-specific economic benefits for solar+EV applications. The use case assessment considers the direct synchronization of on-site solar with EV charging, and also considers other means of coupling solar production with EV charging, including integration with storage, building loads (or other on-site load), and comparing unmanaged and managed charging.

MARKET FOR WORKPLACE CHARGING

To estimate the potential market for solar+EV applications at workplaces, the Minnesota SEIN team assessed parking area data in the Minneapolis/Saint Paul metropolitan area. The Metropolitan Council (a Minnesota SEIN team member) conducted a GIS analysis of surface parking lots in the seven-county metro area as part of an assessment of impervious surfaces and heat island sources. The analysis looked at surface lots that were at least 20,000 square feet (roughly half an acre) and categorized each surface lot by the land use that the parking was serving (see Table 3).[48] The assessment did not capture parking ramps and so likely underestimates opportunities for workplace solar+EV applications.

[47] See *Evaluating Utility Costs Savings for EV Charging Infrastructure* (Elgqvist et al 2019) for more detail. Available here: https://www.nrel.gov/docs/fy20osti/75269.pdf.

[48] The analysis was not systematically ground-truthed, and the LiDAR data both missed some lots and characterized some non-pavement as parking lots. The metro-wide numbers are, according to the meta-data and in discussions with council staff, likely to be fairly accurate. The council also conducted an analysis of surface lots greater than 100,000 sq. feet, and the margin of error was low enough to map the data.

Table 3. Commercial parking lots by type of land use

2016 land use description	Total square footage	Total parking acreage	Total number of parking stalls (140/acre)
Institutional	32,725,451	751.3	105,178
Mixed-use commercial	14,914,408	342.4	47,934
Mixed-use residential	12,541,568	287.9	40,308
Multi-family	179,142,126	4,112.5	575,755
Office	147,119,164	3,377.4	472,835
Retail & other Commercial	589,734,674	13,538.4	1,895,382
Sum	**976,177,391**	22,409.9	3,137,393

Over three million parking stalls are in surface lots in the metro area, most of which have a sufficient solar resource to accommodate a solar carport with EV charging. Looking just at the workplace use categories (office and institutional), there are over 550,000 parking stalls in surface lots.

The Minnesota SEIN team conducted a national scan to compare other cities' EV charging requirements for commercial parking areas.[49] The scan focused on parking standards, zoning requirements, and flexible zoning standards such as planned unit developments (PUDs).[50] Current standards used by cities to require EV installations generally set a floor on the number of EV chargers required (at one or two) and then set a minimum percentage of parking stalls (1-5%) that must either have EV charging installed or have "make-ready" infrastructure installed (all the conduit and electric work done out to a site where EV chargers can be installed in the future). Some communities were considering as many as 10% of stalls to meet "make-ready" standards.

If 5% of stalls in Twin Cities surface parking lots were equipped with solar+EV installations by 2030, this would result in almost 29,000 Level 2 chargers at workplaces and institutions. If the solar+EV applications were solar carports, the solar capacity associated with the EV chargers would total approximately 50 MW (see Table 4).

While 29,000 chargers is a large increase over the metro area's current 600 (approx.) public and workplace chargers, the number of public (non-home) chargers needs to be increased to over 30,000 to meet Minnesota's 20% market penetration goal by 2030.

[49] Cooke, Claire and Brian Ross, GPI, *Summary of Best Practices in Electric Vehicle Ordinances* (2018), https://www.betterenergy.org/wp-content/uploads/2019/06/GPI_EV_Ordinance_Summary_web.pdf.

[50] Some cities used building codes rather than zoning tools to achieve the same outcome, but building codes are not currently a tool that Minnesota cities can use to implement EV charging in private development.

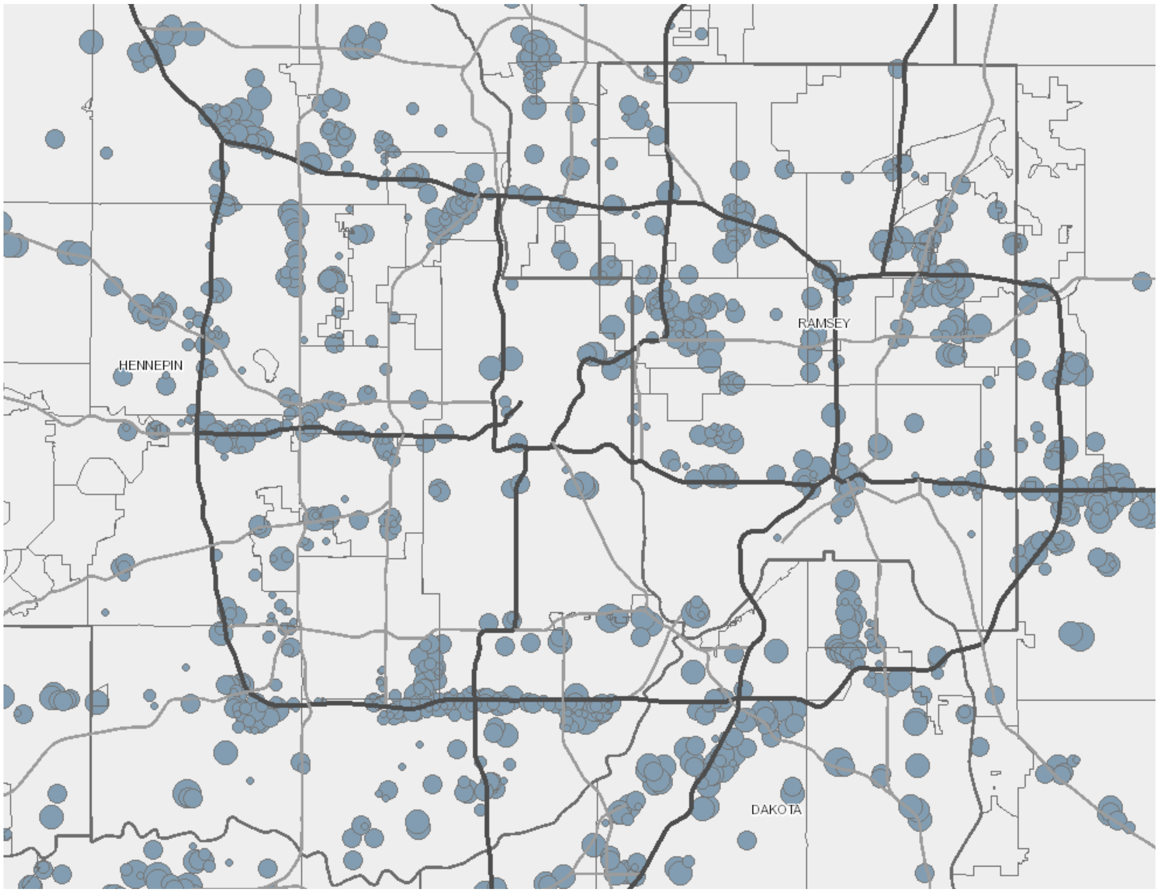
Table 4. Market potential for workplace solar+EV installations

2016 land use description	Total number of parking stalls (140/acre)	5% of stalls to Solar+EV	Solar capacity (kW)
Institutional	105,178	5,259	8,940
Mixed-use commercial	47,934	2,397	4,074
Mixed-use residential	40,308	2,015	3,426
Multi-family	575,755	28,788	48,939
Office	472,835	23,642	40,191
Retail & other Commercial	1,895,382	94,769	161,107
Sum	3,137,393	156,870	266,678

The Metropolitan Council also mapped surface parking lots greater than 100,000 square feet (about 2.2 acres) for the purpose of assessing solar development potential.[51] Figure 12 shows the distribution of these very large parking areas. Not surprisingly, the large parking areas tend to be located along the major transportation corridors and not in the dense urban core.

[51] The 100,000 sq. ft size allowed a higher level of confidence in site specific information than in the results for the 20,000 sq. ft threshold analysis.

Figure 12. Locations of large surface parking lots in the Minneapolis/St. Paul metro area by solar development capacity



Source: Metropolitan Council GIS Map viewer. The size of the circle indicates the solar development potential for this site. Most of the circles show solar potential over a MW in size.

MODELING SITE OWNER VALUE PROPOSITION

This project analyzed the customer value proposition for co-deploying solar photovoltaic (PV) and EV charging in two ways: analyzing data from the combination of solar PV and EV chargers in the field, and partnering with NREL to model combined PV, EV chargers, and building loads. In both the pilots and the modeling, managed charging was considered. The pilots pursued a strategy of EV charging that tracked PV production (solar synchronization). The NREL modeling sought an optimal dispatch strategy that took PV generation into account while also considering stationary storage options and the building load. The two complementary approaches to unpacking the customer value proposition highlight real-world findings on site owner value and potential future opportunities to expand the scope of solar+EV alongside building load and stationary storage.

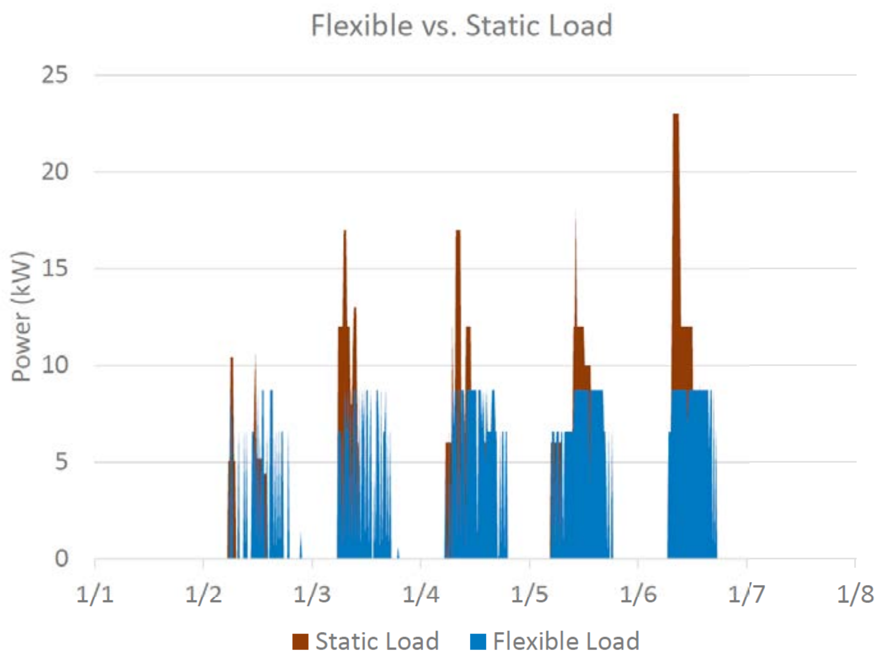
This subsection begins with a brief discussion of managed charging before turning to discussion of the solar synchronization piloting. It concludes with the modeling results developed by NREL.

No consideration was given in the modeling to qualitative benefits, such as the higher perceived value of green energy to the EV owner or site owner, benefits of shade structure and heat island effects of solar carports, or amenity considerations for employees or public parking patrons.

Managed Electric Vehicle Charging

The time and rate of charging can be modified through a variety of means, including programming or controlling the vehicle's internal call for power, and controlling the charging unit that the vehicle is plugged into. This is referred to as managed charging or smart charging, and can be used to achieve a variety of beneficial outcomes, such as charging only when electric rates are low or not charging at times of peak energy use for either the site owner or the electric utility (which are frequently not the same time).

Figure 13. Unmanaged (static) and managed (flexible) charging to limit demand

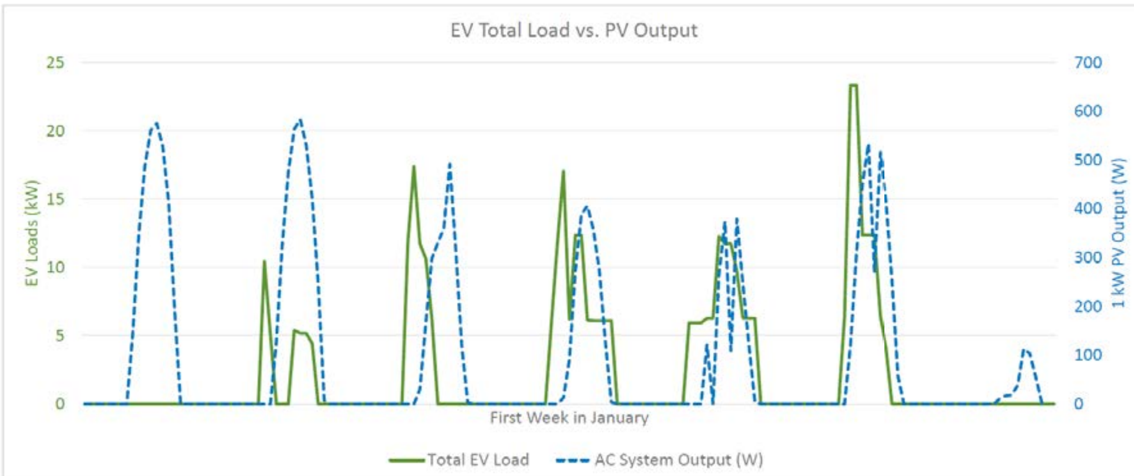


Source: NREL analysis conducted for the Minnesota SEIN project. This chart superimposes unmanaged charging (red) and managed charging (blue) to avoid simultaneous peaks from individual EVs for six chargers being used during the day at a workplace or public parking facility where cars are parked for most of the business day. The peaks from the six chargers in the unmanaged scenario also sometimes coincided with building load peaks.

Solar Synchronized Management

Solar synchronized charging is another approach to managed charging in which vehicles are charged when a solar array (either on-site or remote, or for the "fleet" of solar generation at the bulk power level) is producing power. In this scenario, when the vehicle is plugged in, charging will not start (or will start at a lower rate) unless there is sufficient solar production to cover the charging load. Charging will thus be shifted from early morning to later in the day, when solar production increases. The shift is generally no more than 2-3 hours and the battery can be fully charged in most cases.[52] Figure 14 shows an illustrative example of the mismatch between solar production (blue dotted line) and EV charging. Solar synchronization seeks to improve the overlap between solar production and EV charging load.

Figure 14. Mismatch of unmanaged charging and solar production



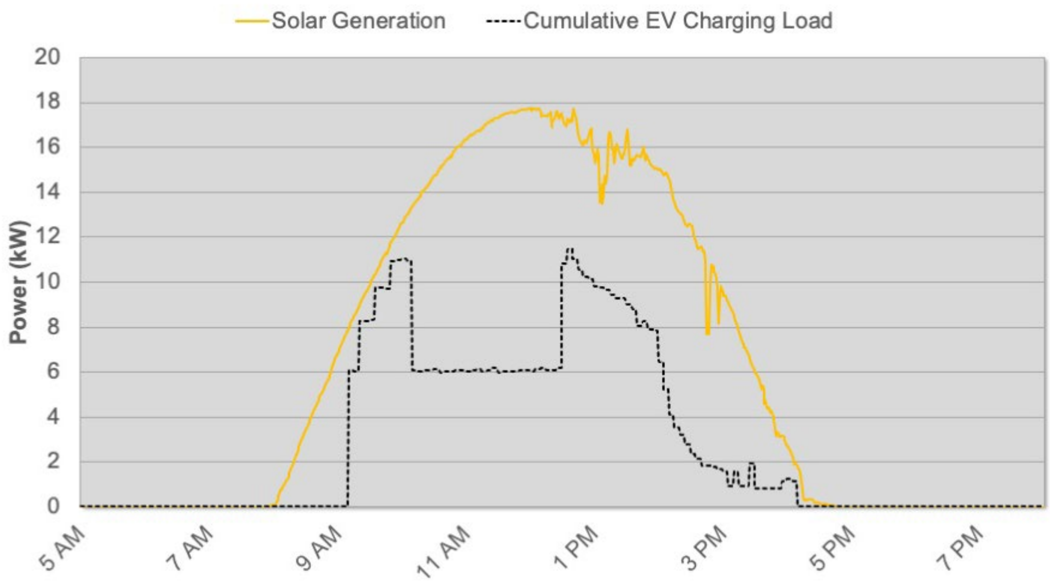
Source: NREL analysis for Minnesota SEIN project, showing the modeled charging patterns for six workplace chargers and the solar production curve for a January week. The timing mismatch is broadly consistent across days but could be matched through managed charging with a shift of only a couple of hours.

Piloting Solar Synchronization

The Minnesota SEIN Team analyzed the results from a solar synchronized set of chargers installed at the Greenway office building in Minneapolis (at GPI's headquarters). The building had an existing rooftop solar array, and the chargers were virtually linked to the array via a communications network system developed by ZEF Energy (a Minnesota SEIN team partner). Initial results demonstrated that the technology is viable, with solar production and EV charging sampled and adjusted every minute, as shown in Figure 15.

[52] If charging is synchronized with an on-site solar array, the ability to capture value from the solar array will depend on the size (capacity) of the solar array. On-site arrays can be sized to the EV charging load to manage peak load (approximately 7 kW per Level 2 charger), or to provide sufficient energy to meet charging energy needs over the day (approximately 1.3 kW per Level 2 charger). On-site solar arrays sized for additional building loads (larger than needed for just EV charging) provide more flexibility in solar synchronization but raise the possibility that another managed charging goal may provide greater value than synchronizing with EV charging alone.

Figure 15. Pilot test results of solar synchronization technology

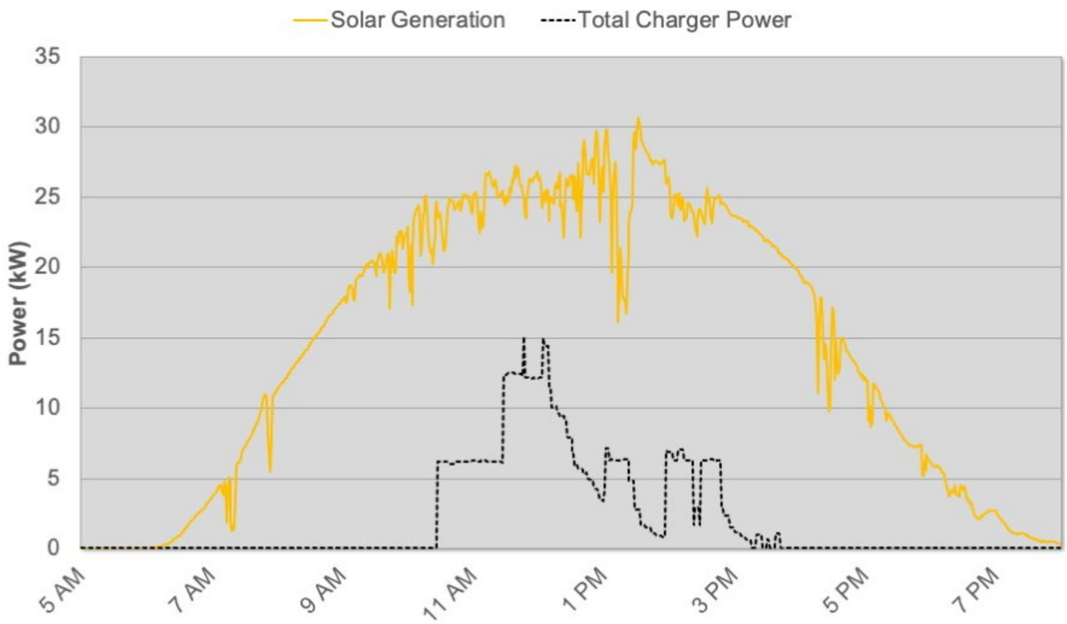


Source: GPI analysis of the Greenway solar synchronization pilot project. On this January day, solar production does not ramp up until after the start of business hours and declines prior to the end of business hours. In this case, no more than two chargers were used at any one time, and only one brief moment of simultaneous charging. Chargers will provide at least a Level 1 charge, regardless of solar production.

If the solar array is large enough relative to the maximum possible demand from EV charging, the demand from the chargers can be completely met by the solar array. The 30 kW solar array at the pilot site has a significantly larger rated capacity than the 20 kW maximum demand from the three Level 2 chargers. Moreover, the maximum coincident demand from the chargers in the months examined never exceeded 15 kW.[53] Thus, the size of the solar array provides a significant cushion that reduces the need for managed charging to cloudy days and early winter mornings.

[53] At least two of the five EVs owned by employees had a maximum Level 2 draw of 3.3 kW, rather than the 6.6 kW or larger demand posed by today's full electric vehicles.

Figure 16. Solar production and EV charging load, Greenway pilot site

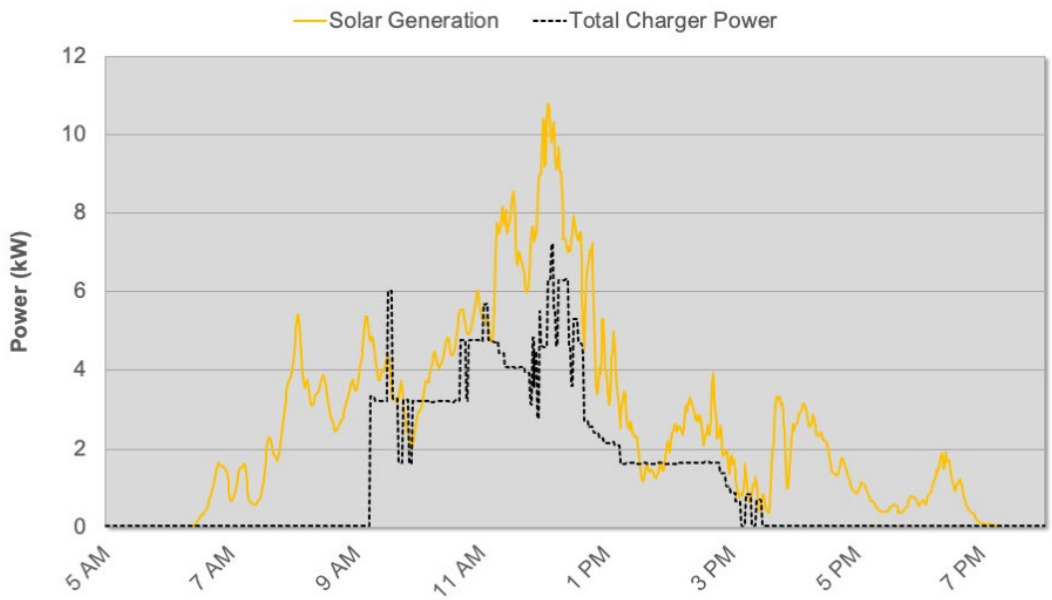


Source: GPI analysis. Solar production (late July) substantially exceeds maximum EV load. Even at 9:00 a.m., the solar capacity would cover the 15 kW peak. In contrast, winter solar production and cloudy days present circumstances when synchronized charging is needed to reduce demand charge impacts.

Pilot Background

The Minnesota Pollution Control Agency, Wellington Management, ZEF Energy, and GPI partnered on a solar-synchronized EV charging technology deployed at the Greenway Building in south Minneapolis. The technology developed by ZEF Energy allows a normal Level 2 EV charging station to match charging to the production of a 30 kW on-site rooftop solar array. The solar array production is not matched to building load, and thus did not provide any demand charge savings, but only provided energy savings. When the solar array is producing at full capacity, it can supply power for all three chargers at their full (6.6 kW) rated output. When the solar is not producing, the EV charging is slowed so that charging never exceeds solar output.

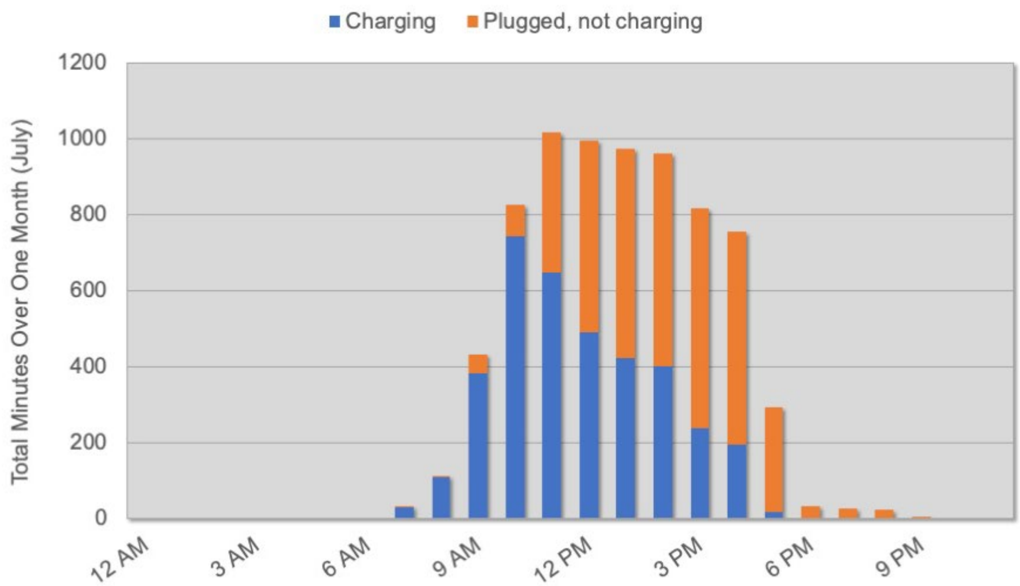
Figure 17. Solar synchronization at Greenway pilot site



Source: GPI analysis. A mostly cloudy day with intermittent solar production. Some mismatch of charging is shown because the charging data is shown at five-minute intervals and the solar production is at one minute.

Because the site is providing workplace charging, cars tend to be plugged in for much of the day and the consumer is rarely impacted by the variable charging speed. An analysis of charging "tenure" or how long vehicles were plugged in shows that nearly all instances result in a full charge for the EV owner at the pilot site.

Figure 18. Total charging time and total time plugged, Greenway pilot



Source: GPI analysis of Greenway pilot project. Vehicles are getting fully charged early in the day, as July sun is sufficient in the morning to meet charging demand. Vehicles are generally plugged in far longer than needed to charge.

Commute Shed and Charging Needs

In addition to parking tenure, the "commute shed" of the workplace can affect the ability of EV owners to get a full charge under a solar-synchronized charging scenario. Commute shed is the area within which workers at a site are traveling from home to get to work. A survey of EV users at this workplace reveals that nearly all the EV owners live within 10 miles of the workplace, with an average commute distance of less than 5 miles, and only one did not have access to home charging. The average commute for the metropolitan region is significantly longer, at approximately 12 miles.[54] The effect of a small commute-shed is that the vehicles have a smaller charging need; EVs are thus more likely to be fully charged even on a cloudy day compared to a workplace with a larger commute shed.

The Greenway pilot project demonstrates the functional operation and added value of a combined and synchronized solar+EV application, and issues of management and design of future systems.

[54] US Department of Transportation, National Household Travel Survey, *Summary of Travel Trends* (2017), https://nhts.ornl.gov/assets/2017_nhts_summary_travel_trends.pdf; US Census Bureau, American Community Survey, *Selected Economic Characteristics (*2017), Table DP03, distributed by American Factfinder, https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk.

SITE OWNER SOLAR+EV VALUE PROPOSITION

The REopt model assumptions for workplace charging can be also be adapted to public parking charging to assess the site owner value proposition. The scenarios that integrate building load were not relevant for the public parking use case, assuming that on-site energy use for public parking facilities would probably not benefit from optimization. For those public parking scenarios with significant on-site electric load, the profile is likely similar to the office building.

Modeling Background

In order for workplace and public parking solar+EV applications to be deployed on a wide scale, site owners must have a convincing economic value proposition. The Minnesota SEIN Team worked with NREL to model the site owner's economic value proposition under a variety of different assumptions and circumstances.

NREL's modeling assumed that the workplace charging scenario had the following conditions:

- **Chargers**: Six Level 2 EV chargers were installed in the building's parking area.
- **EV loads**: The modeling leverages the EVI-Pro tool to develop realistic charging behavior based on agent-based modeling that draws on data from driving behavior adjusted for the annual temperature profile of Minneapolis (to represent the changes in battery behavior across seasons). The EV loads assume one charger per EV at the location (i.e. vehicles do not need to be rotated during the day). The dataset has day-to-day variability in driving behavior, such as drivers going out for lunch.
- **Building load**: Building electric load profile for a mid-sized office building in an urban Minnesota location is based on DOE's reference buildings.
- **Rate**: Xcel Energy General Commercial rate schedule
- **Solar generation:** Systems were sized to serve on-site loads based on the scenario but were restricted from grid export to isolate the synergies between solar and EV charging in particular.

The base case was EV charging with no solar or storage integration and no building load. The optimization model assumed that the site owner would install six EV chargers regardless of whether other devices or solar were installed. The optimization scenarios thus held constant the installation cost of the EV chargers and examined changes in net present value for changes in capital costs associated with installed solar and storage.

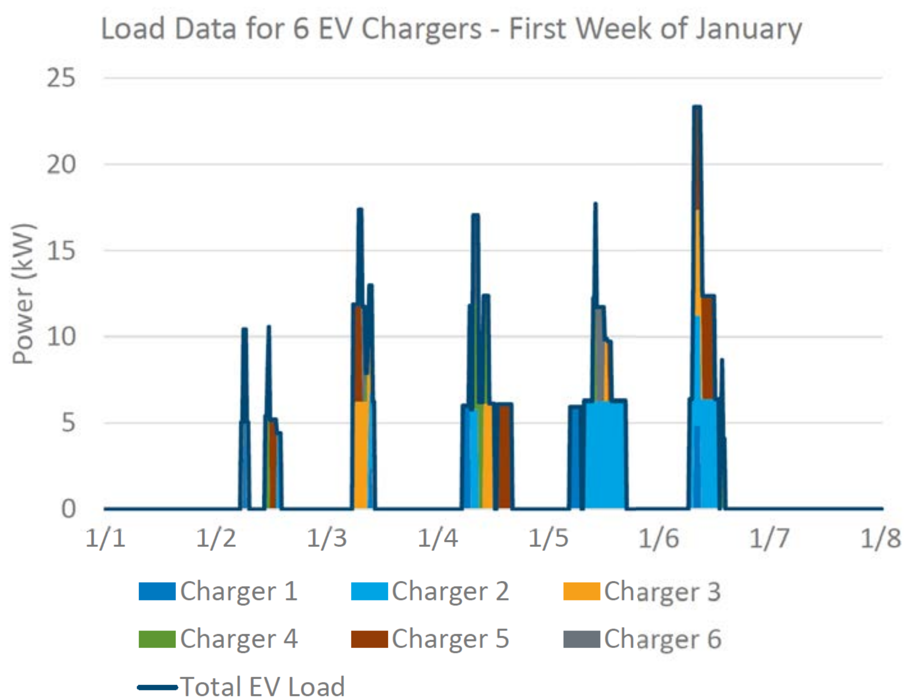
Specifically, the NREL modeling evaluated the following application and integration methods for a mid-sized commercial office building in Minnesota:

1. *Co-located solar and EV charging*. This scenario would be relevant both to solar carports and rooftop solar co-located with EV chargers. This scenario assumes that the solar and the EV chargers are on the same meter and using a standard electric rate for commercial customers. EV charging is not "managed," so that charging always starts at full rate and runs until the vehicle is fully charged. This scenario also includes the option of using stationary energy storage (if cost-effective).

2. *Co-located solar and EV charging paired with a building load*. This scenario adds building load to the first scenario, again with EV charging that was not "managed."
3. *Solar integrated with EV chargers (co-located or virtually) with managed charging*. This scenario assumes that the charging is managed, so that charging occurs when it is most cost-effective to do so. The constraints to the managed charging are that each vehicle needs to be charged before the driver needs to deport and the maximum charging rate is determined by the Level 2 charger. In this scenario the solar and charger are on the same meter.
4. *Managed EV charging integrated with building load with solar and/or storage*. This managed charging scenario adds the building load to the same meter as the solar and charging. Similarly, the EV charging (and battery dispatch) is managed to minimize costs.

This discussion will focus on scenario #2 and scenario #4 in particular to highlight the scenarios that include the building load. See *Evaluating Utility Costs Savings for EV Charging Infrastructure* (Elgqvist et al 2019) for the full modeling results.

Figure 19. One week of EV charging profile from NREL model



Source: Elgqvist et al (2019). This figure shows six chargers for a week in January. The charging profiles were developed for this project, incorporating winter and summer charging profiles that reflect temperature data for Minneapolis, Minnesota

The modeling effort optimized for cost savings for the site owner on utility bills with constraints and assumptions across a wide range of variables, including the following:

- EV charging
- On-site distributed solar
- On-site battery storage
- Managed or unmanaged charging
- Behind the meter with building load or stand alone

Modeling Results

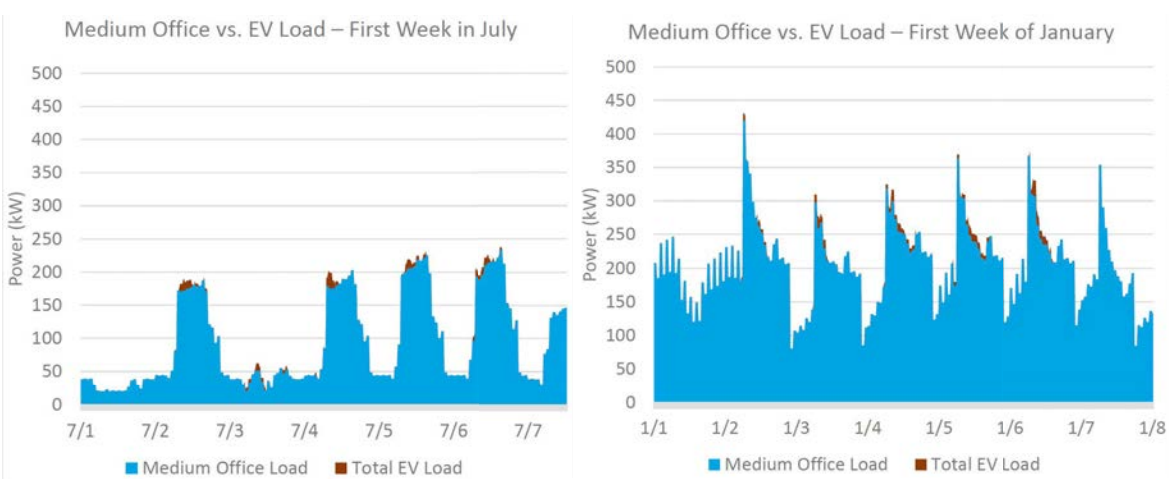
Both workplace and public parking solar+EV scenarios show a positive economic value proposition for the site owner. The solar+EV economic case for stand-alone solar synchronization with energy storage shows an annual reduction in electric costs of approximately $3,000 and a lifecycle cost saving (savings after paying for the capital costs over a 25-year period) of approximately $20,000. When building load can be integrated with the EV charging, the optimized system helps offset both EV charging costs and electric costs for the building. The optimized system is significantly larger with much higher capital costs but reduces annual energy costs by almost $30,000 and generates a lifecycle cost savings of over $200,000 (compared with a stand-alone EV charging installation).Key findings from the modeling results are described in further detail below.

WORKPLACE CHARGING

Integrating EV charging with the building load (both EV charging and building energy demand are on the same meter) allows the greatest economic benefit to the site owner and enables cost-effective deployment of solar and storage.

The EV charging load sometimes peaks at different times than the building's peak demand, depending in part on the season. Combining these loads under the same meter significantly reduces (but does not eliminate) the cost of demand from the EV chargers.

Figure 20. Contribution of EV charging to building demand



Source: Elgqvist et al (2019). Demand from six EV chargers is quite small compared to this building load, but still contributes to peak demand on most days, in both July and January. The building electric load profile for a mid-sized office building in an urban Minnesota location is based on DOE's reference buildings.

Also, similar to unmanaged EV charging, building load has a consistent peak mismatch with solar production. On-site solar production would thus be unlikely to cost-effectively or reliably reduce the demand portion of the electric bill (a common finding for commercial solar installations). Most building load is not flexible, and a battery storage system would be needed to move solar production to the time of peak building demand.

Elgqvist et al (2019) shows that adding six EV chargers to the site, but putting these chargers on a separate meter, would increase the total annual electric bill by $5,600 with a lifecycle cost (excluding the capital for the chargers) of $140,000 and a total energy cost to the site owner of $2,669,000.

Figure 21. Office building base case, separate meter for EV charging

Scenario	EV Chargers Only	Building Only	Building + EV Chargers (Separate Meters)
PV Size (kW)	0	0	0
Battery Size (kW)	0	0	0
Battery Size (kWh)	0	0	0
Total Capital Cost ($)	$0	$0	$0
Electricity Purchases (kWh)	17,400	1,022,700	1,040,100
Percent RE (%)	0%	0%	0%
Year 1 Energy Costs ($)	$1,100	$63,100	$64,200
Year 1 Demand Costs ($)	$4,500	$42,900	$47,400
Year 1 Fixed Costs ($)	$300	$300	$600
Year 1 Total Electricity Cost ($)	$5,900	$106,400	$112,200
25 Year Lifecycle Cost ($)	$140,000	$2,529,000	$2,669,000

Source: Elgqvist et al (2019). The base case for the analysis assumes that chargers will be installed in every scenario and so those capital costs are not included.

Incorporating managed charging with this scenario eliminates the remaining contribution that EV charging makes to peak demand. Moreover, managed charging enables a larger solar array to be cost-optimal and reduces the need for battery storage to link solar production to peak building demand. Solar+EV applications can use managed charging to mitigate demand charges associated with the EV load, but building loads are not as flexible, and storage is the more effective way to marry load and on-site solar production.

The combination of all these elements (solar, managed EV charging, storage, and building load all behind the same meter) creates an economic opportunity for a solar+EV application that is applicable to a wider variety of cases in Minnesota. The REopt analysis reports the following:

- When PV and storage is evaluated at the office building along with the flexible EV load, the optimal size of PV is larger, and the optimal size of storage is smaller, compared to the same scenario with the static EV load.
- The EV load flexibility is serving the same purpose as stationary storage, as the charging can be modified to mitigate demand charges.
- Because of this, additional PV is cost-effective; the flexible EV load enables it to shave a wider part of the demand peak.[55]

Figure 22. Net present value of optimized deployment of solar, storage, managed charging, building load

Scenario	Chargers (Combined Meter Static EV Load)	Building + EV Chargers (Combined Meter) Flexible EV Load	(Combined Meter) Flexible EV Load Add PV + Storage
PV Size (kW)	0	0	211
Battery Size (kW)	0	0	60
Battery Size (kWh)	0	0	71
Total Capital Cost ($)	$0	$0	$521,000
Electricity Purchases (kWh)	1,040,100	1,040,100	791,692
Percent RE (%)	0%	0%	26%
Year 1 Energy Costs ($)	$64,200	$64,200	$48,900
Year 1 Demand Costs ($)	$43,700	$43,000	$33,400
Year 1 Fixed Costs ($)	$300	$300	$300
Year 1 Total Electricity Cost ($)	$108,200	$107,400	$82,500
25 Year Lifecycle Cost ($)	$2,573,000	$2,554,000	$2,458,000
NPV ($)	**$0**	**$19,000**	**$96,000**

Source: Elgqvist et al (2019). Combining all four of these elements creates an economic synergy and savings with a net present value of $211,000 (base case cost is not shown, $2,669,000)

As shown in Figure 22, simply combining the EV and building loads in a single electric account (behind one meter rather than separate meters) captures benefits of managed

[55] Cutler, Dylan, et al, National Renewable Energy Laboratory (NREL), *REopt: A Platform for Energy System Integration and Optimization, NREL/TP-7A40-70022* (September 2017), https://www.nrel.gov/docs/fy17osti/70022.pdf.

charging (savings have a net present value [NPV] of $19,000). However, the synergy created with solar production is substantial, and the total savings from the base case of the optimized solar+EV, managed charging, and storage has an NPV of $115,000. Annual electricity cost savings is roughly $25,700.

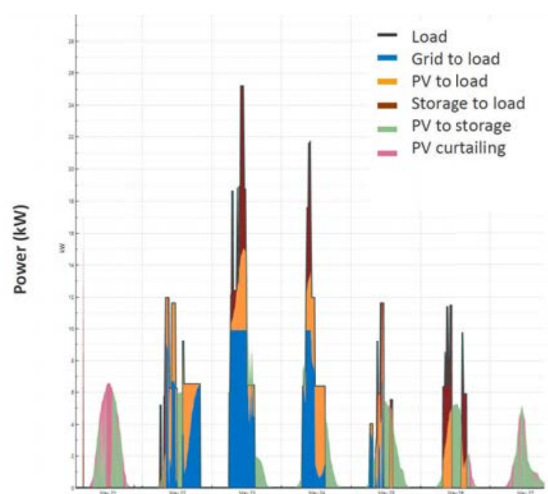
PUBLIC PARKING CHARGING

The public parking use case has many of the same inputs and circumstances as the workplace charging use case. The primary difference is the existing electric demand on the parking site; public parking will rarely have a large existing electric load that can be married to the EV charging electric load. For this use case, the focus is on solar+EV applications that consider only the EV charging load itself.

Interpreting the analysis through that lens, the primary finding from the modeling analysis is that managed charging provides substantial benefit to the site owner in off-setting demand charges. If the parking tenure is consistent with the modeled parking and charging behavior created by NREL, charging can be spread out across the day to significantly limit demand charges. Spreading out the charge over a longer period of time will also still provide an equivalent amount of charge to the EV owner as would have occurred under the unmanaged scenario.

A related finding in all modeled scenarios is that managed charging is a less expensive means of managing demand than energy storage. Some of this finding is a vestige of the model, which works with perfect foresight to manage charging behavior and solar production. But the flexible load of the EV is serving the same purpose as energy storage and doing so at a lower cost.[56]

Figure 23. EV charging managed with solar+storage



Source: NREL REopt analysis. The solar array directly supplies the charger, charges the battery, or is curtailed (no credit is modeled for net metering).

[56] The REopt model did not assign capital costs to the managed charging scenario, but networked chargers do have a higher cost than non-networked chargers. The costs for just the ability to manage charging would be incremental, most likely having a payback of a little over a year.

The REopt results show that a small solar array (9 kW) coupled with a small battery system (17 kW/28 kWh) generates $3,100 of energy savings annually and a lifecycle benefit of $21,000 (after paying off the capital costs of the solar and storage). The solar synchronized version would need a larger solar array to compensate for the inability to move across days. This increases the cost of the solar array, but eliminates the upfront cost of the energy storage.

Market Transformation Recommendations

For Minnesota to successfully meet its GHG reduction goals, emissions must be dramatically reduced in both the electric generation and the transportation sectors. Both objectives can be supported through deployment of solar+EV applications. Minnesota's distributed solar and grid modernization goals also support these applications. Solar+EV applications present a strong economic case for site owners needing or desiring to provide EV charging in workplace and public parking use cases. Managers of the distribution grid and the bulk power system can also benefit from the ability of solar+EV deployment to mitigate some of the challenges associated with increasing penetrations of each technology. As a result, a variety of market stakeholders stand to benefit from widespread solar+EV deployment.

Barriers to Deployment

A number of barriers prevent the economic and policy benefits of solar+EV applications from being realized. The barriers are listed in Table 5 in five categories.

Table 5. Barriers to solar+EV deployment

Resource and Economic Barriers
Sun only shines during the day (most charging occurs at night)
Mismatch between solar energy production and daytime EV charging needs
Cost of charging to the EV owner is likely lowest at home (where charging is not frequently during daytime hours), limiting solar+EV opportunities
To capture full value from solar+EV applications, the EV charger and the solar array must be on the same meter
Perception by solar vendors/developers of lack of market interest in solar+EV applications
Perception by commercial property developers/managers of no EV market demand
Lack of visible solar+EV examples in the Minnesota market

Site Owner Barriers
Difficult business proposition for charging to pay for itself in fees to site owner
Split incentive for commercial building owners, property managers, for installing solar+EV
Limited on-site electric capacity in existing commercial buildings for EV charging infrastructure
Commercial metering with multiple meters for different loads on the same site

Utility System Barriers
Utility revenue loss from on-site solar deployment
EV-charging utility rates frequently prohibit combining solar+EV on the same meter
Demand charge rate structures limit capture of solar capacity benefits
Limited understanding of how to measure value of DERs on the distribution grid
Coincident EV charging can stress and overload distribution grid components at multiple points on the system

Local Government Barriers
EV charging is not part of parking or development standards
Solar installations are not allowed by-right, or are discouraged, in development regulations
Perceived lack of ability to influence transportation electrification goals
Unfamiliarity with local government best practices for solar- and EV-ready communities

State Policy or Societal Barriers
Opposition to prioritizing solar+EV applications in supporting climate-related initiatives
Equity issues regarding who benefits from solar or EV charging infrastructure
Lack of sufficient EV charging infrastructure to achieve transportation GHG reduction targets
Emissions externalities are not accounted for in market pricing for vehicles and infrastructure

The Minnesota SEIN Team and stakeholders considered a variety of vectors for addressing these barriers to a self-sustaining market for solar+EV deployment. The recommendations for addressing barriers can be placed into four categories on the basis of which stakeholders would lead them:

1) Private sector initiatives to capture solar+EV value in products and services
2) Local government development regulations, programs
3) Utilities rates and programs
4) State policy or program initiatives

Each of these categories is led by a different set of actors who have interest and opportunity to increase deployment of solar energy or EV charging infrastructure. Most of these actors are already working on market transformation efforts for solar deployment or electrification of transportation.

For each of these market transformation vectors, we investigated:

- The solar+EV value proposition opportunity, and each actor's existing initiatives (if any) to promote solar development or EV deployment; and
- New tools or initiatives needed to create an economically self-sustaining market for solar+EV applications.

PRIVATE SECTOR INITIATIVES

The primary private sector actors for workplace/public parking use case market transformation are the solar energy industry (contractors, developers); EV installers and vendors; and commercial property managers and developers. Some of these market participants are more familiar with solar+EV applications than others. The EV vendors were most aware of solar+EV applications, being familiar with the benefits of managed charging and its ready application to on-site solar generation. Commercial property managers and developers, in contrast, were largely unaware of a solar+EV value proposition other than the "green marketing" benefits. Very few of these private sector actors had developed solar+EV market products, with only a few EV charging companies offering specific solar+EV products.

Tools or Initiatives

The solar and EV industries can play two market transformation roles that fit within their existing business models: (1) helping to educate the market (site owners/managers) that value and opportunity exist; and (2) developing plug and play products or services that capture construction synergies and maximize value to the market. The solar industry and the EV industry have opportunities to create solar+EV products and services as a value-added product to their existing offerings. For the workplace or public parking use cases, demand is growing for EV charging infrastructure and on-site solar. Commercial developers and property managers could offer solar+EV amenities to clients as a future-proofing or value-added component of the development or lease. Demonstrating economically viable solar+EV applications to private sector industries would strengthen the case for market transformation actions by industry.

Recommendation—Create solar+EV market products to notify the market of the value-added opportunity.

- Co-market existing products with a solar or EV value-added option.
- Develop pre-engineered solar carport products that capture construction and design economies.
- Include synchronization hardware in commercial solar projects.
- Develop financing options specific to solar+EV applications.
- Promote use cases for combined DERs (solar, storage, managed charging).
- Incorporation of solar+EV into commercial and mixed-use development by building managers and developers.

LOCAL GOVERNMENT INITIATIVES

Cities are the primary authorities having jurisdiction for development of DERs. All development is ultimately local, and local governments are in a primary position to be either a catalyst or barrier to market transformation. Cities are also active and routine participants in economic development initiatives, not only reacting and regulating market activity, but also encouraging market activity to serve community goals. The Minnesota SEIN team engaged a wide array of cities during the SEIN project to assess knowledge and interest in solar+EV applications as a means of meeting community goals. Cities can be particularly enthusiastic about EV market transformation, but seldom have a clear idea how to use local tools to encourage EV charging deployment. Cities are also supportive—although less consistently enthusiastic—of solar development.

Tools or Initiatives

The tools for EV, solar, and solar+EV market transformation are the same tools that local governments use to achieve community goals for other forms of development (housing, job creation, infrastructure, etc.). Zoning and parking standards, incentive regulation, economic development tools such as financing, and technical assistance are well-established tools for shaping local private sector development. Local governments also routinely make public infrastructure investments to provide specific public benefits, including development and maintenance of public parking facilities. Moreover, a number of local governments in Minnesota have adopted climate action or energy goals that include encouragement of solar development and support for electrifying transportation.

Recommendation—Incorporate EV charging infrastructure into local ordinances, codes, and development programs, similar to solar distributed generation best practices.

- Modify development regulations (parking standards, zoning) to enable or require EV charging, solar+EV land uses for priority land uses (multi-family, workplaces, destinations).
- Support code changes or stretch codes that require EV charging infrastructure, reflect solar-synchronized charging benefits.
- Link city development incentives (financial or regulatory), grants, sustainability programs with EV infrastructure and solar+EV outcomes.
- Create city collaborations with the electric utility to expand market for solar+EV and capture distribution grid benefits.
- Develop an EV-ready city certification program to supplement existing city certification or technical assistance programs such as Minnesota's GreenStep Cities program and the national SolSmart certification program for local governments.

EV-READY CITIES

While action at the state level is critical for deployment at scale, local governments also play an important role. Local governments can help meet the demand for new infrastructure, grow EV adoption, and capture community and individual benefits of lower operating and maintenance costs, zero tailpipe emissions, and energy independence by becoming EV ready. There are five principles for local governments to become EV ready:

1. **Policy**: Acknowledge EV benefits and support development of charging infrastructure.
2. **Regulation**: Implement development standards and regulations that enable EVSE (electric vehicle supply equipment) use.
3. **Administration**: Create transparent and predictable EV permitting processes
4. **Programs**: Develop public programs to overcome market barriers.
5. **Leadership**: Demonstrate EV viability in public fleets and facilities.

Twenty-eight cities in Minnesota took steps toward becoming EV ready by participating in Cities Charging Ahead!, a peer-learning cohort led by GPI and Clean Energy Resource Teams that ran in parallel with the SEIN solar+EV project. This facilitated collaborative education and program development on EV readiness and resulted in market transformation in many cities, demonstrated in the table below.

Table 6. Minnesota cities taking action to become EV ready

Principle	City	Action
Policy	Burnsville*	Included supportive language in its comprehensive plan to increase EV adoption by encouraging the buildout of charging stations.
Regulation	St. Louis Park*	Developed EV parking standards: Requires all new or reconstructed parking structures/lots with at least 50 parking spaces to install EVSE. • Multi-family land uses need 10 percent Level 1 for resident parking and one Level 2 station for guest parking • Non-residential lots for general public need 1 percent Level 2 stations with a minimum of two spaces
Programs	Red Wing*	Installed a 25 kWh DCFC in a downtown parking lot, collaborated with private sector to expand Level 2 charging in key locations.
Leadership	Minneapolis	Purchased Chevy Bolts and incorporated them into its city fleet, plans for expanding to dozens of vehicles and solar+EV charging.

*Cities Charging Ahead! participant

UTILITY RATES AND PROGRAMS

The utility value proposition is complex and difficult to quantify, particularly the distribution grid value of solar+EV as both EV and solar market penetration rise.

- For distributed solar, the growth of "prosumers" (electricity consumers who also produce power) raises questions about how to design the grid to accommodate power flow in both directions, to and from the end user.
- For EV charging, the question is raised of the capacity of local and regional grid infrastructure to accommodate significantly scaled up electric demand. Even at low overall penetration levels, some analyses have identified "clustering" effects of a relatively small number of EVs on a single distribution circuit. Simultaneous use of unmanaged level 2 chargers on a feeder or behind a line transformer can affect voltage

Recommendation for national laboratories, universities, regulators—Identify and measure predictable grid value from solar+EV applications, design programs to capture value

- Identify and document distribution grid benefits, anticipating the expansion of EV charging as a significant end use with potentially significant cost and reliability consequences on the distribution grid.
- Identify and document bulk power system benefits, determining the potential for managed load with distributed solar to provide a variety of bulk power system services.

standards, overload service transformer, decrease life of other system components, and create the need for grid updates and capacity improvements.

Regulators and utilities have several opportunities to capture solar+EV value, including revenue through improved utilization of existing infrastructure, increasing the amount of renewable energy on the system, and limiting the risk of infrastructure capacity shortfalls as EV market penetration grows.

Via the regulatory process (in collaboration with a wide range of stakeholders), a wide range of utility-managed EV incentives are place, along with some distributed solar incentives. The EV charger incentive programs and incentive rate structures for EV charging are primarily targeted to residential applications.

Recommendation—Investigate equity opportunities for solar+EV applications.

- In program and rate designs, actively mitigate potential rate impacts to low-income customers of solar distributed generation and EV charging and enable participation by low- to moderate-income households in solar and EV incentive programs.
- Creating financeable EV deployment in multi-family buildings.
- Develop public charging mobility hubs (shared vehicles, public charging, electric bikes/scooters, ride share centers) with solar charging.

Tools or Initiatives

A number of utility initiatives are underway in Minnesota to accelerate transportation electrification. For rate regulated utilities (four in Minnesota) these initiatives are mostly in their pilot phases, but include co-funding of EV chargers, “make ready” installations paid for and owned by the utility, and a variety of EV rates that provide price signals to encourage EV charging at off-peak times or when renewable energy is most likely to be curtailed for lack of load. Most of these programs and rates are currently directed toward residential or fleet EV use and charging infrastructure. Solar+EV market transformation for the priority use cases (workplace charging and public parking charging) can use the same set of tools, but they need to be designed with the solar+EV value in mind.

Recommendation—Develop EV charging utility rates and incentives that capture potential demand charge savings, grid benefits, and bulk power benefits.

- Enable customers to manage EV charging with building loads, and synchronize with on-site generation for peak load reduction.
- Provide make-ready investments for solar-synchronized public charging.
- Identify and target distribution grid benefits:
  - ✓ manage system peak capacity
  - ✓ provide frequency regulation, ramping, and balancing capability
- Create EV rates that capture bulk power benefits of solar+EV applications, such as combined wind/solar synchronization.

STATE POLICY AND PROGRAMS

The State of Minnesota has adopted a variety of supportive policies for GHG reduction, renewable energy development, and electrification of transportation. Integrating solar+EV into the existing set of incentives and policy initiatives will help the state meet its existing goals and enhance existing programs. Policy and program initiatives are currently being considered that could play a critical role in solar+EV market transformation.

Recommendation—Develop program or regulatory initiatives to increase the opportunities for solar+EV deployment.

- Recognition of, or priorities for, solar+EV value in state grant programs.
- Support for research into grid or bulk power benefits.
- Incorporate solar+EV benefits in state infrastructure or regulation.
- Implement the PUC's grid modernization principles in resource and distribution system planning, utility business model alternatives, and other regulatory processes.

Tools or Initiatives

Minnesota has a strong policy foundation for taking action in the Next Generation Energy Act.[57] The state has been a leader in solar-supportive policies for a number of years, including community solar gardens, using value-of-solar pricing, developing integrated distribution planning and grid modernization, and transforming utility business models to achieve policy goals. Minnesota's EV-supportive policies are significantly weaker, but policy models for EV market transformation from other states have been tested and are available for adaptation to Minnesota circumstances and markets. Minnesota has maximized use (15 percent) of the Volkswagen settlement funds for EV infrastructure grants and has programmatically prioritized use of renewable energy for grant making.

Recommendation—Create supportive policy and standards for development of solar+EV markets.

- Enable statewide code changes for EV charging installation, and solar+EV synergies in managing loads
- Develop a low-carbon or clean fuel standard for Minnesota. Such a standard will emphasize the importance of coupling clean energy, particularly solar and wind energy generation, with EV charging.
- Implement the Minnesota PUC's grid modernization principles in resource and distribution system planning, utility business model alternatives, and other regulatory processes.

[57] Next Generation Energy Act, 2007 Minn. Laws Ch. 136, https://www.revisor.mn.gov/laws/2007/0/136/.

Appendix A. Engaging Stakeholder and Market Participants

A critical part of the project was engaging market participants and key stakeholders to understand market perception of vendors, developers, and decision makers for key use cases. The Great Plains Institute (GPI) has completed a number of stakeholder input processes and events to support the development of the solar+EV market transformation action plan. The stakeholder input processes included both processes created and administered specific to the SEIN project, and stakeholder engagement in related ongoing work that supported multiple projects including the SEIN project.

SEIN Stakeholder Processes

- Minnesota Stakeholder Kickoff Workshop
- Minnesota Stakeholder Findings Workshop
- Minnesota Stakeholder Implementation Workshop
- Stakeholder participation on the Minnesota SEIN Team
- Solar industry interviews and survey
- Developer/property manager interviews
- Volkswagen Settlement Grant Program Assistance to cities for solar
- Stakeholder engagement for SEIN Working Sessions and Symposium

Stakeholder Input from Other Projects that Support SEIN Research and Outcomes

- GreenStep Cities
- Local Government Project for Energy Planning
- Cities Charging Ahead! cohort
- SolSmart Upper Midwest Cohort
- Drive Electric Minnesota
- Midcontinent Transportation Electrification Collaborative
- Regulatory proceeding on EVs and DERs, utility engagement on EV planning and distribution grid planning

SEIN STAKEHOLDER PROCESSES

GPI created stakeholder engagement processes as part of the SEIN project in order to:

- gather market information on perceptions and awareness of solar+EV applications by distinct stakeholder and market participant cohorts,
- engage a variety of market participants and stakeholder cohorts on study analyses, findings, and draft recommendations; and
- set the stage for broader implementation of solar+EV applications and initiated processes for removing barriers and creating incentives for broader market activity.

The market participant/stakeholder engagement processes generated a number of key findings that shaped the solar+EV market transformation recommendations and helped set up several solar+EV demonstrations.

Stakeholder Engagement Strategies

The following market participant/stakeholder engagement processes were designed into the SEIN solar+EV process:

- Stakeholder participation on the Minnesota SEIN Team
- Three day-long stakeholder workshops
- Developer interviews and engagement
- Solar industry interviews and survey
- Volkswagen Settlement Grant Program Assistance
- Stakeholder engagement in SEIN Working Sessions and Symposium

MINNESOTA SEIN TEAM PARTICIPATION:

A team of key stakeholders was formed for the SEIN project to directly engage key market participant/stakeholder cohorts or entities with access to key cohorts. The Minnesota SEIN Team met monthly throughout the project, each member having specific EV and/or solar initiatives that they brought to the table for this project. In addition to reporting on individual initiatives, the Minnesota SEIN Team participated in providing feedback on SEIN analyses, findings, recommendations, and program work, and participated in the larger SEIN Working Sessions. The Minnesota SEIN Team included:

1. GPI, with an internal team working on solar and EV market transformation in five distinct programs.
2. The Minnesota Department of Commerce, State Energy Office, which had active solar and EV program initiatives and ongoing research.
3. The Minnesota Department of Administration, Office of Enterprise Sustainability, which is in charge of all solar and EV development efforts in state facilities and fleets, and which leads joint purchasing efforts (including EV and EVSE) for Minnesota local governments.
4. The Metropolitan Council, Community Development Division, which oversees local comprehensive planning for 188 metro area local governments, and is staffed to provide solar, EV, and resilience technical assistance to local governments. The Metropolitan Council is also the US DOT designated Metropolitan Planning Organization for the metro region.
5. Metro Transit, the regional transit organization running the metro region bus fleet, Park and Ride facilities, Metro Mobility program, and light rail transit system.
6. ZEF Energy, a Minnesota manufacturer, installer, and owner of EVSE, and the developer of the initial solar+EV charging pilot project.
7. The Minnesota Solar Energy Industry Association, the primary advocate for the solar industry in Minnesota.
8. The Center for Energy and Environment, an NGO with engineering and technical capacity working on both policy and implementation for clean energy applications, including energy efficiency, integrated solar energy, and EV market transformation, and having a long history of working with contractors and developers.
9. Xcel Energy, the largest electric utility in Minnesota, which in the process of developing EV market transformation programs and administering the largest community solar garden program in the nation.

10. The Minnesota Pollution Control Agency, which oversees Minnesota's climate goals, tracking GHG emissions against Minnesota's mandatory targets, and administering the Volkswagen Settlement Grant programs.
11. The City of St. Cloud, one of Minnesota's leading cities on implementing clean energy and solar energy initiatives for public buildings, and a primary participant in the GreenStep Cities program.
12. The City of Rochester, Minnesota's third largest city, is a GreenStep City and Cities Charging Ahead! participant, and is working on a 100 percent clean energy goal, EV bus initiatives, and EVSE deployment.
13. The City of Minneapolis, Minnesota's largest city, is taking initiative on 100 percent renewable energy goals, EV market transformation, and collaborating with its energy utilities in a "Clean Energy Partnership" that includes solar and EV initiatives.

MINNESOTA STAKEHOLDER WORKSHOPS

Three stakeholder workshops were designed into the process to convene key stakeholder cohorts and engage the stakeholders in collaborative discussion about solar+EV use cases, market potential, and technical analyses. Two workshops were completed in 2018, one in May and one in December, to discuss best practices around solar and EVs, emerging research on the topic, modeling efforts, and how collocating and integrating solar and EV charging fits into GHG emission reduction goals. Stakeholder input from these meetings helped to direct the project team and in the creation of the action plan.

1. **Kickoff Workshop**: 28 organizations were represented at this workshop. The workshop focused on discussing and defining use cases and potential markets for solar+EVs. The process identified eight distinct use cases, characteristics, and opportunities for market deployment of solar+EV.
2. **Findings Workshop**: 20 organizations were represented at this workshop. The workshop focused on completed research and findings to support and guide market transformation efforts, modeling results for EVs and solar+EVs, and recommendations for solar+EV deployment. Stakeholders participated in several rounds of presentations and small group discussion on key takeaways relating to solar+EV applications and provided feedback and modifications on draft action plan recommendations.
3. **Implementation Workshop**: 25 organizations were represented at this workshop. This workshop presented the draft final modeling on solar+EV use cases, action plan findings and recommendations, and identified new solar+EV initiatives for implementation.

ASSESSING MARKET PERCEPTIONS AND OPPORTUNITIES

The project engaged two private sector market participants cohorts regarding their perceptions of market opportunities for incorporating solar+EV applications into their business operating practices and offerings among market participants.

Solar Energy Industry Survey and Interviews

> *Finding*
>
> The solar industry acknowledges the latent solar+EV market, but has taken few steps toward developing the market. Value propositions under existing rules, markets, rate structures are uncertain, or difficult for market participants to understand.

The Minnesota Solar Energy Industry Association surveyed 50 stakeholders from the solar industry to better understand industry perceptions on the viability and status of integrating solar development with EV charging, including current solar industry stakeholder perceptions of the Minnesota market for pairing solar and EV products. Solar industry perceptions are provided first on a general basis and are then assessed specifically concerning community solar garden (CSG) subscriptions paired with EV charging products. Findings and perceptions were captured in the fall of 2018 in several industry surveys, queries, and interviews.

Developer Interviews and Engagement

> *Finding*
>
> The commercial development/ property management industry does not see demand for EVSE and has largely adopted a wait and see approach. Moreover, these market participants have little incentive to capture operating savings such as lower electric costs with up-front capital investment.

The Minnesota SEIN project team engaged commercial, multi-family residential, and mixed-use developers to assess market interest and activity in both installation of EV infrastructure in the development process and the perceived value proposition for linking solar and EV charging on the same site. Developer voices were part of the use case development process. The team followed up earlier engagement of developers by creating a one-on-one interview process to assess perceptions of the short- and long-term market opportunity to incorporate solar+EV applications into development projects and property management activities.

Volkswagen Settlement Grant Program Assistance

The Minnesota SEIN Team engaged nine cities specifically on local implementation goals for solar+EV installations in public parking facilities and provided direct assistance to cities on development of Volkswagen settlement funding proposals for solar+EV charging pilots. Most of these cities participated in Cities Charging Ahead! (see description below) but had not participated in the SEIN project or developed concepts of how to link EV charging with solar energy production.

While only three facilities were ultimately funded via the grant (funds are just now available for installations), the process engaged and educated both the cities and the MPCA (the state agency administering the funds) on possibilities and definitions of solar+EV for meeting GHG reduction goals.

SEIN Working Sessions and Symposium

GPI used the SEIN Working Sessions (hosted by NREL in Golden, CO) to engage team members and bring additional stakeholder into the solar+EV project (as noted above in the Minnesota SEIN Team discussion). The SEIN Working Sessions, and the Symposium near the end of the project, provided a unique opportunity to bring team members more fully into the project, and to help them connect the solar+EV work with other solar initiatives being undertaken across the nation. Participating in the workshops provided a retreat-like format where team members could fully focus on the project and initiate new ideas for integrating the market transformation concepts into the daily work of these stakeholders.

Engaging Stakeholders and Market Participants—Other Projects

The GPI is working with key stakeholder cohorts in a variety of other projects that work in synergy with the SEIN Solar+EV project. This work was being conducted simultaneously with the SEIN project and provided significant opportunity to draw from stakeholder engagement on EV and solar energy market transformation efforts for the benefit of the SEIN project.

The engagement processes focused on three primary key stakeholder cohorts for the SEIN solar+EV project: (1) cities and other local governments; (2) EV industry (car industry stakeholders and EVSE manufacturers); and (3) utilities, from distribution-only utilities to interstate investor-owned utilities and independent system operators of the bulk power grid.

CITIES

GPI works with dozens of cities in Minnesota on policies and programs to promote the electrification of transportation system and to build solar-ready communities. These efforts have occurred through four initiatives:

1. The **GreenStep Cities** program, with over 125 actively participating cities and tribal nations, co-managed by GPI and the Minnesota Pollution Control Agency, and overseen by a steering committee of local government organizations, NGOs, and state agencies.
2. The **Local Government Project for Energy Planning (LoGoPEP**), where GPI was the technical assistance provider to over 30 cities and counties that were incorporating energy and climate goals (including solar and EV deployment goals) into comprehensive plans or energy/climate plans.
3. The **Cities Charging Ahead! (CCA)** cohort, where GPI and the Clean Energy Resource Teams (CERTs) worked in parallel with the SEIN project to engage 28 cities across Minnesota and prepared their cities for broad adoption of EVs. The initiative used the following engagement strategies:

- Multiple cohorts across the state organized by geographic region
- Each cohort had in-person meetings once a quarter for a total of six meetings
- Surveyed CCA cities multiple times about challenges, existing barriers, and lessons learned to track progress
- EV-olution, an all-day event of CCA cities, non-CCA cities, utilities, state agencies, businesses, etc., to identify lessons learned, barriers, and opportunities for EV adoption in Minnesota

4. **SolSmart**, where GPI is leading a three-state initiative of over 40 cities and counties on local solar energy market transformation, including opportunities to link solar deployment with EV charging and other flexible loads. This also includes incentivizing solar carports in parking standards and other development regulation. Cities were engaged on distributed solar market transformation in the following ways:

- Led direct technical assistance to cities on becoming solar-ready
- Led workshops on best practices in solar planning, zoning, and development with an emphasis on solar carports and solar+EV integration

These four programs worked in tandem to help communities identify goals and priorities related to electrification of transportation and to remove barriers and create opportunities for distributed solar installations.

Engaging Electric Vehicle Industry and Stakeholders

A number of ongoing programmatic and regulatory initiatives on EVs provided access to stakeholders and market participants and informed the SEIN project and recommendations, including the following two key stakeholder participant initiatives.

DRIVE ELECTRIC MINNESOTA

Drive Electric Minnesota is a coalition of stakeholders dedicated to encouraging the deployment of EVs and the establishment of EV charging infrastructure through public-private partnerships, financial incentives, education, technical support, and public policy. Drive Electric Minnesota provides a market perspective on barriers and opportunities from advocates, state agencies, utilities, businesses, and value chain industries. Drive Electric Minnesota conducts education and outreach and has participated in a variety of EV policy and regulatory initiatives.

MIDCONTINENT TRANSPORTATION ELECTRIFICATION COLLABORATIVE

The Midcontinent Transportation Electrification Collaborative (MTEC) looked at EV market transformation opportunities within the Midcontinent Independent System Operator (MISO) footprint. MTEC consists of automakers, electric utilities and cooperatives, EV charging companies, environmental groups and state officials from the region, co-convened by the Midcontinent Power Sector Collaborative and the Charge Up Midwest coalition. GPI convenes the Midcontinent Power Sector Collaborative.

> *Finding*
>
> Utilities, industry, and regulators acknowledge the synergistic relationship of matching EV charging with renewable energy production at the bulk power level.

MTEC developed consensus principles for the design of utility EV programs,[58] and then developed a transportation electrification road map in the MISO region.[59] The process included a series of stakeholder meetings and technical analyses and modeling conducted by MTEC and consultants. The analyses indicate that EVs bring great potential benefits to the region, including the potential to manage load so as to optimize renewable resources like wind and solar at the bulk power level.

[58] Midcontinent Transportation Electrification Collaborative, GPI, *Electric Utility Roles in the Electric Vehicle Market: Consensus Principles for Utility EV Program Design* (April 2018), https://www.betterenergy.org/wp-content/uploads/2018/04/MTEC_White_Paper_April_2018-1-1.pdf.

[59] Midcontinent Transportation Electrification Collaborative, GPI, *A Road Map to Decarbonization in the Midcontinent: Transportation Electrification* (2019), http://roadmap.betterenergy.org/wp-content/uploads/2019/02/GPI_Roadmap_Electrification_Online2.pdf.

Appendix B. The Eight Use Cases

Each use case demonstrates a different system for deploying solar+EV applications and a distinct set of actors for deploying decisions. A detailed description is provided below, identifying:

- users of the charging equipment
- decision makers for deployment
- example projects
- site owner value propositions
- expected synergies or benefits with other stakeholders (non-site owner benefits)
- possible barriers and limitations to realizing value

1. Workplace charging

Customers: Employees or visitors to a business or office complex of businesses that need to charge their vehicle while at work or participating in meetings.

Owner/decision maker: Large employers who own their offices or buildings, business/property owners managing employment centers with multiple businesses and that can benefit from on-site solar production.

Description: This use case focuses on EV charging during business hours at places of employment (8:00 a.m. to 6:00 p.m., Monday through Friday). This use case requires charging at a commercial building or in a commercial parking area (lot or ramp). The buildings or parking areas offer opportunities for on-site solar in either the parking lot or on the roof of the building. The use case includes large employers who own their own facilities and employment centers in which multiple businesses lease space from a property management company.

Example sites: A large variety of sites, from small office complexes to large corporate campuses fit into this use case. Other possible sites include institutions such as hospital or medical complexes, technology business parks, and local and state government administrative operations. Within the seven-county Minneapolis/St. Paul metropolitan area there are over 4,000 acres of surface parking lots associated with office and institution land uses.

Site owner value proposition: EV charging can become a standard feature of commercial parking lots, and the solar+EV application can enable EV charging without demand charge impacts for the site (creating a demand charge benefit for on-site solar, something that typically is not a benefit of commercial solar energy systems). Managed, synchronized charging also allows the site owner to install more charging units on fewer circuits, and to limit risk to on-site transformers from peaking EV charging. Many of these facilities could optimize on-site solar for both building load and EV charging at a low marginal cost to the solar+EV application. Solar carports in surface parking lots serve as shade structures and weather protection to add value to the EV charging space. Providing EV charging can also potentially help employers recruit or retain staff who drive electric vehicles.

Expected synergies and other benefits: Workplace charging is a critical component of meeting transportation electrification goals, as over 30 percent of Minnesota households are renters and will have less access to overnight charging (benefiting cities that have climate action goals and the state's goals for both GHG reduction and renewable energy adoption). The potential deployment size of workplace charging could mean substantial distribution grid benefit and increasing the amount of renewable energy resources on the grid. Solar+EV in workplaces can address the transportation portion of city and state GHG reduction goals.

Barriers and limitations: Barriers to realization of the customer value proposition for this use case include the following issues.

- Metering issues: In order to capture demand charge savings, the EV charger and the solar array must be on the same meter.
- EV owner value proposition: Most EV charging is done overnight at the home and is the cheapest option for EV drivers. If the property owner or manager chooses to charge a fee for use, daytime EV charging may not offer enough value to EV drivers to use.
- EV charger capacity: As EV market penetration increases, the number of charging stalls may be insufficient for demand by employees, or the electric demand from charging could overload property transformers.

2. Public Parking Facilities

Customers: Individuals using public such parking facilities include employees, customers of nearby businesses, and businesses relying on facilities for customer or employee parking and wanting to provide a charging amenity.

Owner/decision maker: Local governments and transit authorities who own and manage large parking facilities such as park & ride lots and downtown parking ramps serving a number of businesses and employers.

Description: Parking facilities are not always associated with a specific destination, business, or land use, but can be instead a part of public infrastructure supporting a group of businesses such as a downtown or regional or local transit operations. Examples include park & ride facilities owned by transit operators, city-owned parking ramps supporting commercial nodes with many businesses, and private parking ramps (serving the public) in locations such as downtown areas or the airport. Drivers using these facilities are generally staying for longer periods of time, and the number of users is sufficient to ensure EV participation or need. Such facilities tend to be publicly owned, and thus have a different value proposition (a public benefit) compared to workplace parking/charging opportunities. Such facilities could have substantial areas for on-site solar development, although parking ramps in downtowns may have little on-site solar resource.

Example sites: Transit park & ride lots, public or private airport parking facilities, and downtown parking ramps that have solar resources,

Customer value proposition: Provides an amenity for transit or to distinguish parking ramp from others, solar on park & ride lots is a new revenue source, longer typical park allows for greater level of charge even on cloudy days, and longer parking allows for greater flexibility to move charging time to match solar production.

Expected synergies and other benefits: Encourages improved utilization of transit for commuters coming from more distant origins, encouraging low- or zero-carbon commuting across the region and improves "green branding" of transit options. For surface parking areas, on-site solar could provide an additional amenity as a shade structure. Light rail transit stations in mixed-use areas could be utilized by residents in nearby transit-oriented design developments at night to increase utilization of infrastructure. Direct public control of EV+solar investment offers cities/regional/state opportunities to meet GHG reduction goals for the private transportation sector.

Barriers and limitations: Barriers to realization of the customer value proposition for this use case include the following issues.

- Solar resource: Parking ramps may not be able to accommodate on-site solar, or may not have a solar resource is in a dense commercial area.
- Size of on-site load: On-site electric energy load would be lower relative to other commercial use cases, resulting in a diminished opportunity for optimizing combined load with on-site solar and storage.
- Charging for use: Transit operators or cities may have to make a financial case that would require fees for charging and diminish use.
- Parking tenure: Long parking times at park & ride lots limits the ability to cycle a fully-charged car out of the charging station.

3. Mixed-Use Multi-family

Customers: Residents, business customers, business employees.

Owner/decision maker: Commercial developers building large mixed-use or multi-family buildings, commercial building owners of such facilities for existing buildings, property management companies that manage mixed-use buildings on behalf of others.

Description: Mixed-use multi-family buildings typically lack the necessary charging infrastructure, making it difficult for residents to own EVs. Many of these buildings are located near or above commercial spaces. To make it possible for more residents to drive EVs as well as serve the broader public, solar+EV could be incorporated into new multi-family mixed-use developments in and around metro area downtowns as well as suburban master-planned developments. Applicable developments would include multi-family apartments or condos with commercial space on ground-floors or those adjacent to shared parking lots. By pairing multi-family buildings with commercial applications, the charging infrastructure gets more utilization and can be tied to both solar and wind production. The solar production on-site could be limited for urban developments, given the small roof area relative to the intensity of the load. However, the EV load could be linked to nearby rooftop or other solar production that is on the same grid circuit, substation, or other distribution infrastructure that would benefit from the link. In urban areas, parking for commercial use could be shared with surrounding commercial areas, providing EV charging capability to a broader area, rather than a single property. Cities could incorporate solar+EV as a required amenity as part of the development process, as part of parking standards, flexible zoning conditions (planned unit development or other), or the development agreement with the city.

Example sites: Substantial development in urban core areas (Minneapolis, Saint Paul, Rochester) offer new models for incorporating EV charging and EV+solar at the time of development, lowering the installed costs. Suburban master-planned developments that are increasing density and incorporating mixed-use concepts are similarly becoming more common.

Customer value proposition: This use case provides EV infrastructure for apartment/condo residents and also can provide nearby business customers with EV charging access, increasing utilization rates and cost-effectiveness. Property owners can be more competitive in the marketplace for having an EV charging amenity. Synchronizing solar energy reduces demand charges associated with EV charging during peak times of the day, and can be optimized for building load if the solar resource is sufficient.

Expected synergies and other benefits: Installing EV charging infrastructure (trenching and conduit) and solar during the development process compared to retrofitting buildings–meaning that the project capital would be part of the overall development costs and easier to obtain. Other benefits include future proofing new development to contribute to city GHG emissions reduction goals, providing access to EV charging to renters (encouraging further EV adoption), and providing renewable night and day (wind and solar respectively) charging with the same infrastructure. The potential deployment size of such infrastructure on multi-family buildings could provide distribution grid benefits and increase the amount of renewable energy resources on the grid. Solar+EVs in mixed-use development can address the transportation portion of city and state GHG reduction goals.

Barriers and limitations: Barriers to realization of the customer value proposition for this use case include the following issues:

- Dense urban areas have limited on-site solar development opportunities, which would impact benefits to the grid. Linking to remote solar and wind could increase the load on the distribution system rather than mitigate it.
- Additionally, there is limited transferability to suburban areas where the market for mixed-use development is weak.
- Other barriers include potential careful management required of the property manager for shared charging infrastructure, potential requirement of a developer subsidy or other incentive, and perceived risk of technological obsolescence in an era where EVs and their charging needs are quickly changing.

4. Electric Buses

Customers: Transit authorities, school bus operators, para-transit providers.

Owner/decision maker: Transit authorities, school districts, governmental or non-profit para-transit providers.

Description: Currently, electric bus batteries may not have enough capacity to last the entire day without recharging for some routes. Many buses, especially school buses, can take advantage of a longer charge time during the day since most of the routes are performed in the morning and afternoon/evening to get riders to and from work or school. Electric buses could also take advantage of a longer charge time overnight, which would work well for a solar+EV+storage application.

Example sites: Several transit agencies in Minnesota are transitioning to electric buses, and some school bus providers are also considering electrifying some of their fleet. Metro Transit is currently in the planning stages for a new bus garage to serve a large new fleet of dozens and eventually up to as many as 200 electric buses. The new facility is likely to use both energy storage for charging resilience and to be solar ready for as much as two MW of rooftop solar.

Customer value proposition: Solar-synchronized charging can be integrated with daytime or in-route charging to reduce the long-term costs of charging and help meet Minnesota's and local government GHG reduction targets. Converting to EV buses will reduce operating & maintenance costs for transit fleet, and solar synchronization will reduce demand charges and hedge against future rate increases. The system will also improve air quality in bus garages.

Expected synergies and other benefits: Conversion to EV buses will reduce significant emissions and meet GHG reduction goals. Solar synchronization will allow utilities to see increased revenue with reduced peaks and distribution system impact. EV buses will improve air quality along the routes that they operate, which primarily benefits low-income and people of color who are disproportionately disadvantaged by air pollution. Daytime DC fast charging needs are aligned with solar production if the on-site solar is larger enough to provide DC fast charging.

Barriers and limitations: Barriers to realization of the customer value proposition for this use case include the following issues:

- Electric bus routes are being sized to not having to charge during the day, meaning that charging would happen overnight. In route charging may present some value in some instances.
- Electric buses have larger batteries and therefore need to rely on DC fast charging instead of slower Level 2 charging to ensure the batteries charge to 100 percent before running routes. The large demand charges associated with this use would require either very large solar arrays or large battery banks.
- While net present value analyses can be attractive, up-front costs are high with EV buses and infrastructure as well, which can be difficult to fund when relying on taxpayer dollars.
- Uncertainty dampens opportunity for the business proposition at transit agencies without on the ground demonstration of overall cost, environmental impacts, grid reliability, and future grid demand pricing.

5. Fleets

Customers: Commercial fleets vehicles, public sector fleet vehicles.

Owner/decision maker: Local governments with fleets, state agencies (usually under authority of the Minnesota Department of Administration), private sector fleet operators of light- to medium-duty delivery vehicles.

Description: Similar to electric bus fleets, there are many commercial and public sector fleets that remain parked for hours at a time. Ideal locations for this use case are where fleet park and drive patterns coincide with a good solar resource and daytime charging.

Example sites: Public (city, state) and private fleets that have enough vehicles to have a consistent need for charging. The Minnesota Department of Administration is working to electrify its fleet to 20 percent of its light-duty fleet by 2020. The department is also deploying 575 kW DC solar on the Minnesota State Capitol complex where many fleet vehicles are currently charged.

Customer value proposition: Solar+EV applications reduce charging costs and enable demand charge savings that would be associated with daytime charging. Long term risk reduction from better fuel cost predictions. Solar array can be sized to be optimized for other loads at lower marginal cost.

Expected synergies and other benefits: Like other use cases, solar synchronization also contributes to agency/company GHG reduction goals and allows them to serve as an example to inspire further solar+EV development. There is a potential for distribution grid benefits, particularly if public and private fleets are considered.

Barriers and limitations: Barriers to realization of the customer value proposition for this use case include the following issues:

- Solar+EV in this use case is completely dependent on whether fleets can take advantage of daytime charging and the site having good on-site solar resources.
- Fleet managers may have a perceived risk of technological obsolescence since charging infrastructure needs and fleet patterns may currently be unclear.
- Other limitations include weak grid benefits if the on-site solar is limited, the need for careful management by property owners if chargers are open to the public, and slow conversion to EVs within the fleet.

6. Single Family Homes

Customers: Households owning EVs.

Owner/decision maker: Single family homeowners, residential developers.

Description: In this use case, solar+EV is incorporated into residential homes by private EV owners and possibly new home builders, or existing solar energy systems are linked to new EV chargers. EV charging infrastructure is for the exclusive use of the homeowner, and charging is synchronized with either solar and/or wind production as specified in the utility program offer. Tying charging to on-site solar production or other nearby solar production on the same grid circuit, substation, or other distribution infrastructure is possible. The program and its adoption are scalable by both electric utilities and their customers.

Example sites: This use case is dependent on an electric utility offering a program for residential customers who have an EV and who are willing to accept utility terms for rate and timing of charging in exchange for savings on the EV portion of their electricity bill.

Customer value proposition: EV owners save money on transportation fuel over time as the levelized cost of energy from the solar can be lower than marginal retail rates. The homeowner is compensated for the value of customer-sited solar and the willingness to have variable charging. Managed EV charging can also be less restrictive than the off-peak charging rules that are more common today.

Expected synergies and other benefits: Benefits of this use case are primarily felt by the individual homeowner: they reduce GHG emissions (gain additional solar credibility), in addition to reducing fueling costs for their vehicle. There are some broader community benefits: utilities and all electric customers can save money per kWh when new EV loads are integrated into the grid, programs are a natural progression from existing off-peak programs, and the project costs are relatively low if performed on a new home or home with existing solar and charging infrastructure on site.

Barriers and limitations: Barriers to realization of the customer value proposition for this use case include the following issues:

- Poor match between charging profile and solar production; in winter months there is a complete mismatch. Summer peaking utilities may still gain grid benefits, but additional modeling or piloting would be needed.
- The difference between synchronized and unsynchronized solar+EV charging to a residential customer may be difficult to sell. Home builders (for installations in new homes) may similarly not understand the value to them for synchronized charging.
- Grid benefits could be weak with limited on-site solar and production/charging mismatch.

7. Community Solar Gardens (CSG)

Customers: Commercial CSG subscribers, EV owners (employees, visitors, customers) utilizing the chargers.

Owner/decision maker: Commercial CSG subscribers.

Description: CSGs are currently the most prominent form of solar deployment in Minnesota with over 550 MW of installations, and commercial subscribers comprise the lion's share of energy consumed from CSGs. Commercial CSG subscribers can be offered a "smart" EV charging station at their business (or use an existing station if possible) that can be controlled during business hours to match CSG output. There is an added benefit to the customer if renewable energy credits (RECs) go with the EV subscription (RECs can be "re-bundled" with the power even if the CSG project RECs are captured by the utility). Utility financial participation is possible in order to ensure both installation of "smart" charging and appropriate managed charging practices to match solar production. The utility could also bundle wind energy with the charging profile, opening up the possibility of participation by residential CSG subscribers.

Example sites: Any existing CSG with multiple commercial subscribers that want to link EV charging to clean energy would be able to access this combined technology immediately upon installation of the EV chargers or use of existing networked chargers.

Customer value proposition: Reduction in the business's GHG emissions if RECs are included in the subscription, but some "green" credibility can still be realized without the RECs. Subscriber feels a closer tie to the energy they are buying with synchronization. Excess CSG production can be utilized by EV load demand; green power charging benefits mean better GHG mitigation at the state level; and it opens opportunities for CSG subscribers to participate in solar+EVs if on-site opportunities for solar are limited.

Expected synergies and other benefits: Bulk power benefits are achieved by ensuring that charging can follow the utility's solar production when that best responds to cost and reliability concerns. The deployment of EV charging infrastructure could be accelerated by coupling it with a popular solar program. There is potential for utility programs to encourage the use of controllable charging and demand response/load control capability. The utility could also link charging to wind energy production to create a solar+wind charging program. It can be scaled fairly broadly as the CSG market continues to grow.

Barriers and limitations: Barriers to realization of the customer value proposition for this use case include the following issues:

- Costs of "smart" or managed EV charging infrastructure would be borne by the project developer or by the customers, in addition to the cost of the CSG.

- This use case is a potentially complicated transaction for both the developer and the customer to understand.
- Potential regulatory check for the utility (interconnection standards/REC ownership/administrative delay) and process development to ensure smooth transition to EV + solar gardens.
- Shared charging infrastructure may require careful property management;
- Adding EV to the CSG subscriptions may increase the load on the distribution system.
- Potential PV load matching the time of highest EV charging demand issue could be mitigated with onsite storage, or east-west solar tracking.

8. Destination Land Uses

Customers: Destination visitors owning EVs, destination business that are lessees and want to provide charging amenities to their customers.

Owner/decision maker: Businesses that own their property or building, property managers that lease to destination businesses, public entities that own and manage destination locations (local governments, state and federal agencies).

Description: Destinations are places that people go to spend time for pleasure. Destinations offer a compelling case for a solar+EV applications due to the large number of opportunities (parks, malls, resorts, retail, etc.) and scalability (a large number of sizable parking areas and numbers of customers). Ideal destinations would include those where customers would be staying for sufficiently long periods of time that customers would be interested in charging, and that have a relatively consistent daytime customer base. Lodging, for instance, is a strong candidate for installing EV chargers, but a lessor candidate for solar+EV applications. Malls or similar aggregations of retail establishments have a diversity of customers and sufficient size and large parking areas so that daytime use is highly likely.

Example sites: Shopping malls, retail establishments that want to encourage longer stays by customers such as restaurants or casinos, public destinations such as Minnesota State Parks or city recreation facilities where long-term ownership of solar arrays is guaranteed (and renewable charging is supported by public policy).

Site owner value proposition: Owners of destination businesses have a particularly unique value stack for solar+EV applications. As EV market penetration increases, offering EV charging has the potential to increase attendance or duration of stay, with quantifiable benefits in sales or attendance. Solar energy synchronization reduces demand charges associated with EV charging during what is likely to be peak times of the day, and larger parking areas allow for optimization of the solar array to serve both building and EV loads. Co-location, such as a solar carport, adds “green credibility” to both the business and the charging opportunity that may add value to the amenity.

Expected synergies and other benefits: The solar addition adds value to the EV owner over simply charging their vehicle somewhere else. Destination businesses have geographic diversity that allow the utility to incentivize areas with locational benefits on the distribution grid for both the solar and the EV charging. The sheer size of parking at retail centers and associated destinations offers a unique opportunity for increasing solar distributed generation deployment and achieving high-visibility EV charging for market transformation benefits.

Barriers and limitations: Barriers to realization of the customer value proposition for this use case include the following issues:

- There is no guarantee the chargers will be used in the near term, reducing the business's near-term value proposition to a market actor that demands short, demonstrable paybacks for infrastructure decisions.
- Destination businesses may perceive that ongoing maintenance or fees (such as network fees) associated with EV chargers and solar arrays are uncertain or too high.

Appendix C. EV Market

Vehicle Availability

Part of the market transformation toward EVs relies on available vehicles as they need to appeal beyond the early adopter. While vehicle availability is currently lacking, the future of the market shows promise in the Midwest as more automakers make commitments to sell EVs. Additionally, companies like Workhorse and Rivian have electrified light-duty trucks that will spur additional EV adoption.

As of May 2019, there were eight battery electric vehicles (BEVs) and 19 plug-in hybrid vehicles (PHEVs) available to buy in Minnesota.[60] But there remain two critical barriers to overcome for widespread market adoption of EVs: continued cost premiums and available body styles. Using data provided by IHS Markit, the Auto Alliance reported that nearly 30 percent of new vehicle purchases in Minnesota are SUVs and pickups.[61] However, there are currently only three luxury EV SUVs available and no EV trucks, making BEVs unappealing for this segment of the population. Available PHEVs offer a higher variety of choices but not the same level of benefits regarding air quality and lower maintenance due to the internal combustion engine within PHEVs.

As of May 2019, there were eight battery electric vehicles (BEVs) and 19 plug-in hybrid vehicles (PHEVs) available to buy in Minnesota, as shown in tables 1 and 2.

Table 1: Available BEVs to purchase in Minnesota as of May 2019

Make/Model	Body style	Drive type	Base MSRP	Electric range
Audi etron	SUV	AWD	$74,800	204
BMW i3	Hatchback	RWD	$44,450	153
Chevrolet Bolt	Wagon	FWD	$37,495	238
Jaguar I-PACE	SUV	AWD	$69,500	234
Nissan Leaf	Hatchback	FWD	$29,990	150-226
Tesla Model 3	Sedan	RWD/AWD	$39,500	240-325
Tesla Model S	Sedan	AWD	$78,000	270-370
Tesla Model X	SUV	AWD	$83,000	250-325

Source: "Midwest, US and D.C. Area EV Info Lists," PlugInConnect, May 1 2019, https://www.pluginconnect.com/mnpevmodels.html.

While there's a mixture of BEVs available to meet drivers' needs, there remains two critical barriers to overcome: cost and available body styles. By and large, Minnesota

[60] "Midwest, US and D.C. Area EV Info Lists," PlugInConnect, May, 1 2019, https://www.pluginconnect.com/mnpevmodels.html.

[61] "Autos Drive Minnesota Forward," Auto Alliance, accessed October 4, 2019, https://autoalliance.org/in-your-state/MN/.

drivers prefer SUVs and trucks to navigate rural roads and winter driving conditions. There are currently only three luxury SUVs available and zero trucks, making BEVs unappealing for the average consumer. Available PHEVs offer a higher variety of choices as seen in table 2 but not the same level of benefits regarding air quality and lower maintenance due to the internal combustion engine within PHEVs.

Table 2: Available PHEVs to purchase under $60,000 in Minnesota as of May 2019

Make/Model	Body style	Drive type	Base MSRP	Electric range
BMW 330e		RWD	$45,600	14
BMW 530e	Sedan	RWD/AWD	$53,400	16
Chevrolet Volt	Sedan	FWD	$33,170	53
Chrysler Pacifica Hybrid	Mini van	FWD	$42,000	33
Ford Fusion energi	Sedan	FWD	$34,595	26
Honda Clarity PHEV	Sedan	FWD	$33,400	48
Kia Niro PHEV	SUV	FWD	$27,900	26
Mercedes-Benz GLC350e		AWD	$50,650	10
Mini Cooper S E ALL4		FWD	$36,900	12
Mitsubishi Outlander PHEV	SUV	AWD	$34,595	22
Toyota Prius Prime	Hatchback	FWD	$27,100	25
Volvo XC60T8		AWD	$55,300	17

Source: "Midwest, US and D.C. Area EV Info Lists," PlugInConnect, May 1 2019, https://www.pluginconnect.com/mnpevmodels.html.

State Policies that Support EV Markets

Although an EV market can exist without supportive state policies, as seen in Minnesota, a number of policies have been shown to increase adoption rates particularly in the early adoption years. This is evident from examining policies in place in California, which is one of the states with the highest level of EV adoption in the United States. Table 4 compares policies that exist today between Minnesota and California.

Table 4: Policies at work in Minnesota and California

Policy	Minnesota	California
EV rebate		X
Low carbon fuels standard		X
Infrastructure grants for alternative fuels		X
EVSE loan & rebate program		X
High-occupancy vehicle lane access for EVs		X
Special vehicle registration fee	X	X
State agency vehicle procurement requirement	X	

Sources: “California Laws and Incentives,” Alternative Fuels Data Center, US Department of Energy, Accessed October 4, 2019, https://afdc.energy.gov/laws/all?state=CA.

“Minnesota Laws and Incentives,” Alternative Fuels Data Center, US Department of Energy, Accessed October 4, 2019, https://afdc.energy.gov/laws/all?state=MN.