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Unlocking System Savings With Flexible EV Charging: Lessons From Colorado

Part of RAP and ICCT's *Benefits of EVs Through Smart Charging* Global Project

By David Farnsworth, Shawn Enterline, Hussein Basma & Camille Kadoch

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Amy Wagner and Jamil Farbes, Evolved Energy Research

Authors

David Farnsworth, Regulatory Assistance Project

Shawn Enterline, Regulatory Assistance Project

Hussein Basma, International Council on Clean Transportation

Camille Kadoch, Regulatory Assistance Project

Regulatory Assistance Project

50 State Street, Suite 3, Montpelier, VT 05602

info@raponline.org | www.raponline.org | @RegAssistProj

International Council on Clean Transportation

1500 K Street NW, Suite 650, Washington, DC 20005

communications@theicct.org | www.theicct.org | @TheICCT

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Benefits of EVs Through Smart Charging: A Joint Project by RAP and ICCT

This paper is part of a global project by the Regulatory Assistance Project (RAP) and the International Council on Clean Transportation (ICCT) studying the economic and environmental benefits of deploying smart electric vehicle (EV) charging in specific geographies. The study identifies those benefits as avoided system costs and avoided emissions, and shows how system costs can be reduced based on four use cases in selected areas within the four largest global EV markets: China, the United States, Europe and India.

The global market for EVs is maturing quickly. In 2022, EVs accounted for almost a quarter of the new vehicle registrations in China, 19% of vehicle registrations in Europe, and 7% in the United States.[1] This is two to three times higher than EV registrations in 2020 in the mentioned regions. India has seen year-on-year growth in EV sales with substantial potential emissions reduction potential and air quality improvements. National and local policies in several jurisdictions targeting tailpipe emissions of road transport vehicles further contributed to this growth, resulting in an increasing EV fleet globally over the past decade, such as the European carbon dioxide (CO_2) standards for light-duty vehicles[2] (LDVs) and the light-duty vehicle greenhouse gas emissions regulations in the United States.[3]

With a continuously growing fleet, challenges and opportunities arise with regards to the integration of the EV fleet into the power grid. If additional demand from EVs remains unmanaged, this would lead to substantial cost increases for meeting their power and delivery needs, as EVs would likely be charged during existing peak periods, thus exacerbating peak demands. If this transition is not managed carefully, the associated growth in electricity demand will lead to higher costs for consumers, the power system, and the environment and may slow down the transition to a cleaner road transport sector.[4, 5]

Smart or managed EV charging can help overcome many of those challenges and utilize EV charging to provide optimum system flexibility. Smart charging is a key tool to reduce the consumption of fossil-powered electricity and integrate more variable renewables into the grid by charging EVs when there is sufficient renewable energy available. In doing so, smart charging can maximize carbon emission reductions and reduce the need for costly and

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[1] Monteforte, M., Rajon Bernard, M., Bernard, Y., Bieker, G., Lee, K., Mock, P., Mukhopadhaya, J., Mulholland, E., Ragon, P.L., Rodriguez, F., Tietge, U., Wappelhorst, S., & Zhang, Y. (2023, January). *European vehicle market statistics 2022/23*. International Council on Clean Transportation. https://theicct.org/publication/european-vehicle-market-statistics-2022-23/

[2] European Commission. (2024, February 12). *CO_2 emission performance standards for cars and vans*. https://climate.ec.europa.eu/eu-action/transport/road-transport-reducing-co2-emissions-vehicles/co2-emission-performance-standards-cars-and-vans_en

[3] U.S. Environmental Protection Agency. (2023, November 21). *Light-Duty Vehicle Greenhouse Gas Regulations and Standards.* https://www.epa.gov/regulations-emissions-vehicles-and-engines/light-duty-vehicle-greenhouse-gas-regulations-and

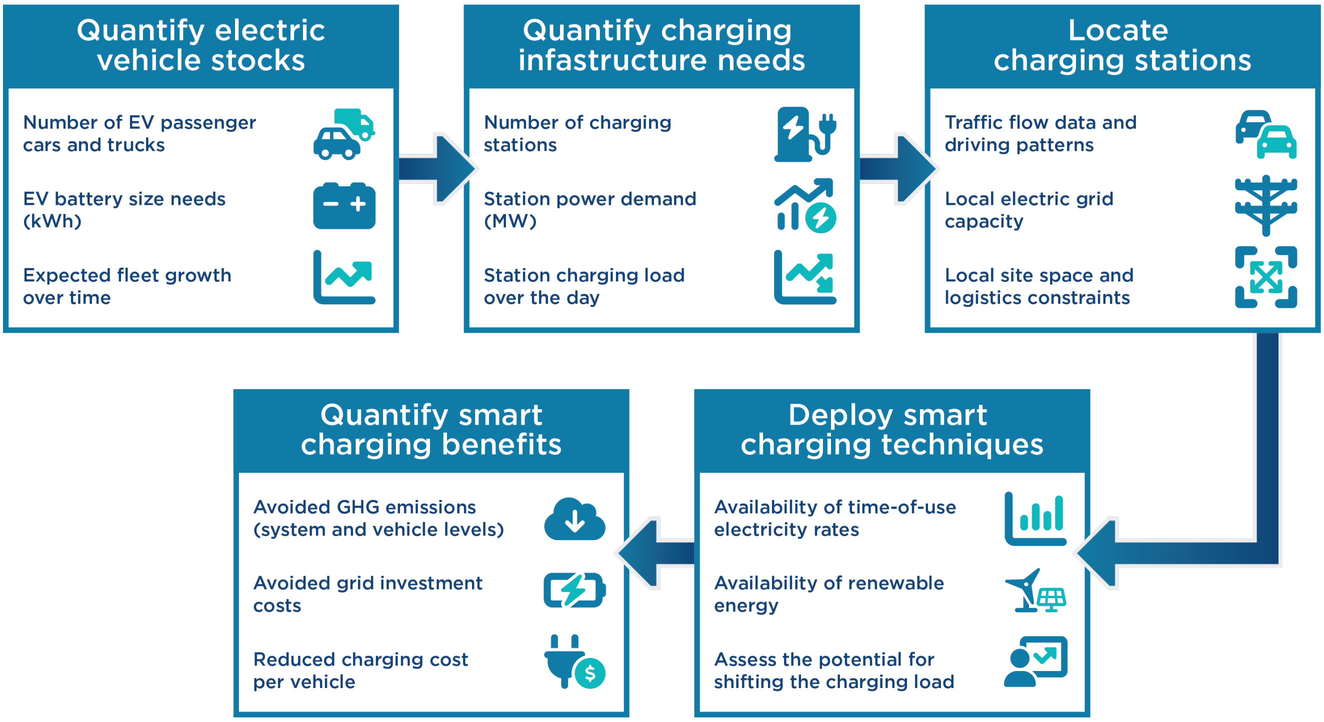
[4] Das, H.S., Rahman, M.M., Li, S., & Tan, C.W. (2020, March). Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review. *Renewable and Sustainable Energy Reviews, 120*(109618). https://doi.org/10.1016/j.rser.2019.109618

[5] Ashfaq, M., Butt, O., Selvaraj, J., & Rahim, N. (2021, May). Assessment of electric vehicle charging infrastructure and its impact on the electric grid: A review. *International Journal of Green Energy, 18*(7), 657–686. https://doi.org/10.1080/15435075.2021.1875471

unnecessary upgrades of the power grid.[6] While smart charging of EV fleets has been studied from the user benefits point of view,[7] it is important to better understand the value that EVs can have as flexibility assets for the power system[8] and for power networks in large EV markets.[9, 10]

The analytical framework used in this project to demonstrate the economic and environmental value of smart charging of electric light-duty and heavy-duty vehicles is composed of five sequential steps, summarized in Figure 1 below.[11]

Figure 1. Framework for smart electric transport



Source: Basma, H. (2024, April 26). *Assessing the Economic and Environmental Benefits of Electric Vehicles Smart Charging*

This interplay between EVs and power systems represents a significant opportunity for demand flexibility, if policymakers and planners in the power and transport sectors integrate

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[6] Hildermeier, J., Kolokathis, C., Rosenow, J., Hogan, M., Wiese, C., & Jahn, A. (2019, December). Smart EV Charging: A Global Review of Promising Practices. *World Electric Vehicle Journal, 10*(4), 80. https://www.mdpi.com/2032-6653/10/4/80

[7] Hildermeier, J., Burger, J., Jahn, A., & Rosenow, J. (2023, January). A Review of Tariffs and Services for Smart Charging of Electric Vehicles in Europe. *Energies, 16*(1), 88. https://www.mdpi.com/1996-1073/16/1/88

[8] International Energy Agency. (2022, December). *Grid Integration of Electric Vehicles - A manual for policy makers*. https://iea.blob.core.windows.net/assets/21fe1dcb-c7ca-4e32-91d4-928715c9d14b/GridIntegrationofElectricVehicles.pdf

[9] Anwar, M.B., Muratori, M., Jadun, P., Hale, E., Bush, B., Denholm, P., Ma, O., & Podkaminer, K. (2022, January). Assessing the value of electric vehicle managed charging: a review of methodologies and results. *Energy & Environmental Science, 15*(2), 466–498. https://doi.org/10.1039/D1EE02206G

[10] Xue, L., Jian, L., Ying, W., Xiaoshi, L., & Ying, X. (2020, January). *Quantifying the Grid Impacts from Large Adoption of Electric Vehicles in China*. World Resources Institute. https://www.wri.org/research/quantifying-grid-impacts-large-adoption-electric-vehicles-china

[11] Basma, H. (2024, April 26). *Assessing the Economic and Environmental Benefits of Electric Vehicles Smart Charging* [Presentation]. EVS37.

smart charging in decision-making, e.g. charging infrastructure build-out. Results of regional case studies illustrate benefits from smart EV charging for both power sector planning and transport policymakers.

Findings, conclusions and recommendations

This study finds that vehicle charging flexibility has the potential to reduce Colorado's electrical infrastructure costs by $100 million to $300 million per year in 2035 and $200 million to $900 million in 2050.

The majority of these savings come from two sources:

1. Avoided transmission and distribution costs
   - Flexibility can be used to flatten system peaks, which avoids investment in transmission and distribution infrastructure.
2. Avoided generation capacity costs
   - Flexibility can help avoid investments in generation capacity and related battery storage.

Recommendation 1: Design vehicle charging programs for the residential sector first, then focus on managing flexibility in other sectors.

Recommendation 2: Develop customer-focused programs and complementary tariffs, e.g. cost-reflective electricity pricing, that help secure the benefits of vehicle flexibility.

Recommendation 3: Ensure that customer programs are well integrated into utility operating systems.

Recommendation 4: Ensure that customer programs are well integrated into utility planning processes.

1 Introduction

In recent years the consensus of international climate scientists has only deepened the conviction that the world is facing unprecedented challenges associated with climate change, because of human activities — principally because of the combustion of fossil fuels that emits CO_2 and other greenhouse gases (GHGs). Inger Anderson, Executive Director of the United Nations Environment Programme, warned that “humanity is breaking all the wrong records when it comes to climate change. Greenhouse gas emissions reached a new high in 2022.”[12] This January, the National Oceanic and Atmospheric Administration (NOAA) reported that the Earth’s average land and ocean surface temperatures in 2023 were the highest global temperatures among all the years in NOAA’s 1850-2023 climate record.[13]

In the United States, the transportation sector generates the largest share of the nation’s GHG emissions — 28% of the total in 2021.[14] Over 94% of the fuel used for transportation is petroleum-based, primarily gasoline and diesel.[15] Our current reliance on fossil fuels for transport confirms one critical conclusion: unless we decarbonize transportation, we cannot hope to make the progress needed to avert the worst impacts of climate change.

In addition to the inherent capability of an EV to convert energy more efficiently than a fossil-fuelled vehicle, the fundamental rationale for transportation electrification and using electricity as a fuel source is that, to meet climate goals, electricity can be decarbonized more readily than the fossil fuels that are currently being used.[16] The U.S. power sector is becoming less carbon-intensive due to electricity markets’ increased use of less carbon-intensive resources. Since 2011, for example, more than 100 coal-fired power plants were either replaced or converted to natural gas.[17] Not counting related methane emissions, electricity produced with natural gas emits around half the carbon produced by coal-fired generation. Additionally, electricity produced with renewable generation — wind, solar, hydro, biomass and geothermal — doubled between 2008 and 2018, to 17.6% of the country’s electricity

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[12] UN Environment Programme. (2023, November 20). *Broken Record – Temperatures hit new highs, yet world fails to cut emissions (again). Emissions Gap Report 2023*. https://www.unep.org/emissions-gap-report-2023

[13] National Oceanic and Atmospheric Administration (NOAA). (2024, January 12). *2023 was the world’s warmest year on record, by far*. https://www.noaa.gov/news/2023-was-worlds-warmest-year-on-record-by-far#:~:text=Earth's%20average%20land%20and%20ocean,0.15%20of%20a%20degree%20C

[14] U.S. Environmental Protection Agency (EPA). (n.d.). *Sources of Greenhouse Gas Emissions*. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions. GHG transportation emissions come from burning fossil fuel for cars, trucks, ships, trains and planes.

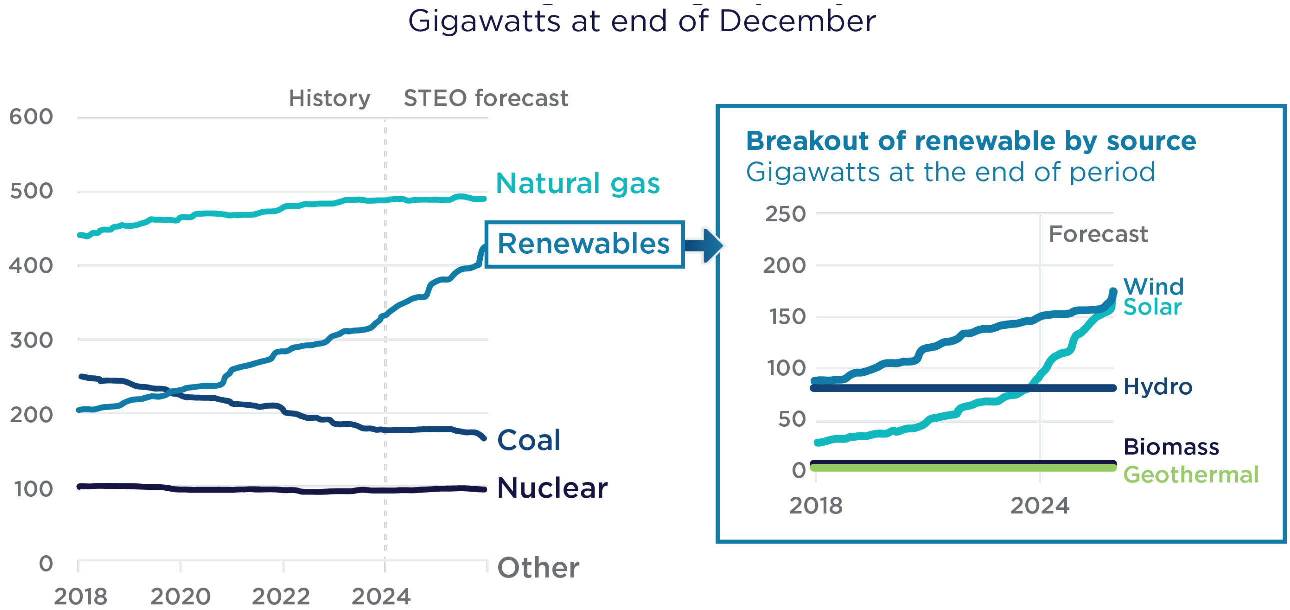
[15] U.S. EPA, n.d.

[16] This is not to say that there are no thermal applications that can be met with renewable fuels. McKinsey contends, for example, that a “decarbonization pathway for the energy system based solely on electrification, renewables, and storage without clean fuels or carbon sequestration” results in net higher societal costs. Booth, A., Brown, G., Wagner, A., de Sá, S., Houghton, B., Polymeneas, E., Raspino, B., & Tai, H. (2022, March 2). *Decarbonizing US gas utilities: The potential role of a clean-fuels system in the energy transition.* McKinsey & Company. https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/decarbonizing-us-gas-utilities-the-potential-role-of-a-clean-fuels-system-in-the-energy-transition

[17] Aramayo, L. (2020, August 5). *More than 100 coal-fired plants have been replaced or converted to natural gas since 2011*. EIA, Today in Energy. https://www.eia.gov/todayinenergy/detail.php?id=44636#. EIA indicates that this trend has been driven, in part, by stricter emission standards, low natural gas prices, and more efficient gas generation technology.

generation.[18] That trend continues, and today renewables constitute roughly 22% of U.S. generation (see Figure 2).[19]

Figure 2. U.S. annual electric generating capacity 2018-2025



Data source: U.S. Energy Information Administration. (2024, January). *Short-Term Energy Outlook (STEO)*

As these trends continue, power grids decarbonize, and because their fuel is electricity, EVs will become a progressively cleaner means of transport.

U.S. EV sales increased by 70% in 2022.[20] Americans bought nearly 1.4 million EVs in 2023. This brings the EV share of the U.S. vehicle market to over 9%, up from 5.9% in 2022.[21] EV adoption is being further stimulated by various federal programs. The Inflation Reduction Act supports EV adoption with tax credits for light-duty EVs, used EVs, commercial EVs, and EV charging infrastructure.[22] The U.S. Department of Transportation's National Electric Vehicle Infrastructure (NEVI) Program provides states with over $7 billion in funding to deploy

[18] Marcy, C. (2019, March 19). *U.S. renewable electricity generation has doubled since 2008*. EIA, Today in Energy. https://www.eia.gov/todayinenergy/detail.php?id=38752#

[19] Antonio, K. (2024, January 16). *Solar and wind to lead growth of U.S. power generation for the next two years.* EIA, Today in Energy. https://www.eia.gov/todayinenergy/detail.php?id=61242#:~:text=Renewable%20sources%E2%80%94wind%2C%20solar%2C,the%20first%20time%20in%202022

[20] International Energy Agency (IEA). (2023, April). *Global EV Outlook 2023*. https://www.iea.org/reports/global-ev-outlook-2023

[21] Cox Automotive. (2024, January 9). *A Record 1.2 Million EVs Were Sold in the U.S. in 2023, According to Estimates from Kelley Blue Book*. https://www.coxautoinc.com/market-insights/q4-2023-ev-sales/ and Irle, R. (2024, January 22). *Global EV Sales for 2023*. EV Volumes. https://ev-volumes.com/news/ev/global-ev-sales-for-2023/

[22] The White House. (2024, January 19). *FACT SHEET: Biden-Harris Administration Announces New Actions to Cut Electric Vehicle Costs for Americans and Continue Building Out a Convenient, Reliable, Made-in-America EV Charging Network.* https://www.whitehouse.gov/briefing-room/statements-releases/2024/01/19/fact-sheet-biden-harris-administration-announces-new-actions-to-cut-electric-vehicle-costs-for-americans-and-continue-building-out-a-convenient-reliable-made-in-america-ev-charging-network/

charging stations and an interconnected network to facilitate data collection, access and reliability.[23]

Federal and state environmental policies are also stimulating EV adoption. These include the Environmental Protection Agency's proposed Phase 3 Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles. The proposed rule contains emissions standards, affecting model years 2027 through 2032, for delivery trucks, refuse haulers, public utility trucks, transit, shuttle, school buses and tractors such as day cabs and sleeper cabs on tractor-trailer trucks.[24] In its Light-Duty Vehicle Greenhouse Gas Regulations and Standards, the EPA finalized standards to strengthen GHG emissions requirements for passenger cars and light trucks through Model Year 2032, and this is expected to result in a 53% EV sales share by 2030 and a 68% share by 2032.[25] In July 2020, 15 states and the District of Columbia adopted a Memorandum of Understanding in which they commit to achieve 100% sales of electric trucks by 2050, and an interim target of 30% zero-emission vehicle sales by 2030.[26] Part of this effort has been for states to adopt versions of California's Advanced Clean Truck Rule which contains a zero-emissions sale requirement for manufacturers.[27] California's Advanced Clean Cars II regulation for LDVs, which requires 100% ZEV (zero-emission vehicle) sales by 2035, has to date been adopted by 17 states including Colorado.[28]

Given the policy efforts and economic forces that are encouraging vehicle electrification, it is a critical time for utilities, regulators, policymakers and technology developers to plan how they will incorporate EVs into electricity planning and rate design.

This is why focusing on vehicle charging flexibility — the capability of moving electricity use in time, either scheduled in advance or deferred, to avoid unnecessary expense — is so important (see *How flexible loads and VRE diversity work together* text box). Significant amounts of the electricity load associated with transportation electrification are flexible and controllable. Utilities and policymakers need to recognize flexibility as a resource, and, of course, need to take steps to control that load, either directly or through pricing (i.e., rate design).

Unlike other types of electricity uses, like in refrigerators or air conditioners, where electricity is generated and consumed at virtually the same time, vehicle charging occurs at times other

[23] Alternative Fuels Data Center (AFDC). (n.d.). *National Electric Vehicle Infrastructure (NEVI) Formula Program*. U.S. Department of Energy, Energy Efficiency & Renewable Energy. https://afdc.energy.gov/laws/12744#:~:text=The%20U.S.%20Department%20of%20Transportation's,collection%2C%20access%2C%20and%20reliability

[24] U.S. Environmental Protection Agency. (2023, April). *Proposed Rule: Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles – Phase 3*. https://www.epa.gov/regulations-emissions-vehicles-and-engines/proposed-rule-greenhouse-gas-emissions-standards-heavy

[25] ICCT. (2024, March 20). *The EPA Final Multi-Pollutant Rule for Light and Medium-Duty Vehicles Sends a Resounding Message About the Accelerating Transition to Electric Vehicles in the U.S.* [Press release]. https://theicct.org/pr-epa-final-multi-pollutant-rule-for-light-and-medium-duty-vehicles-sends-a-resounding-message-about-the-accelerating-transition-to-ev-in-the-us-mar24/

[26] Northeast States for Coordinated Air Use Management. (2020, July 14). *15 States and the District of Columbia Join Forces to Accelerate Bus and Truck Electrification*. [Press release]. https://www.nescaum.org/documents/multistate-truck-zev-mou-media-release-20200714.pdf

[27] California Air Resources Board. (n.d.). *Advanced Clean Trucks*. https://ww2.arb.ca.gov/our-work/programs/advanced-clean-trucks

[28] California Air Resources Board. (n.d.). *Advanced Clean Cars II*. https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/advanced-clean-cars-ii

than when the vehicle needs to be used. This means that charging can be scheduled in ways that are beneficial for the consumer and the power system. LDVs especially have low "capacity utilization." In other words, they are idle more than 95% of the time.[29] This downtime provides flexibility, allowing charging to be managed over the course of the day in response to conditions on the grid.[30]

The opportunity for utility companies, therefore, is increasingly to ensure that the power system can use EV charging like an electric system resource. Innovative technologies like smart thermostats, controlled water heating, and managed EV charging allow utilities and customers to make more informed decisions about their energy use. Storage capacity in EVs, especially, offers an unprecedented opportunity to schedule charging to avoid more expensive and often more carbon-intensive system peaks, and to absorb greater amounts of variable renewable energy (VRE) resource production like electricity from solar and wind.

A key to making this happen is to understand and put in place programs — direct load control or pricing — that help EV owners charge their vehicles at optimal times. It is also critical to encourage customers, technology developers and utilities to adopt the charging technology that unlocks this flexibility. Another critical part of this transition, once programs are in place, is to ensure that utilities can demonstrate that they are in fact securing the results of programs that are supposed to manage EV charging. Furthermore, with the information that programs produce, utilities can better plan for EV infrastructure development.

The Regulatory Assistance Project (RAP) in collaboration with the International Council on Clean Transportation (ICCT) has undertaken this study to assess the opportunities for managed EV charging, and to provide recommended actions for policymakers.[31] For the purposes of this report, we commissioned the expertise of Evolved Energy Research (EER) to model the potential for EV flexibility to be used to lower the costs of transportation electrification in the state of Colorado. We are grateful to EER for offering insights to this report.[32]

What have we found? Vehicle charging flexibility has the potential to reduce Colorado's electrical infrastructure costs by $100 million to $300 million per year in 2035 and $200 million to $900 million in 2050. This is enough to provide all households in the state with Level 2 (L2) chargers, and implies that the benefits of efficient EV charging can cover the costs of the transition. Most of these savings come from three sources: avoided transmission and distribution system costs, avoided generation costs, and increased variable renewable generation adoption enabled by managed EV flexibility.

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[29] Langton, A., & Crisostomo, N. (2013, October). *Vehicle-Grid Integration: A Vision for Zero-Emission Transportation Interconnected Throughout California's Electricity System*. California Public Utility Commission. https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M080/K775/80775679.pdf

[30] Conditions on the grid include such things as price, GHG intensity and congestion.

[31] This study is part of a global series of case studies analyzing economic and environmental benefits of smart charging with other case studies carried out in Europe, India and China.

[32] The technical analysis by EER underpinning this report can be found here: https://www.evolved.energy/post/value-of-flexible-ev-load-in-co

In the following pages we explain our research approach (Section 2), the relevant market and policy context (Section 3), what we studied (Section 4), our findings (Section 5), and our conclusions and policy recommendations (Section 6).

2 Savings From Managed EV Charging: Case Study Colorado

RAP and ICCT engaged EER to develop a study of the potential value of EV charging flexibility to the broader electric system. The study focuses on the state of Colorado, whose significant grid decarbonization targets and vehicle electrification goals and policies are supported by its utilities. The six utilities that are responsible for 99% of Colorado's generation have committed to at least 80% GHG reductions. Public Service of Colorado, the state's largest utility, is expected to reduce carbon emissions by 87% from a 2005 baseline by 2030. It will supply approximately 85% of retail electric sales from wind and solar resources.

The goal of the study is to quantify the potential dollar value of flexible charging to the electricity sector and to the broader decarbonized energy system. The study is structured around the presumption that EV charging flexibility can be optimized by understanding two variables:

- The percentage of the charging load shape that can be shifted in time.
- The number of hours the load may be delayed.

The model optimizes these variables across four categories of infrastructure, i.e., archetypal feeders (residential, commercial, industrial and highway fast charging).[33] It tracks changes in peak loads across these archetypal feeders. The value of managing EV charging loads is quantified by comparing the cost of serving the different peak loads across the archetypal feeders under three scenarios: low flexibility, medium flexibility and high flexibility.

3 Regional Market and Policy Context

Colorado was selected as a case study based upon several factors, including the availability of energy sector and transportation data, its macroeconomic profile as a growing state, and the fact that it contains a large and growing transportation corridor.[34] Colorado is also rapidly acquiring and integrating large amounts of VRE resources, a trend also occurring in other states.[35] Xcel Energy, Colorado's largest utility, has an approved plan to reduce its electricity-

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[33] In this paper, we use the term "archetypal feeders" to denote substation infrastructure and lines to the end-use customer.

[34] IBISWorld. (2022) *Colorado - State Economic Profile*. https://www.ibisworld.com/united-states/economic-profiles/colorado/#:~:text=In%202022%2C%20the%20state%20of,the%205%20years%20to%202022, and Colorado Department of Transportation. (2022, September). *Vision for Colorado's Transportation System*. https://www.codot.gov/programs/yourtransportationpriorities/your-transportation-plan

[35] The U.S. Department of Energy's Energy Information Administration (EIA) projects that renewable generation will supply 44% of U.S. electricity by 2050. https://www.eia.gov/renewable/

related carbon emissions by roughly 87% by 2030. It plans to do this by, among other things, adding 10,000 megawatt (MW) of new wind and solar power in the next decade, retiring coal plants and increasing energy storage.[36] For these reasons Colorado is a useful illustration for other jurisdictions as they contemplate incorporating variable energy resources.

Vehicle electrification is an important component of Colorado's emission reduction strategy. In 2022, Colorado had about 4.7 million LDVs registered in the state, and about 116,000 of these were EVs.[37] This represents about 1.4% of all LDV registrations. The state has a goal of 940,000 EV registrations by 2030.[38] This level of EV penetration is expected to result in significant new electric loads.[39]

The analysis in this paper also models Colorado's electricity system in isolation, only considering the investment and operation decisions within the state and assuming a fixed schedule of imports and exports from neighboring states. The model consequently focuses on the type and amount of renewable resource growth, including its location. The model also adopts what EER estimates are reasonable upper bounds for rates of growth of renewable deployment.

Hydrogen production via electrolysis is included in the analysis. As modelled, it reflects deployment of electrolysis in response to Colorado's clean energy mandate, the state's clean hydrogen incentives and federal incentives.[40] Because the analysis models how the state would meet its own target, it constrains the growth of both renewables and hydrogen production to the level needed for in-state end uses.[41] The model assumes that annual renewable builds rise to the maximum historical build rate seen in the state by 2025 (14.4%). The model continues to grow at that rate through 2034, and at 7.2% afterward, based on economics shaped by incentives, policy and supply constraints. Because of Inflation Reduction Act incentives, electrolysis growth is limited in this model to displacing existing hydrogen demand in the state rather than developing hydrogen for export to other states for energy conversion purposes (e.g., creating clean fuels derived from hydrogen). The model also recognizes the growing transportation demand for hydrogen. That level of demand

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[36] Colorado Public Utility Commission. (n.d.) *Clean Energy Transition Progress*. XcelEnergy. https://corporate.my.xcelenergy.com/s/sustainability/clean-energy-transition. See also, XcelEnergy. (2022, August 23). *Colorado Clean Energy Plan leads the way*. https://stories.xcelenergy.com/ArticlePage/?id=c614b0b9-3d22-ed11-b83e-000d3a36f0be

[37] AFDC. (n.d.) *Vehicle Registration Counts by State 2022.* U.S. Department of Energy, Energy Efficiency & Renewable Energy. https://afdc.energy.gov/vehicle-registration

[38] Colorado Energy Office. (n.d.) *Zero Emission Vehicles*. https://energyoffice.colorado.gov/zero-emission-vehicles#:~:text=To%20accelerate%20the%20electrification%20of,Emission%20Vehicles%20in%20January%202019

[39] For further detail, refer to Figure 4.

[40] Colorado General Assembly. (2023). HB23-1281. *Advance the Use of Clean Hydrogen.* https://leg.colorado.gov/bills/hb23-1281 and AFDC. (n.d.). *Hydrogen Laws and Incentives in Federal.* U.S. Department of Energy, Energy Efficiency & Renewable Energy. https://afdc.energy.gov/fuels/laws/HY?state=US#:~:text=Producers%20of%20clean%20hydrogen%20are,equivalent%20per%20kg%20of%20hydrogen

[41] "Electrolysis is the process of using electricity to split water into hydrogen and oxygen. This reaction takes place in a unit called an electrolyzer. Electrolyzers can range in size from small, appliance-size equipment … to large-scale, central production facilities that could be tied directly to renewable or other non-greenhouse-gas-emitting forms of electricity production." U.S. Department of Energy. (n.d.). *Hydrogen Production: Electrolysis, Hydrogen and Fuel Cell Technologies Office.* https://www.energy.gov/eere/fuelcells/hydrogen-production-electrolysis

growth is characterized based on EER's use of the IRA scenario in *Annual Decarbonization Perspective 2023 (ADP2023)*.[42]

How flexible loads and VRE diversity work together

Historically, grid operators around the country forecasted energy demand, i.e., customer electricity use, and then built and scheduled supply resources, usually fossil plants, to meet the demand. Today, the power system relies on greater amounts of relatively low-cost VREs. Instead of relying fully on supply-side natural gas generation to support demand when VREs are not available, they can increasingly be managed with flexible, demand-side resources like EVs. Grid operators are now capable of scheduling flexible load to consume energy from VREs depending on what it costs and when it is produced.[43]

In the case of Colorado, renewable diversity is high, and the state has ample renewable resource potential. Wind and solar resources are located in different parts of the state and produce energy at different times of the day. This is beneficial because, together, they are more easily matched up with load. Thus, a combination of demand-side resources, like EV charging, and a diversity of supply-side VREs can compete with natural gas generation and help to manage the electric power system.[44]

Both types of resources, i.e., flexible loads and VREs, are plentiful in Colorado. They include solar and wind generation, utility-scale batteries, managed EV charging and hydrogen electrolysis. This study analyzed the value of each of these. While the current system has some level of flexibility across the different resources identified here, in order to realize the larger potential savings, securing additional flexible resources will be needed. Despite characterizing Colorado, Figure 3[45] on the next page illustrates the usefulness of flexibility with implications for other jurisdictions as well.

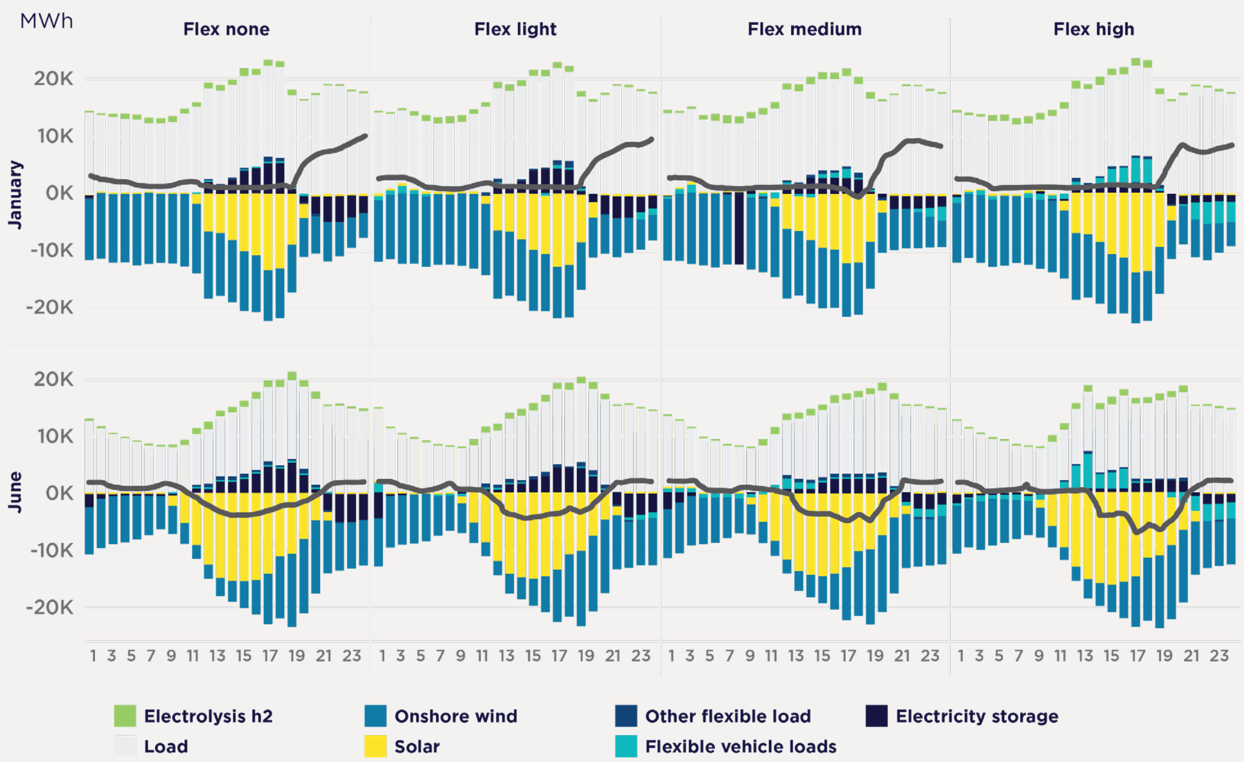
[42] EER describes its ADP as providing "technical blueprints for the transition of the U.S. economy to net-zero greenhouse gas emissions by 2050, including the production and use of energy, industrial processes, the land carbon sink, and non-energy greenhouse gas emissions." See Section 4 for further discussion. Haley, B. (2023, November 7). *EER Releases ADP 2023.* Evolved Energy Research. https://www.evolved.energy/post/usadp2023

[43] Hogan, M. (2023, January). *Tapping the Mother Lode: Employing Price-Responsive Demand to Reduce the Investment Challenge*. Energy Systems Integration Group. https://www.esig.energy/price-responsive-demand-to-reduce-investment-challenge/

[44] Slusarewicz, J., & Cohen, D. (2018, November 16). Assessing Solar and Wind Complementarity in Texas. *Renewables: Wind, Water and Solar, 2018, (5)*7. https://doi.org/10.1186/s40807-018-0054-3

[45] Evolved Energy Research. (2024, May). *Analyzing the value of vehicle flexibility to Colorado's energy system*. https://www.evolved.energy/post/value-of-flexible-ev-load-in-co. Positive values represent load; negative values are supplies. The black line is the net load on the transmission system.

Figure 3. Representative hourly net load: Winter and summer days in 2050



Source: Evolved Energy Research. (2024, May). *Analyzing the Value of Vehicle Flexibility to Colorado's Energy System*

The value of resource diversity also extends to long-distance transmission. When long-distance transmission lines are built, the act of connecting one power grid, i.e., balancing authority, to another links the full range of resources that are available within each. In this way, transmission increases supply diversity, which increases flexibility by expanding the menu of choices that are available to grid operators.

Importantly, the reverse is also true. In other words, the absence of VRE supply diversity produces a greater need for flexibility. In regions with less supply diversity, more flexibility will be required. In these regions, the value of EV charging will almost certainly be greater than what this study shows it to be in Colorado.

4 What We Studied

Study Purpose and Context – Introduction

The purpose of this study is to analyze the value of vehicle charging flexibility to the broader electric system. We analyzed the energy system in Colorado, including the resource mix, existing power system, and the costs and potential options for building infrastructure to meet future grid needs. The analysis also reflects EV penetration, and the capabilities of charging infrastructure needed to meet EV charging demand.

Energy System Modelling

Evolved Energy Research (EER) first modelled the energy sector in Colorado from the present to 2050. This analysis was performed using the EnergyPATHWAYS (EP) and Regional Investment and Operations (RIO) models, which are a complementary set of energy analysis frameworks designed specifically to examine large-scale energy system transformations. They account for the costs associated with producing, transforming, delivering and consuming energy in an economy. EP provides comprehensive energy, cost and emissions accounting of flows from primary supply through final demand. RIO is a linear programming model that combines capacity expansion and sequential hourly operations to find least-cost supply-side pathways. RIO quantifies electricity generation costs as well as electricity transmission and distribution costs by tracking peak load over a set of archetypal feeders.[46]

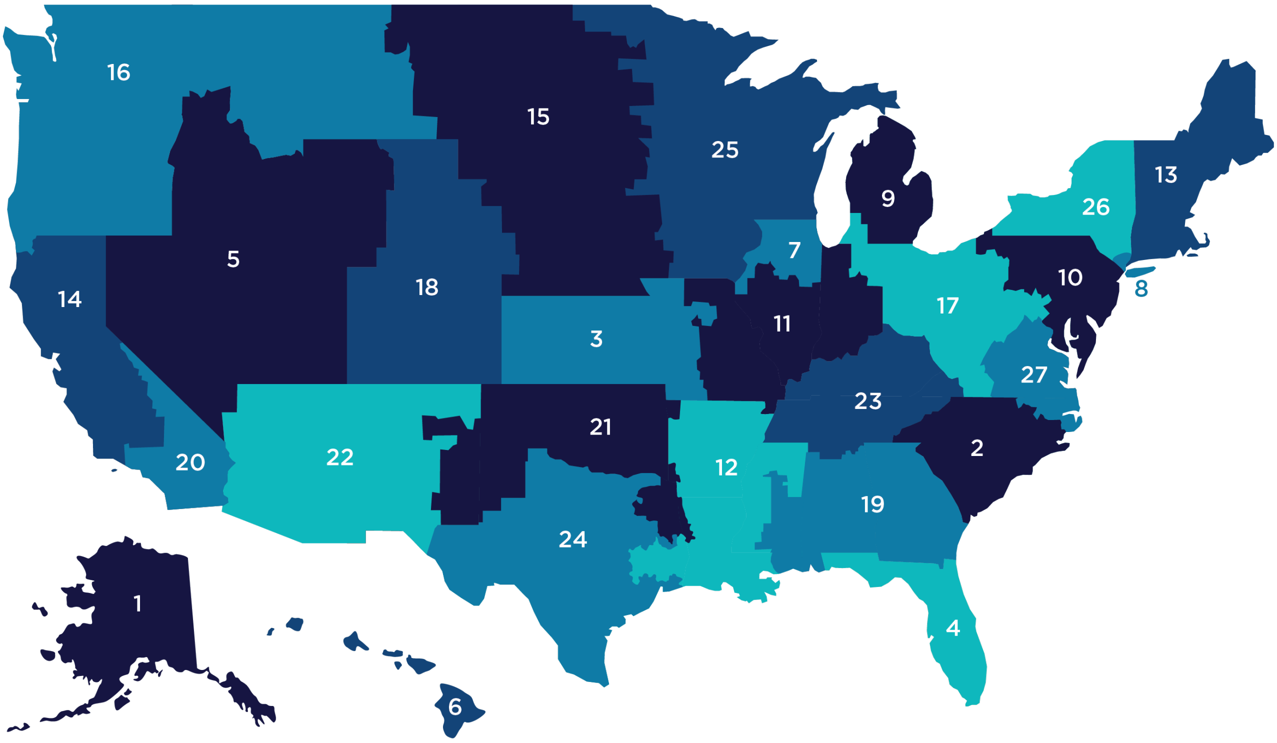
Modelling of future energy systems also requires integration of federal and regional policies that affect power systems and energy flows between regions. To do this, RIO incorporates information from EER's *2023 Annual Decarbonization Perspective (ADP2023)*[47] which provides detailed data on the long-term deep decarbonization pathways for the United States. The ADP helps establish boundary conditions around EER's characterization of decarbonization in the state of Colorado (see Figure 4 below).[48]

[46] Archetypal feeders are grouped together based upon shared characteristics.

[47] Haley, 2023.

[48] Evolved Energy Research, 2024.

Figure 4. Using the ADP zones to build a case for Colorado



1 Alaska
2 Carolinas
3 Central Great Plains
4 Florida
5 Great Basin
6 Hawaii
7 Metropolitan Chicago
8 Metropolitan New York
9 Michigan
10 Mid-Atlantic
11 Middle Mississippi Valley
12 Mississippi Delta
13 New England
14 Northern California
15 Northern Great Plains
16 Northwest
17 Ohio Valley
18 Rockies
19 Southeast
20 Southern California
21 Southern Great Plains
22 Southwest
23 Tennessee Valley
24 Texas
25 Upper Mississippi Valley
26 Upstate New York
27 Virginia

Source: Evolved Energy Research. (2024, May). *Analyzing the Value of Vehicle Flexibility to Colorado's Energy System*

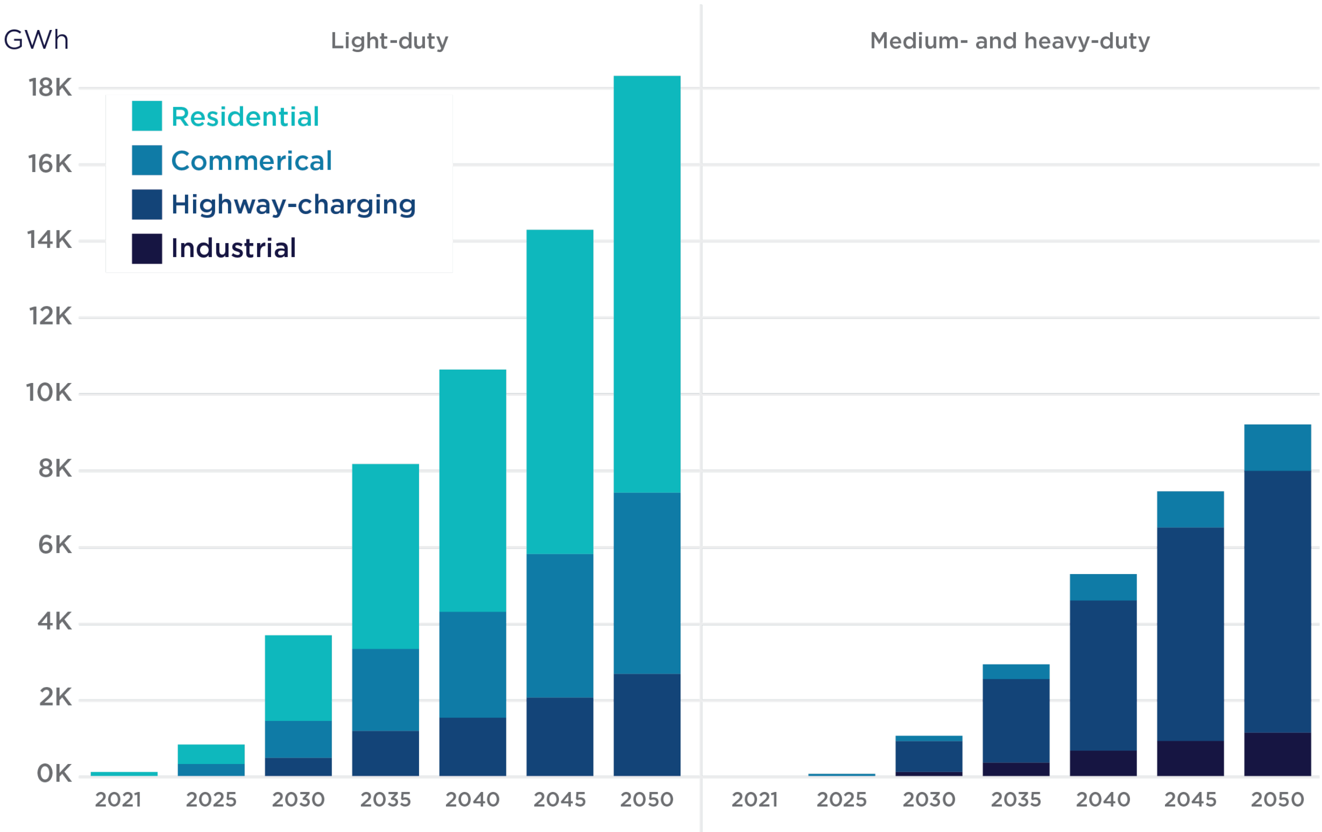
Colorado is in ADP Zone 18, and the modelling uses inputs such as infrastructure buildout, technology choices and investment to understand energy flows between these zones, i.e., the boundary conditions affecting the imports and exports that one should expect to see in that state.

Understanding hourly operations is another key piece of the RIO model's analysis, particularly when analyzing the impact of variable resources and load. To be able to characterize a full year, i.e., 8,760 hours, the RIO model relies on a process called day sampling, which uses a statistical process to select a subset of a year's 8,760 hours. This makes the modelling more manageable by identifying 50 days in a year to characterize what a full year would look like.

Vehicle Electricity Demand Modelling

To determine the value of vehicle flexibility to the system, the model includes EV loads from increasing penetration, load shifting capabilities, the timing and level of charging needs (charging shape), and investment costs. EER used Colorado LDV charging assumptions developed in ICCT's *Colorado Charging Infrastructure Needs to Reach Electric Vehicle Goals*[49] (see Figure 5).[50] These charging assumptions are then allocated to the archetypal feeders: residential (RES), commercial (COM), industrial (IND) or highway (HWY). Home charging is allocated to the RES feeder; workplace and non-residential Level 2 is allocated to a COM feeder; short-haul trucking is allocated to the IND feeder; and direct current fast charging (DCFC) is allocated to the HWY feeder. Medium- and heavy-duty vehicle (MHDV) charging assumptions for Colorado were taken from ICCT's *Benefits of Adopting California Medium- and Heavy-Duty Vehicle Regulations*.[51]

Figure 5. Vehicle loads



Source: Evolved Energy Research. (2024, May). *Analyzing the Value of Vehicle Flexibility to Colorado's Energy System*

[49] Hsu, C-W., Slowik, P., and Lutsey, N. (2021, February 25). *Colorado Charging Infrastructure Needs to Reach Electric Vehicle Goals*. ICCT. https://theicct.org/publication/colorado-charging-infrastructure-needs-to-reach-electric-vehicle-goals/

[50] Evolved Energy Research, 2024. Note that in Figure 5 no LDV charging is assumed in the industrial sector, nor is MDV or HDV charging assumed in the residential sector.

[51] ICCT. (2022, September 27). *Benefits of Adopting California Medium- and Heavy-Duty Vehicle Regulations*. https://theicct.org/benefits-ca-multi-state-reg-data/

Assumptions Used

Significant amounts of electric load associated with transportation electrification are flexible and controllable. Residential LDVs especially have low-capacity utilization and are idle more than 95% of the time.[52] This study assumes that with proper program structure, i.e., one that engages customers and encourages them to participate in managed charging programs, EV drivers can delay daily charging at home and at work for between two to eight hours, and in high-flexibility design could avoid charging in some applications for up to a day. EER developed scenarios to explore the value of flexibility.

These scenarios are not predictive of the actual flexibility that will occur, but instead allow a better understanding of the value of the flexibility if it can be incentivized. The model assumes the same cost of shifting for LDVs across all scenarios. Because an optimization model will use shifting all the time if it comes at no cost, the modelers imposed a $2/MWh price to provide some limitation.[53]

Table 1[54] (next page) sets out assumptions for LDVs under various flexibility scenarios.[55] For example, under column one (RES, Flex light) 61% of energy is on the RES feeder type. On the line below that, 58% of charging is Level 2 or faster while, for COM and HWY feeders, 100% of charging is Level 2 or faster. As the scenarios increase flexibility, they increase the amount of access to Level 2 charging. For example, RES Level 2 charging penetration under Flex medium is 80% and 100% under Flex high.[56]

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52 Langton & Crisostomo, 2013.

53 The actual customer cost to delay charging is very low if they have access to a Level 2 charger as it is using inherent flexibility in their use pattern. Thus, the modeling uses a relatively low value to create some friction but enable the model to select this low-cost flexibility.

54 Evolved Energy Research, 2024.

55 Note a baseline of no flexibility is not shown in Table 1.

56 It is important to note that Flex high is a “boundary” scenario. It is not intended to suggest that the system would expect this level of shifting all the time. In other words, participation will not necessarily be at 75%. Rather that number illustrates the maximum level of shifting that one might get. Charging times of LDVs for personal use might be 10-15%. Seventy-five percent illustrates an approximation of the remainder of time that such vehicles would be available for shifting.

Table 1. Assumptions for light-duty vehicles (LDVs) under various flexibility scenarios

	Scenario 2 — Flex light			Scenario 3 — Flex medium			Scenario 4 — Flex high		
	RES	COM	HWY	RES	COM	HWY	RES	COM	HWY
Share of GWh on feeder	61%	25%	14%	61%	25%	14%	61%	25%	14%
Share Level 2 charging or faster	58%	100%	100%	80%	100%	100%	100%	100%	100%
% Level 2 or faster shifted	50%	0%	0%	75%	25%	0%	75%	50%	0%
Maximum hours delay	4	0	0	8	2	0	24	4	0
Customer cost of shift [$/MWh]	$2	$2	$2	$2	$2	$2	$2	$2	$2

Source: Evolved Energy Research. (2024, May). *Analyzing the Value of Vehicle Flexibility to Colorado's Energy System*

Table 2[57] is comparable to Table 1 but is focused on MHDVs. The first line illustrates how all the gigawatt hours of load are allocated by feeder type: 25% for COM and IND, and 50% for HWY. The allocation does not change across other scenarios. The Flex medium and Flex high scenarios, however, differ from the zero shifting of the Flex light scenario to reflect 50% shifting and 75% shifting, respectively.

Table 2. Assumptions for MHDVs under various flexibility scenarios

	Scenario 2 — Flex light			Scenario 3 — Flex medium			Scenario 4 — Flex high		
	COM	IND	HWY	COM	IND	HWY	COM	IND	HWY
Share by feeder	25%	25%	50%	25%	25%	50%	25%	25%	50%
% load shifted	0%	0%	0%	50%	50%	50%	75%	75%	75%
Number of hours shifted +/-	0	0	0	4	4	2	8	4	4
Customer cost of shift [$/MWh]	$0	$0	$0	$1	$2	$50	$1	$2	$50

Source: Evolved Energy Research. (2024, May). *Analyzing the Value of Vehicle Flexibility to Colorado's Energy System*

[57] Evolved Energy Research, 2024.

Scenarios Modelled

The purpose of the study was to ascertain the value to the electric system of managed versus unmanaged EV charging. To understand the value of shifting vehicle charging requires modelling of the energy system in detail to illustrate, for example, dispatch of resources, system investments, and how the demand profiles of other uses, e.g., HVAC (heating, ventilation and air conditioning), water heating or lighting, change. Consequently, the modelling focuses on the utility management of EV charging by looking at different classes of EV-related electricity loads and infers network cost reductions from reshaping those loads. The modelling identifies savings associated with shifting EV load to avoid peaks on the system. This lowers overall costs for the system, creating savings that state policies, e.g., direct load management or rate designs, can capture and utilize. In other words, managing load away from times of day when it is more expensive to serve load avoids unnecessary costs like additional infrastructure.

For most cases, vehicle charging time can be shifted when drivers are signaled to do so and when the requested shift times are reasonable for vehicle operation. The benefits of managed charging hinge on the timing flexibility of vehicles and their location on the grid. The modelling adopts four flexibility scenarios (see Table 3 below).[58] The first scenario assumes that EV load provides no flexibility. There are three remaining flexibility scenarios: light, medium and high. As set out in Table 1, each scenario reflects three types of EV types – light-duty, medium-duty, and heavy-duty (LDV, MDV and HDV respectively), as well as highway charging. The varying levels of flexibility in each scenario are articulated as a number of hours for which charging can be delayed. For example, Flexibility light assumes that LDV charging can be delayed by up to four hours, whereas Flexibility medium provides a delay of eight hours for LDV charging.

[58] Evolved Energy Research, 2024.

Table 3. Charging scenarios

Scenario Name	Abbreviated Name	Description
Zero flexibility	ZF	Shows system without any transportation load shifting benefits
Flexibility light	Fl	Assumes no flexibility from HDV and MDV or HWY charging and only 50% of LDV are able to shift in residential applications (4 hours of shifting assumed). Driven by no additional uptake or incentives for Level 2 Chargers in residential sector and non-energy economics driving charging pattern in MDV and HDV (e.g., high opportunity cost of not reaching full charge).
Flexibility mid	FM	Assumes minimal HDV and MDV charging flexibility (2 hour delay for overnight charging). No flexibility in HWY charging and 75% of LDV are able to shift (8 hours of shifting assumed). Driven by higher uptake of Level 2 Chargers and significant continued non-energy economics driving charging pattern in MDV and HDV.
Flexibility high	FH	Assumes additional flexibility in HDV, MDV and HWY charging. HWY charging shifting of 4 hours for overnight charging. MDV and HDV shifting of 4 hours for overnight charging. LDV flexibility of increases to up to 24 hour participation in "demand response" like programs with 75% of vehicles participating. Driving patterns and charging profiles show 10% utilization of vehicles on average so this level of response is feasible.

Source: Evolved Energy Research. (2024, May). *Analyzing the Value of Vehicle Flexibility to Colorado's Energy System*

Another key dimension of the analysis is the model's ability to articulate the value of flexible charging to the electricity sector as represented by the four archetypal feeders designated. It is this approach that allows RIO to quantify both electricity generation costs and costs associated with the transmission and distribution systems. The feeder archetypes are representative illustrations of Colorado's power grid, and accurately represent how some loads are likely to be shared within a set of distribution investments.[59] For example, all residential end-uses are assigned to the RES feeder type. The modelling illustrates the distribution costs, the potential upgrades and the coincident peak associated with each feeder type.[60]

The model disaggregates total load from different vehicle class types[61] (including long haul versus short haul for HDV), which are matched to feeder types as illustrated in Table 4,[62] below.

[59] The model uses current end-use load shapes and forecasts the market penetration of non-transport end uses, e.g., HVAC, lighting and water heating.

[60] Energy delivery costs will vary for each feeder type. For example, expenses per unit to deliver on a residential feeder will differ from a more energy-dense commercial feeder.

[61] Using ICCT's Colorado LDV charging assumptions from Hsu et al., 2021.

[62] Evolved Energy Research, 2024.

Table 4. Allocation of vehicle load to feeder type by scenario

	Flex light				Flex medium				Flex high			
	RES	COM	IND	HWY	RES	COM	IND	HWY	RES	COM	IND	HWY
LDV	61%	25%	0%	14%	61%	25%	0%	14%	61%	25%	0%	14%
MDV	0%	25%	25%	50%	0%	25%	25%	50%	0%	25%	25%	50%
HDV LH	0%	0%	25%	75%	0%	0%	25%	75%	0%	0%	25%	75%
HDV SH	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%

Source: Evolved Energy Research. (2024, May). *Analyzing the Value of Vehicle Flexibility to Colorado's Energy System*

5 Findings

Vehicle charging flexibility has the potential to provide substantial energy system value. Flexible vehicle charging can be used to support electric power system planning and operations, and to complement or provide alternatives to conventional supply-side solutions (for example, stationary storage and peaking fossil generation).[63] This study finds that vehicle charging flexibility has the potential to reduce Colorado's electrical infrastructure costs by $100 million to $300 million per year in 2035 and $200 million to $900 million in 2050.[64] Most of these savings come from three sources: avoided transmission and distribution system costs, avoided generation costs, and increased variable renewable generation adoption enabled by managed EV flexibility.

Here, we discuss the various aspects of our modelling which indicate that EV charging flexibility reduces the need for costly electricity grid upgrades across all scenarios. The modelling characterizes EV charging flexibility in numerous ways, identifying prices, sources and locations of flexibility-related value. This section looks at cost savings in total, and cost savings by resource category, charging sector, vehicle classification and feeder type.

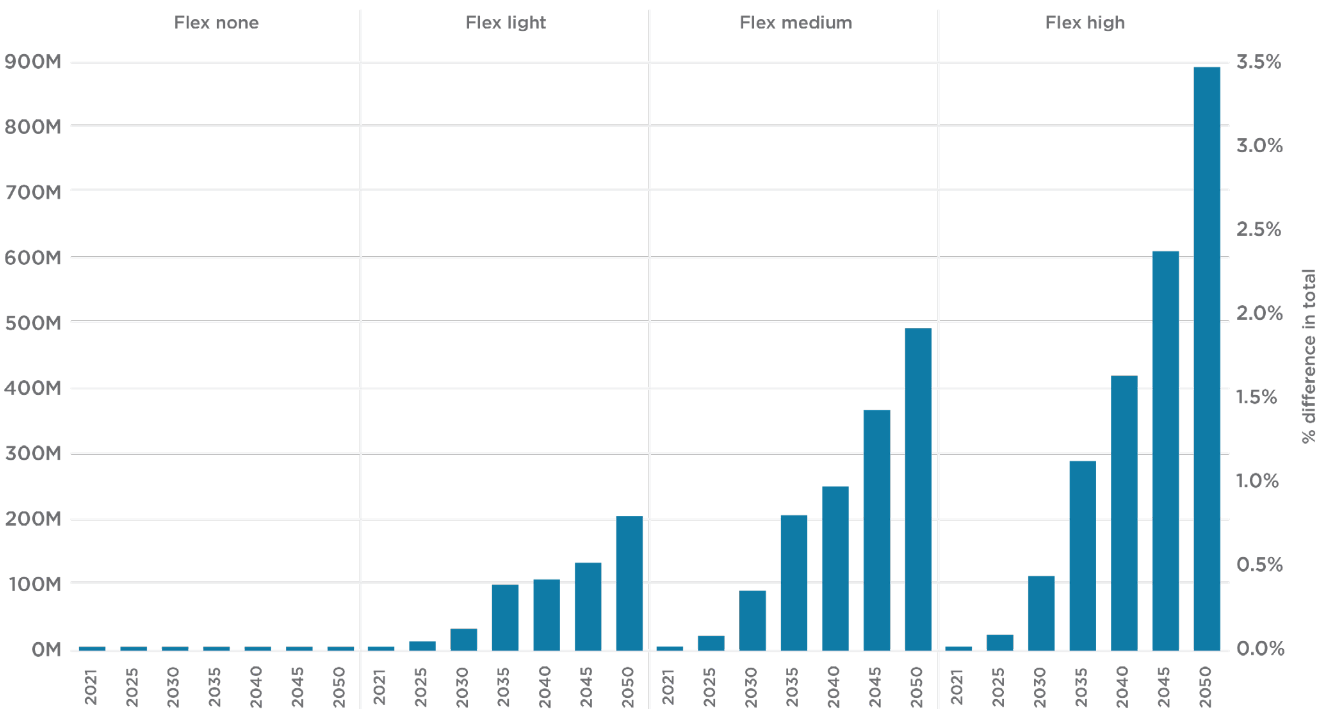
[63] Anwar, M.B., Muratori, M., Jadun, P., Hale, E., Bush, B., Denholm, P., Ma, O., & Podkaminer, K. (2022, January 7). Assessing the value of electric vehicle managed charging: a review of methodologies and results. *Energy & Environmental Science 2022, 2*, 466-498. https://doi.org/10.1039/D1EE02206G

[64] To illustrate, by comparison, Public Service of Colorado reports that in its 2022 Integrated Resource Plan, its budgets for energy efficiency and demand response, respectively, were $85.1 million and $16.8 million. Public Service Company of Colorado. (2023, March 31). 2022 Demand-Side Management Annual Status Report Electric and Natural Gas Public Service Company of Colorado March 31, 2023/Proceeding No. 20A-0287EG. XcelEnergy. https://www.xcelenergy.com/company/rates_and_regulations/filings/colorado_demand-side_management

Flexibility Value Increases as the Amounts of Variable Renewable Energy Increase

Figure 6[65] illustrates that total flexibility value ranges from $100 million to $300 million per year in 2035, and from $200 million to $900 million per year by 2050.[66] The change in value increases as the level of vehicle flexibility increases. The Flex high scenario, consequently, delivers significantly more value than the other scenarios. The vertical axis on the left of the figure illustrates the total ranges in dollars, while the same axis on the right illustrates percentage of system value. Thus, the Flex high scenario in 2050 — approximately $900 million per year in savings — represents approximately 3.5% of the system value.

Figure 6. Total value of vehicle flexibility



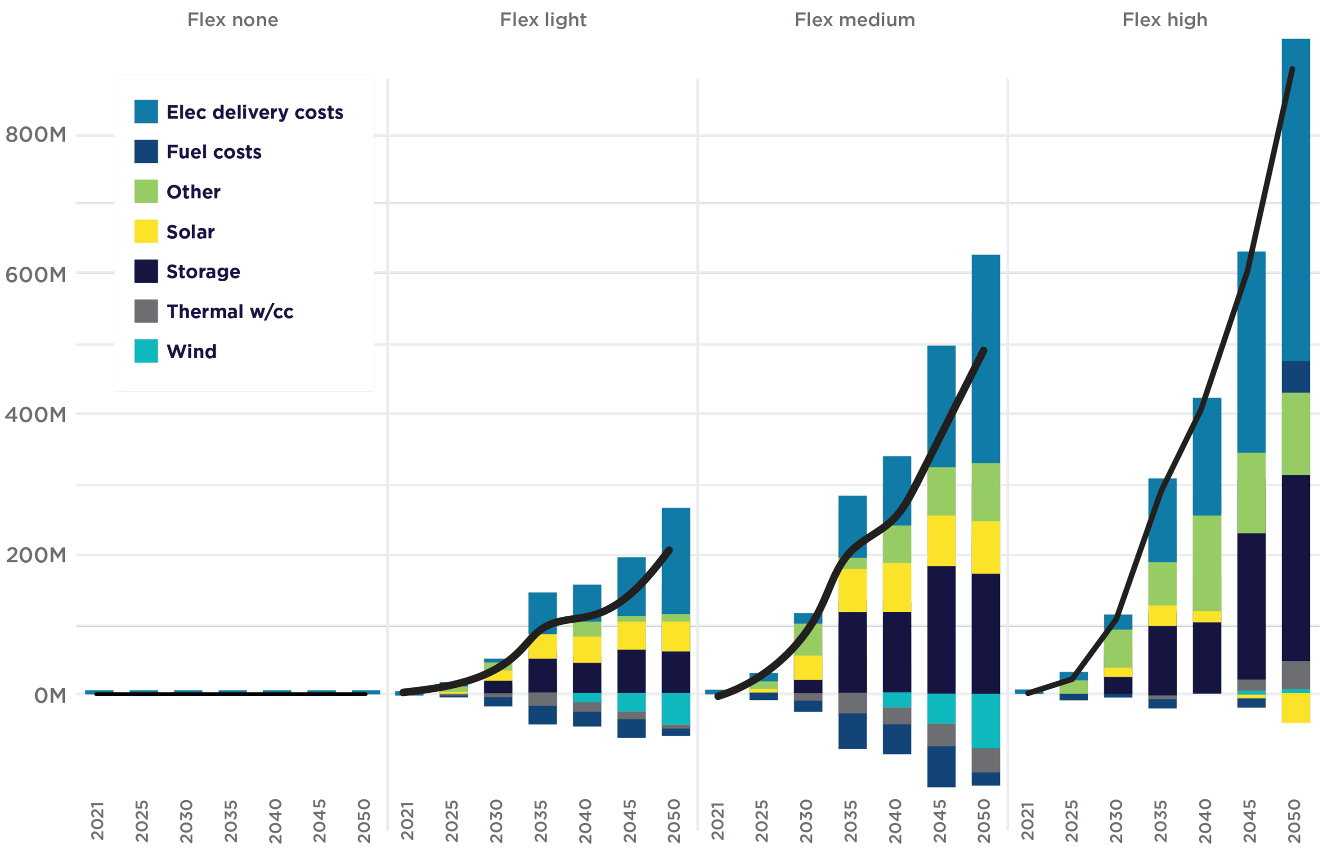
Source: Evolved Energy Research. (2024, May). *Analyzing the Value of Vehicle Flexibility to Colorado's Energy System*

[65] Evolved Energy Research, 2024.

[66] The reason for the 2035-2050 distinction is that IRA benefits sunset in 2035. 2050 represents full system electrification value.

Figure 7[67] illustrates major categories of flexibility-related savings.[68] Distribution costs are reflected at the top of each bar in blue. Savings come largely from avoided capital investments in distribution systems, storage and solar. Distribution cost savings are largely driven by reducing system peaks as well as reduced energy use on the distribution system. In most years, avoided delivery costs and storage are large parts of these cost savings.

Figure 7. Cost savings by category



Source: Evolved Energy Research. (2024, May). *Analyzing the Value of Vehicle Flexibility to Colorado's Energy System*

Investment decisions in the Flex light and Flex medium scenarios, illustrated by Figure 7, require less solar and storage, and use more natural gas and wind to develop a lower-cost system mix to meet the same clean energy goals. The “other” category reflects ancillary services, including reserves and regulation, that allow a system operator to balance supply and demand in real time.[69] In Flex high, however, it is possible to build less generation — of all types. In the outer years, Flex high also enables planners to make fewer thermal investments because of the added demand flexibility.

[67] Evolved Energy Research, 2024.

[68] Most (at least 90%) of the “other” category represents thermal investments that do not have carbon capture, whereas “thermal w/cc” indicates those investments that do. Note the “CC” does not indicate “combined cycle.” Because Colorado has a 100% clean requirement, by 2050 there are generators on the system that are burning “clean” fuels, although they are running very infrequently. So “other” also reflects the infrastructure costs to produce those clean fuels.

[69] U.S. Energy Information Administration. (n.d.). *Glossary*. https://www.eia.gov/tools/glossary/

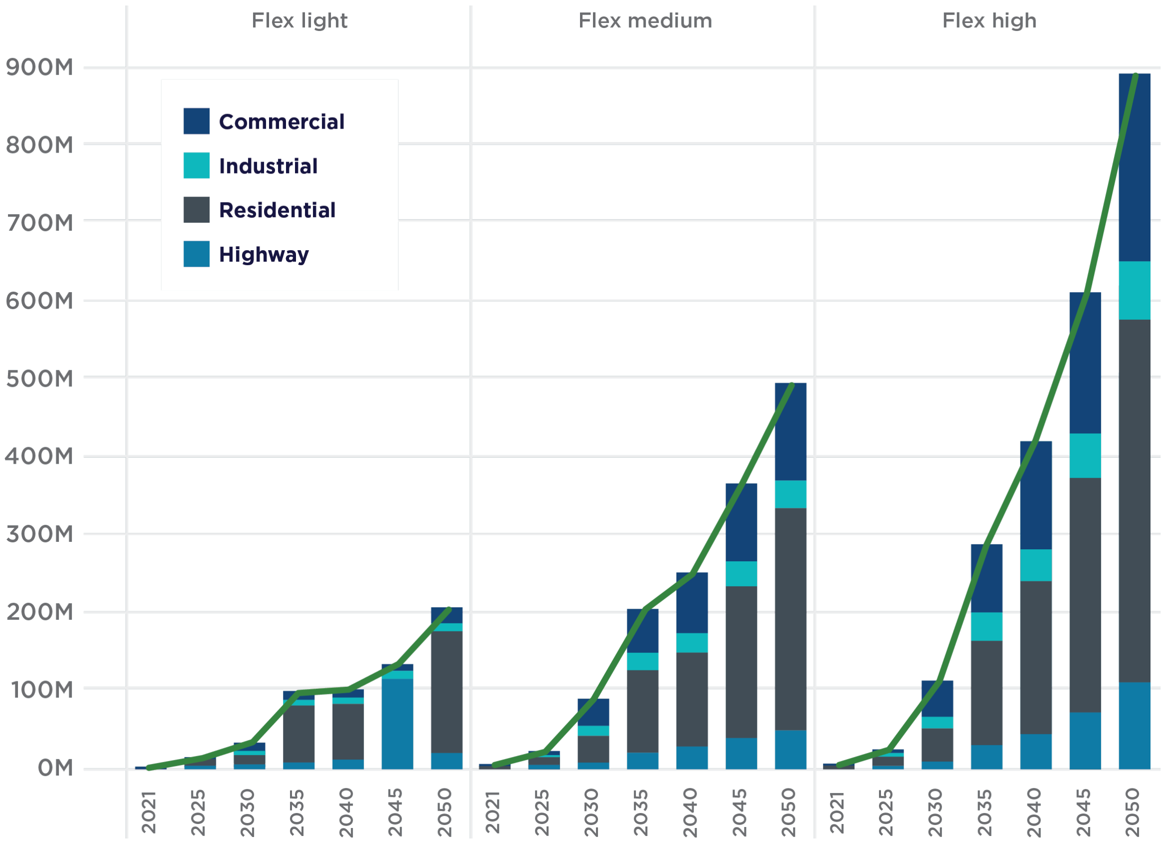
The Majority of Flexibility Value Stems From LDVs in the Residential Sector

In addition to illustrating the overall savings and the various categories of cost savings, the modelling also characterizes flexibility savings by sector, e.g., industrial, commercial and residential. Most savings identified are driven by residential charging flexibility, as illustrated in Figure 8 on the next page.[70] This is the case for all scenarios, but especially for the Flex high scenario.

The majority of the value of the EV load comes from LDVs.[71] Commercial, industrial and highway charging, on the other hand, produce modest value due to the limited flexibility of MDV and HDV loads.[72]

The residential sector also has greater potential for avoiding distribution costs. Due to load factors, or the amount of utilization on residential feeders, distribution costs per unit of energy are typically higher than costs on other feeders.[73] Consequently, the greater the ability to shift load on residential feeders, the more savings one can expect to secure.

Figure 8. Savings allocated by sector (i.e., feeder type)



Source: Evolved Energy Research. (2024, May). *Analyzing the Value of Vehicle Flexibility to Colorado's Energy System*

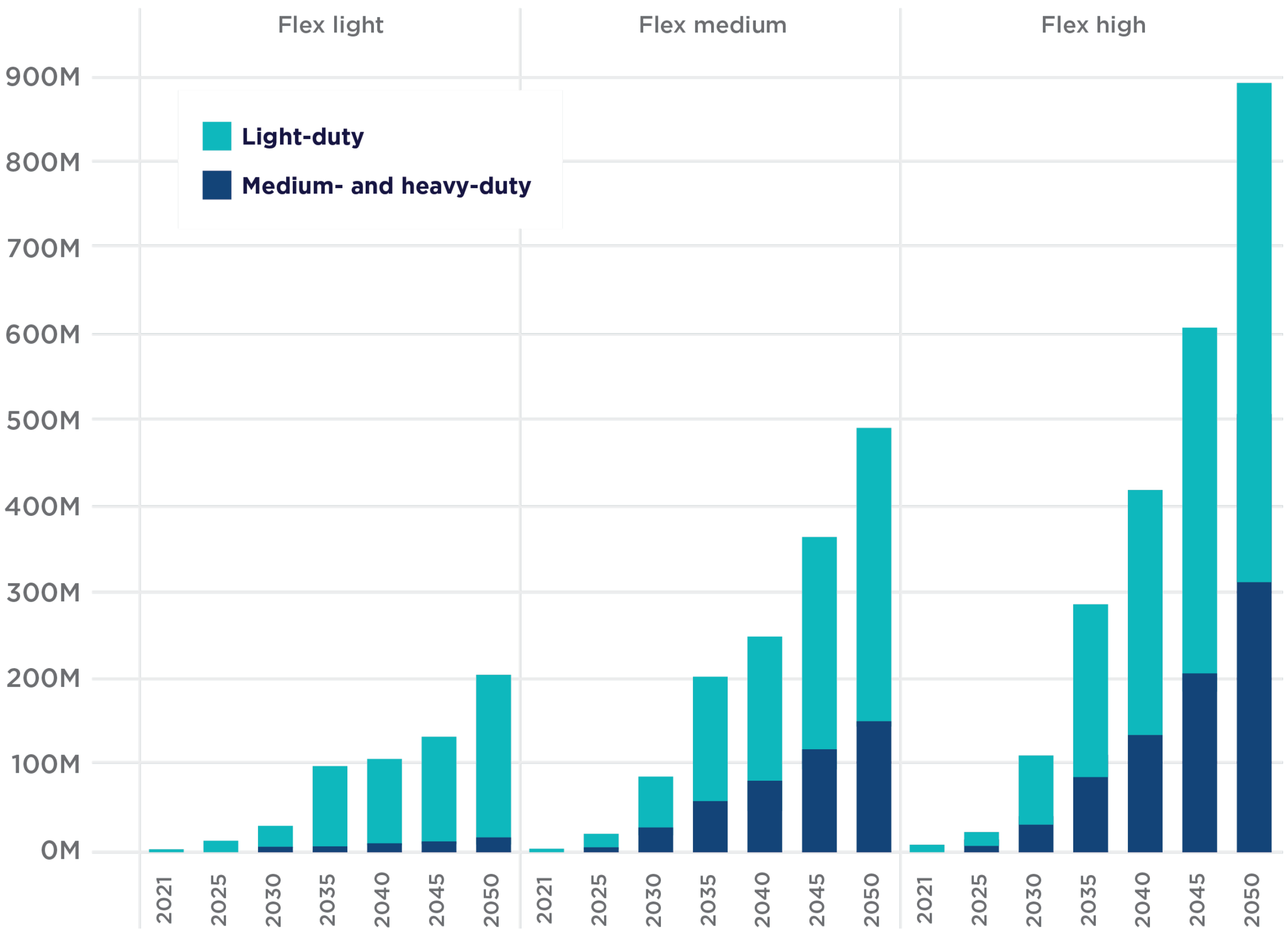
[70] Evolved Energy Research, 2024.

[71] Note that in Figure 5, no LDV charging is assumed in the industrial sector.

[72] No MDV or HDV charging is assumed in the residential sector.

Figure 9[74] illustrates that LDVs (shown in turquoise) deliver the majority of savings. MDV and HDV savings, however, become significant in the Flex high scenario. It takes a significant amount of added flexibility, however, for MDVs and HDVs to produce these higher amounts of savings.

Figure 9. Cost savings by light-duty and medium- and heavy-duty vehicles

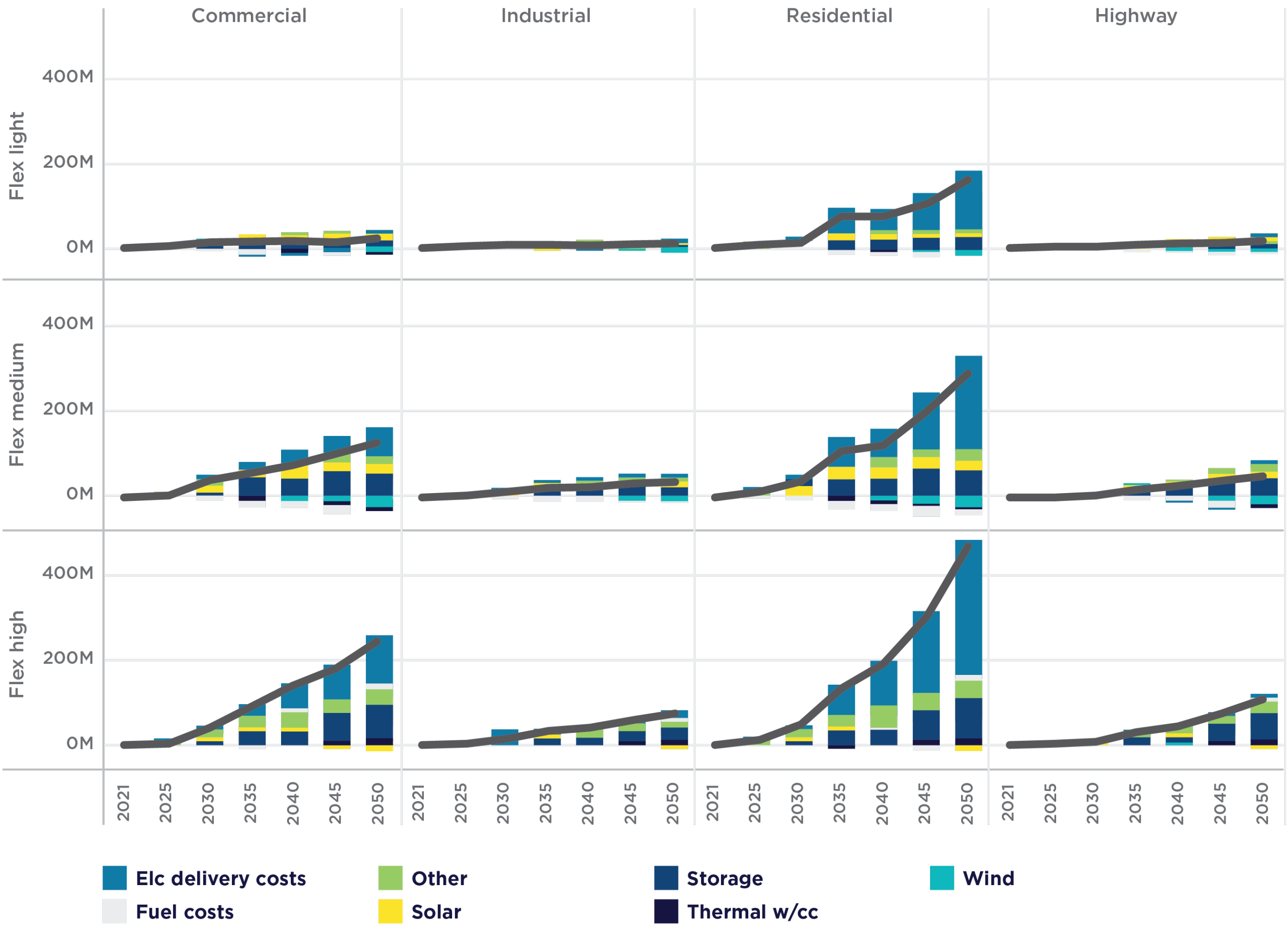


Source: Evolved Energy Research. (2024, May). *Analyzing the Value of Vehicle Flexibility to Colorado's Energy System*

[74] Evolved Energy Research, 2024.

At the feeder level, residential and commercial applications experience the majority of value from flexibility (see Figure 10).[75] The primary source of residential flexibility value comes largely from avoided transmission and distribution costs. This flexibility also enables some reduced supply investment. Limited benefits to highway charging could be due to less opportunity to arbitrage broader system load shape.

Figure 10. Residential and commercial flexibility



Source: Evolved Energy Research. (2024, May). *Analyzing the Value of Vehicle Flexibility to Colorado's Energy System*

[75] Evolved Energy Research, 2024.

Sensitivities modifying base case charging pattern assumptions (see Table 5[76]) still indicate that residential charging creates more value for the energy system. This is illustrated in Figure 11,[77] using high commercial charging patterns versus high residential charging patterns.

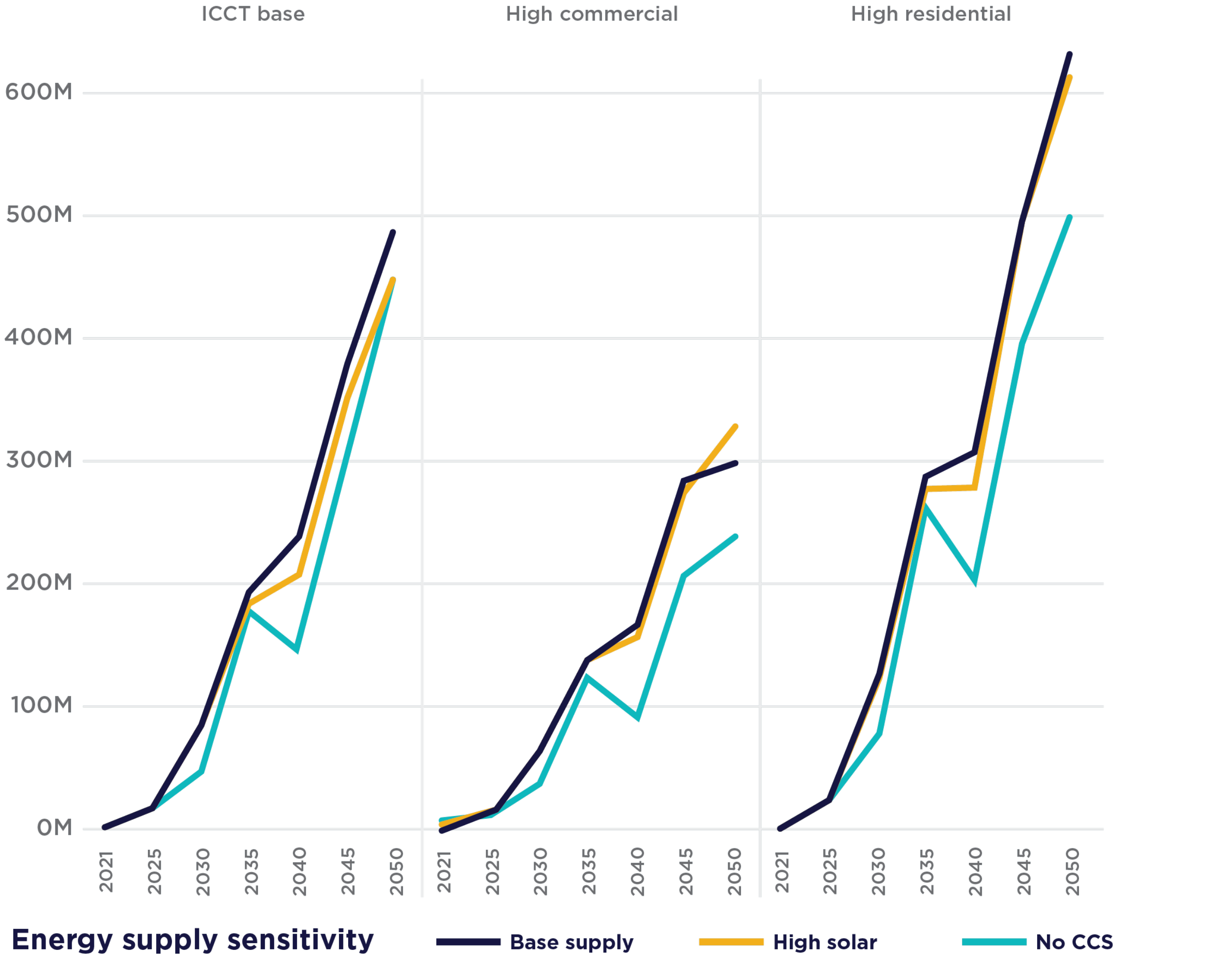
Despite increasing commercial charging and reducing residential charging, the model shows that residential charging creates more value for the electric system.[78]

Table 5. Flex medium charging sensitivities

RES	COM	HWY
80%	10%	10%
41%	45%	14%

Source: Evolved Energy Research. (2024, May). *Analyzing the Value of Vehicle Flexibility to Colorado's Energy System*

Figure 11. Comparison of savings across charging pattern sensitivities for Flex medium scenario



Source: Evolved Energy Research. (2024, May). *Analyzing the Value of Vehicle Flexibility to Colorado's Energy System*

[76] Evolved Energy Research, 2024.

[77] Evolved Energy Research, 2024.

[78] This is true even with different mixes of solar, wind and availability of gas with carbon capture and storage (CCS).

Highway Charging Produces Relatively Less Value When Compared With Other Sectors

By comparison to other sectors analyzed, highway charging provides fewer direct benefits to the electricity system. There are several reasons for this.

First, the assumed cost of delaying charging, from the customer's perspective, is higher in this sector than it is in other sectors. By definition, drivers who seek out direct current (DC) "fast" charging have less flexibility, i.e., have less time to delay charging than those drivers who are content to charge at lower and slower voltages. Thus, fast charging flexibility is expected to have a limited role in the LDV user class given non-economic (convenience) value to customers.

Second, highway charging infrastructure typically interconnects at transmission voltages. This means that highway charging flexibility cannot avoid distribution system investments. Therefore, the highway sector has less potential for flexibility benefits than sectors that avoid both distribution and transmission.

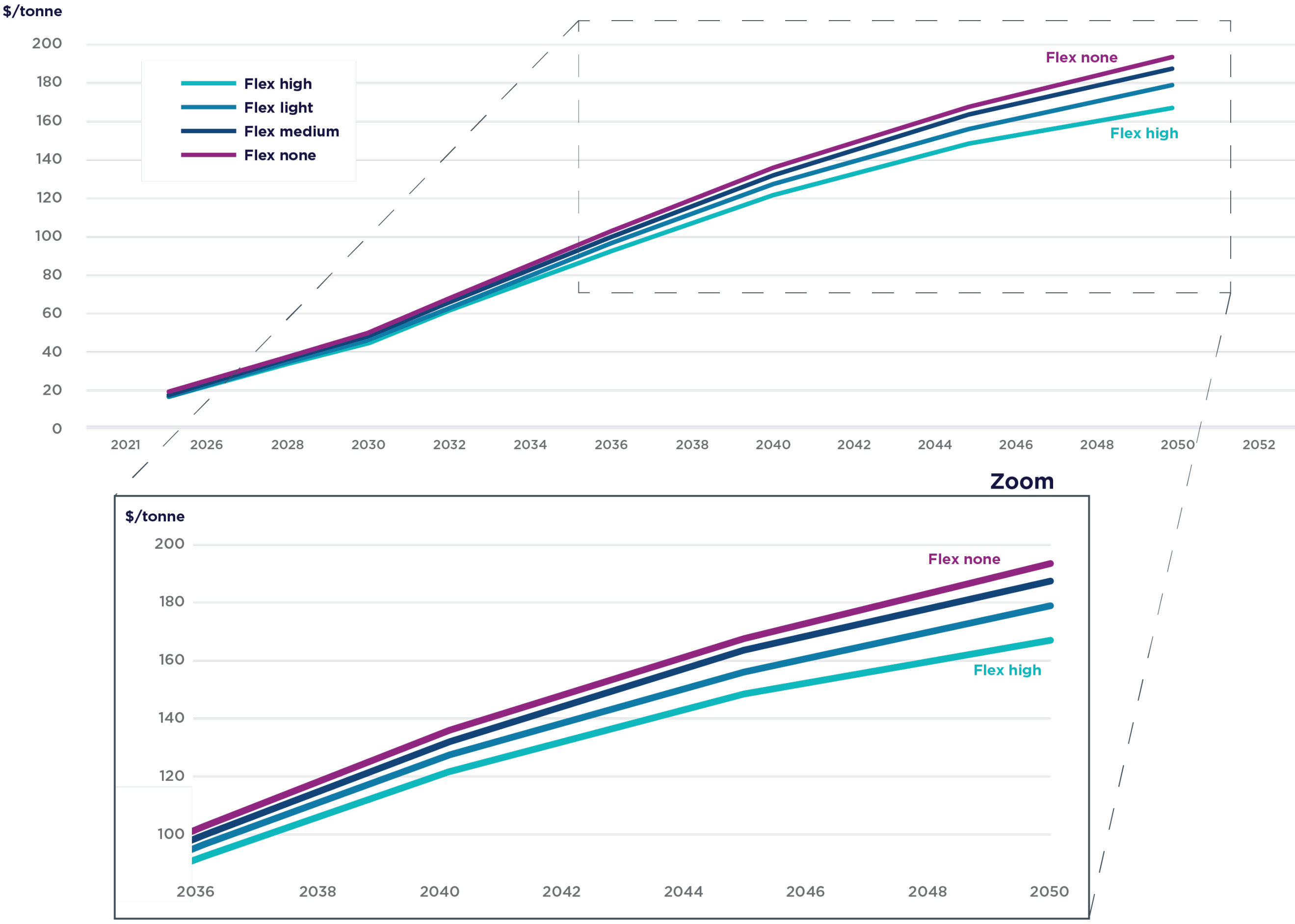
Flexibility Mitigates the Cost of Reducing Electric Sector Emissions

Given the design of this modelling analysis, with all scenarios constrained to reach the same clean electricity targets adopted in Colorado, higher levels of vehicle flexibility do not materially impact emission reductions in the electric sector.[79] The modelling does indicate, however, that higher levels of flexibility produce these results more quickly and at lower costs. The savings from avoided utility investments enabled by higher levels of vehicle flexibility translate into lower abatement costs for the electricity sector. As illustrated in Figure 12 on the next page,[80] the Flex high scenario, for example, reduces the annual dollars-per-ton cost of reducing electricity emissions by roughly 10% in each year of the analysis.

[79] As noted in the discussion above at notes 19-24 and accompanying text, Colorado's policymakers and largest utility have adopted ambitious goals to transition to 100% clean electricity generation.

[80] Evolved Energy Research, 2024.

Figure 12. Annual cost per ton of emissions abated for electricity



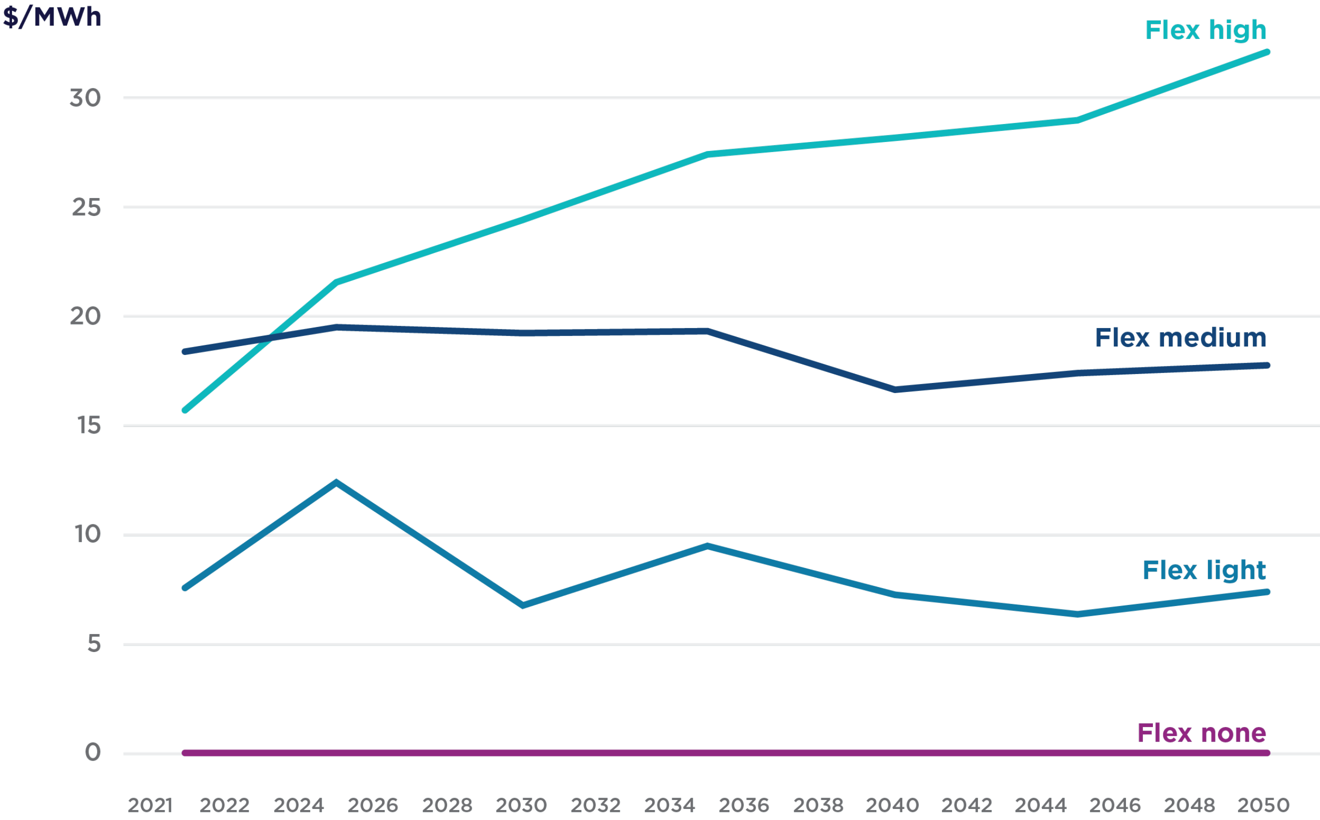
Source: Evolved Energy Research. (2024, May). *Analyzing the Value of Vehicle Flexibility to Colorado's Energy System*

Flexibility Can Provide Significant Consumer Savings

Figure 13[81] (next page) illustrates savings in a different way. It shows that an average of the savings illustrated above in Figures 6-11 produces a range of total $/MWh savings from $7-$30. These savings per MWh of shifting are relatively flat for Flex light and Flex medium. However, once there is enough energy to move through flexible load, as shown in the Flex high slope, the scale of the avoided investments changes. The Flex high slope moves upward in the outer years due to the ability to avoid thermal investments and still maintain reliability requirements using the enhanced flexibility of the demand-side resources.

[81] Evolved Energy Research, 2024.

Figure 13. Savings per MWh of vehicle load shifting



Source: Evolved Energy Research. (2024, May). *Analyzing the Value of Vehicle Flexibility to Colorado's Energy System*

Tables 6 and 7[82] (next page) illustrate another measure of the value — the cost of Level 2 residential chargers — produced by residential flexibility. The net present value (NPV) of residential charging savings would be sufficient to pay for 100% of the cost of 1.3 million L2 residential chargers.[83] Increasing the availability of L2 chargers is key to unlocking the value of charging flexibility and the related saving that it provides. To unlock this value, an incentive program could pay for a part of an L2 charger, and the remaining net present value would reduce net system costs.

Because most incentive programs only cover part of the installed cost of an EV charger, there is an opportunity to give the participating customer a sizable incentive to adopt a controllable L2 charger and still have residual value to reduce costs for nonparticipating customers or to share the savings more generously in other ways, e.g., with low- and moderate-income customers or residents of multi-family housing. These, of course, would be policy decisions that need to be made.

[82] Evolved Energy Research, 2024.

[83] NPV uses a 7% rate, 10-year life and a $2,312/L2 charger in 2030, and a $2,000/L2 charger in 2040.

Table 6. NPV 10-Year lifetime energy system value of Level 2 charger investment

	2030	2035	2040	2045	2050
Flex light	$ 13,893,000	$ 73,346,000	$ 73,219,000	$ 104,639,000	$ 158,418,000
Flex medium	$ 35,259,000	$ 107,340,000	$ 122,678,000	$ 195,563,000	$ 285,396,000
Flex high	$ 43,023,055	$ 134,418,000	$ 195,777,000	$302,089,000	$ 467,356,000

Source: Evolved Energy Research. (2024, May). *Analyzing the Value of Vehicle Flexibility to Colorado's Energy System*

Table 7. NPV of residential charging flexibility translated to number of L2 chargers at 100% incentive

	2030 NPV	L2 chargers (100% incentive)	2040 NPV	2040 L2 chargers (100% incentive)
Flex light	$ 396,953,346	171,693	$ 788,067,498	394,034
Flex medium	$ 607,433,298	262,731	$ 1,316,991,272	658,496
Flex high	$ 753,155,660	325,759	$ 2,014,575,905	1,007,288

Source: Evolved Energy Research. (2024, May). *Analyzing the Value of Vehicle Flexibility to Colorado's Energy System*

Flexibility Flattens the Net Load Curve

Another useful perspective on the value of EV flexibility is provided in Figure 14 below,[84] where all of the sources of supply and flexibility are shown. The figure illustrates a representative summer and winter day in 2050 in Colorado. The bars show how the load and the variable sources of supply and flexibility are optimally dispatched in each hour of the day. Importantly, the bold line shows the load, net of all of the sources of renewable supply: the net load.[85] When the net load is greater than zero it must be served with additional storage or decarbonized dispatchable resources or imports. When the net load is less than zero, power must be exported, used to charge additional storage, or renewables must be curtailed.

[84] Evolved Energy Research, 2024.

[85] Net load is gross customer demand minus the output of uncontrolled VREs.

Without vehicle load flexibility (teal), the system requires much more utility-scale storage (dark blue) to balance the system supply and demand.

Figure 14. Hourly net load on representative winter and summer load days

Source: Evolved Energy Research. (2024, May). *Analyzing the Value of Vehicle Flexibility to Colorado's Energy System*

All three flex scenarios use flexibility in much the same way. During the day, when solar generation is abundant, flexibility is used as a load to make use of the solar generation. Specifically, hydrogen electrolysis is operated primarily during daylight hours, and both battery storage and EV charging flexibility are used as loads during this time. When the solar resource starts to decline in the late afternoon and early evening hours, electrolysers are curtailed, battery storage is discharged, and vehicle charging is delayed until the evening peak load passes.

6 Conclusions and Policy Recommendations

Summary of Conclusions

The findings in Section 5 illustrate that managed EV charging reduces costs for the electric system and the wider decarbonized economy.

Conclusion 1: Vehicle charging flexibility has the potential to reduce Colorado's electric infrastructure costs by $100 million to $300 million per year in 2035 and $200 million to $900 million in 2050.

Managing charging reduces investment in transmission and distribution system infrastructure and generation infrastructure (primarily solar and grid-scale batteries), and it reduces the cost of integrating increasing levels of variable renewable generation. These cost reductions increase over time as more VRE connects to the electric system.

Conclusion 2: Residential-sector cost savings are so large that they could pay for all of the Level 2 charging infrastructure in that sector.

Ensuring residential charging is done at Level 2, rather than lower voltage Level 1, is critical for unlocking flexibility and its associated benefits. The NPV of the cost savings in the residential sector rises from $397 million to $753 million in 2030 to $788 million to $2,014 million in 2040. This is enough value to pay for 100% of the installed cost of 172,000-325,000 L2 chargers in 2030 and 394,000-1,000,000 L2 chargers in 2040. Because customer programs seldom offer incentives of 100% of the cost of an item, there are sufficient cost savings to offer ample incentives to program participants while retaining savings (and lowering costs) for non-participating customers.

Conclusion 3: Managed charging programs and electric rates are necessary for consumers to benefit from vehicle flexibility.

Uncontrolled EV charging loads drive unnecessary investment in grid infrastructure and increase costs for all ratepayers. Unmanaged, these loads will increase system peaks that are more expensive to serve and will not be available to help integrate variable renewable energy resources.

Unmanaged, EV charging loads will increase system peaks that are more expensive to serve and will not be available to help integrate variable renewable energy resources.

In the alternative, programs can be designed to enroll customers at the point of sale, when their interest and motivation is at its height. It is at this point that customers can be introduced to program offerings including complementary tariffs that encourage managed charging. As the terms suggests, managed charging refers to the various ways that a utility can coordinate EV charging to benefit the power grid while meeting the needs of EV owners.[86]
A utility can do this on its own by providing or curtailing power (direct load control) or it can do this by pricing electricity (rate design) in a way that affects the charging practices of the EV owners. Customer programs can also provide infrastructure that can be installed with submetering, communications and control features that enable the utility and the customer to jointly manage and optimize charging loads according to their respective needs and preferences.

Conclusion 4: Electric system costs will be reduced where customer programs and related data are integrated into utility planning and operations.

Even the best programs can fail to reduce investment in the electric system if they are not fully integrated into the utility's planning processes. If distribution system planners exclude or discount the impact of these programs, then they will continue to call for investment in the system that could otherwise be avoided. Similarly, if load forecasters or resource planners exclude or discount the impact of these programs, then they will produce load forecasts that are too high and resource plans that call for more investment in generation than is necessary.

The range of results and the value that can be expected from different kinds of customer programs and electric rates has been well established and analyzed over the past decade.[87] Consequently, it is essential for those who are designing and implementing customer programs to communicate and collaborate with others who are responsible for distribution system and resource planning.

[86] This definition is consistent with the California Energy Commission's definition of vehicle-grid integration, "[T]echnologies, policies, and strategies for electric vehicle (EV) charging which alter the time, power level, or location of the charging (or discharging) in a manner that benefits the grid while still meeting drivers' mobility needs." California Energy Commission. (n.d.). *Vehicle-Grid Integration Program*. https://www.energy.ca.gov/programs-and-topics/programs/vehicle-grid-integration-program

[87] U.S. Department of Energy. (2016, November). *Final Report on Customer Acceptance, Retention, and Response to Time-Based Rates from the Consumer Behavior Studies, Smart Grid Investment Grant Program.* https://www.energy.gov/sites/prod/files/2017/01/f34/CBS_Final_Program_Impact_Report_20161107.pdf

Language on rates

It has long been established, though not universally adopted, that providing EV customers with clear price signals through rate design is one key to achieving the benefits of EVs. Well-designed rate structures can align EV charging with grid needs, help increase utilization of existing resources and reduce costs for all ratepayers. By contrast, poorly designed rates may lead to increased system costs, which are borne by all ratepayers. The Michigan Public Service Commission has observed that the adoption of EVs could have an:

> [I]mpact on customers' rates and electric distribution systems. This will depend on the nature, timing, and location of charging, as well as consumer adoption rates. The uncertainties in EV adoption rates require utilities to be proactive in understanding and mitigating potential impacts to the grid and related infrastructure costs. Effective planning is essential for Michigan ratepayers to ensure reliable energy supply at reasonable rates.[88]

The Washington Utilities and Transportation Commission has also recognized that EV charging services are capable of providing "significant benefits to the overall utility transmission and distribution network if they are properly deployed," but noted that "without a price signal, drivers will generally plug in and charge immediately upon arriving home after work, exacerbating evening peak demand."[89]

Load management is critical for securing the benefits of the flexibility that EVs possess. Reasonably designed programs and electricity rates can avoid circuit overloads and the need to invest in system upgrades by sending price signals to customers that encourage them to charge their vehicles during off-peak periods when there is less stress on the system, and times when greater amounts of variable renewable resources are supplying the grid. Effective rate designs can also protect non-EV customers from subsidizing the system costs imposed by an EV customer who is indifferent to these system dynamics.

[88] Michigan Public Service Commission. (2019, May 2). *Utility electric vehicle pilot programs* [Issue brief]. https://www.michigan.gov/documents/mpsc/EV_Pilot_Issue_Brief_05-02-2019_653974_7.pdf

[89] Washington Utilities and Transportation Commission, Docket UE-160799, Draft Policy and Interpretive Statement Concerning Commission Regulation of Electric Vehicle Charging Services, January 13, 2017, paragraph 70. https://www.utc.wa.gov/casedocket/2016/160799/docsets

Summary of Policy Recommendations

The recommendations in this section are consistent with the conclusions discussed above. They emphasize the role of LDVs in the residential sector, and the value of programs and rate design for educating and coordinating customers. Finally, these recommendations emphasize the importance of integrating EVs into utility operations and planning.

Recommendation 1: Design customer programs for the residential sector first, then focus on managing the flexibility in other sectors.

LDVs in the residential sector have the most charging flexibility and represent about two-thirds of the overall potential savings. Because the size of these savings is similar to savings from energy efficiency and demand response programs, we recommend giving them equal policy priority and attention.

Although MDVs and HDVs have less flexibility to offer than LDVs in the residential sector, they still represent a third of the overall value of charging flexibility. In contrast to the residential LDVs, MDV and HDV customers are relatively few in number and represent larger loads in specific locations.

Recommendation 2: Develop customer programs and complementary tariffs that help secure the benefits of vehicle flexibility.

The first step in securing the benefits of charging flexibility is to enroll customers in managed charging programs and enable their participation through incentives for L2 charging infrastructure. This is best accomplished at the point of sale when the customer's interest is at its height. Program designs that seek to enroll customers after the point of sale are likely to experience both higher customer acquisition costs and lower enrollment rates. Because the value of charging flexibility is so high in the residential sector, failure to recruit customer participation would result in substantial lost opportunity costs.

It is also important to develop customer programs for MDV and HDV owners. They should also be enrolled at the point of sale through traditional utility key account programs. Being profit-driven, they are likely to be attuned to the costs of EV charging and the benefits of charging flexibility. As a result, they may be inclined to invest in electric vehicle supply equipment (EVSE) that includes metering, communications and controls. Still, lost opportunity costs may be incurred if the charging infrastructure that they choose is incompatible with utility programs or systems.

All customers should be offered complementary electric tariffs that compensate them for offering their charging flexibility to the utility and to the grid. This is a fairness issue as well as a customer retention issue. Customers should be fairly compensated for the services that they render to the grid. Furthermore, without fair compensation, customers may lack the incentive to participate in the program over the long term, threatening program retention rates.

Recommendation 3: Ensure that customer programs are well integrated into utility operating systems.

Utilities or their service providers must have the ability to monitor, measure and control the EV loads that are enrolled in their programs. The primary operating system that enables these abilities is typically referred to as a distributed energy resource management system (DERMS), and at a minimum it must be integrated with the utility's billing system.

Consequently, regulators should encourage utilities to invest in these systems to enable customer programs.

Recommendation 4: Ensure that customer programs are well integrated into utility planning processes.

If distribution system planners exclude or discount the impact of managed EV charging programs, they will continue to call for investment in the system that could otherwise be avoided. Similarly, if load forecasters or resource planners exclude or discount the impact of these programs, they will continue to produce load forecasts that are too high and resource plans that call for more investment in generation than is necessary. It is essential, therefore, for the utility staff who are designing and implementing customer programs to communicate and collaborate with the staff who are responsible for distribution system planning and for resource planning.

International Council on Clean Transportation

1500 K Street NW, Suite 650, Washington, DC 20005

+1 000 000 0000
communications@theicct.org
theicct.org

Regulatory Assistance Project (RAP)®
Belgium · China · Germany · India · United States

50 State Street, Suite 3
Montpelier, Vermont 05602
USA

+1 802 223 8199
info@raponline.org
raponline.org