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Aligning Electric Vehicle Customer Charging with Grid Needs

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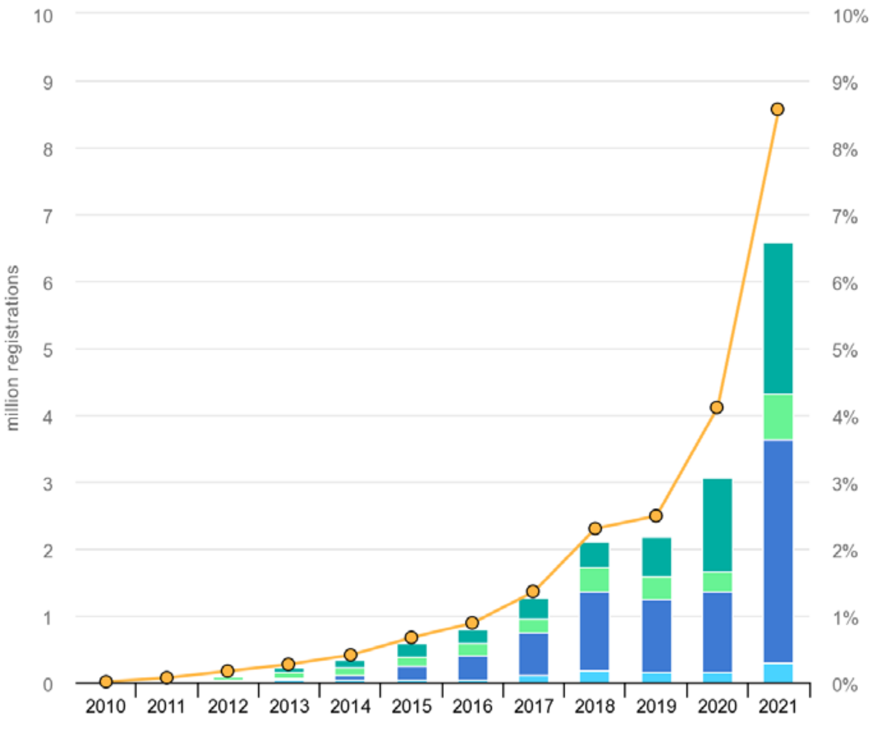
Battery Electric Vehicles: a Success Story

- **Electric vehicles (EVs)** are experiencing a rapid rise in popularity and adoption:
  - Technology has matured and **costs have declined**
  - **Support for clean transportation** has incentivized adoption and promoted awareness
  - Increased **charging opportunities** enabled adoption

- Expected **rapid growth in EV** adoption for passenger vehicles as well as medium- and heavy-duty trucks and other applications (off-road, planes, ships, etc.)

- EVs offer a pathway to decarbonize on-road transportation when coupled to **clean electricity**

Global EV Sales



Source: https://www.iea.org/commentaries/electric-cars-fend-off-supply-challenges-to-more-than-double-global-sales

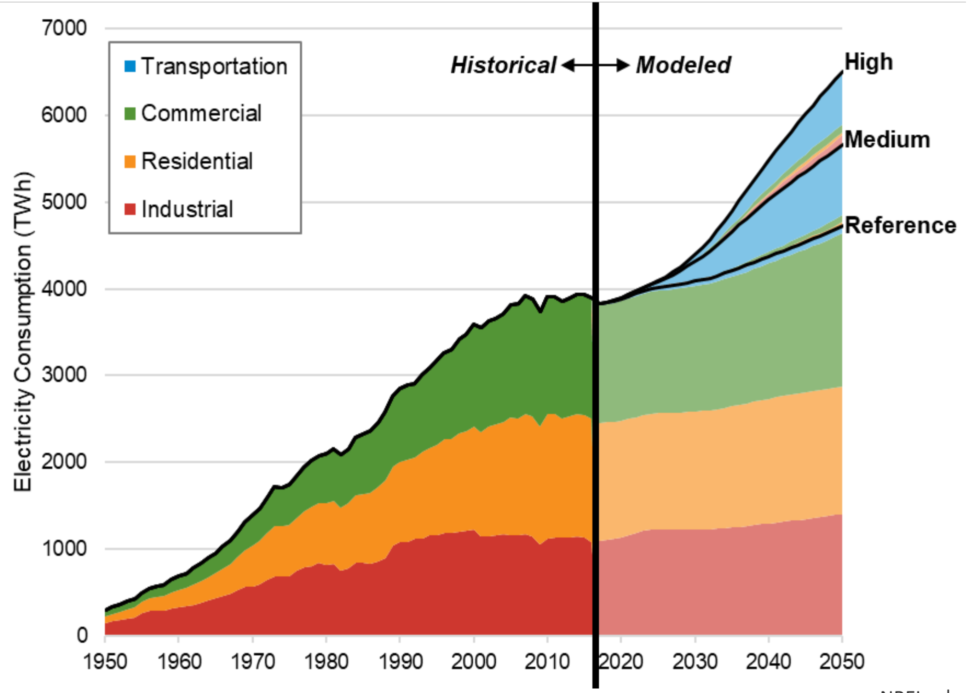
- In 2019, 2.2 million electric cars were sold, representing just 2.5% of global car sales.
- In 2020, the overall car market contracted but electric car sales bucked the trend, rising to 3 million and representing 4.1% of total car sales.
- **In 2021, electric car sales more than doubled to 6.6 million, representing close to 9% of the global market and more than tripling their market share from two years earlier.**

Impact of widespread electrification

Growing EV adoption offers an **opportunity to increase electricity demand**, and will require investments in generation, transmission, and distribution systems.

EFS High scenario, 2050:

- Transportation share of electricity use increases **from 0.2% in 2018 to 23% in 2050** (1,424 TWh electricity consumption increase), and more recent net-zero studies show even more aggressive growth



Source: https://www.nrel.gov/analysis/electrification-futures.html

How Valuable is Electric Vehicle (EV) Managed Charging?

- **Uncoordinated** charging of EVs will lead to increased system peak load, possibly exceeding the maximum power that can be supported by distribution systems and generally **increasing power system stress**
- Vehicles are underutilized assets parked ~96% of the time: **managed EV charging can satisfy mobility needs while also supporting the grid**:
  - We identify critical gaps and remaining challenges that need to be addressed to fully realize effective EV-grid integration

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Assessing the value of electric vehicle managed charging: a review of methodologies and results

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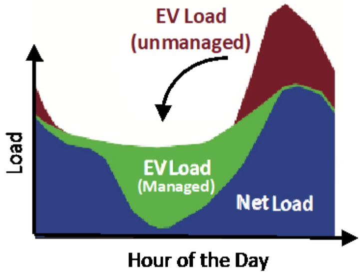
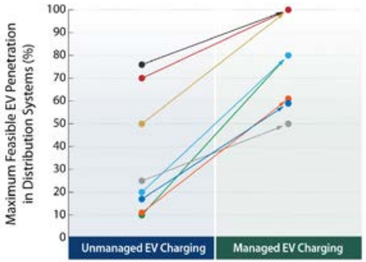




The grid is also transforming

The **electric power system is undergoing profound changes**.

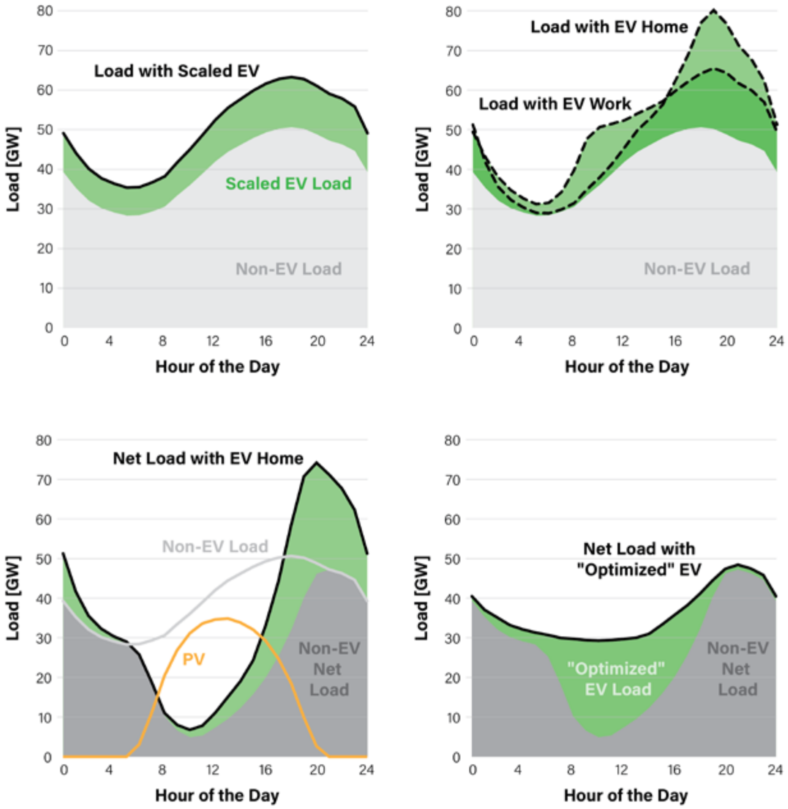
The traditional system paradigm of dispatching central generation to match demand is evolving into a **more integrated supply-demand system** in which demand-side distributed resources (generation, energy storage, and demand response) respond to supply-side requirements, mainly driven by variable renewable generation.

EVs are expected to be one of the largest sources (and often the single largest) of **demand-side flexibility**

When and *where* EV charging occurs will be as critical as *how much* electricity is needed

a) ASSUMPTION:
EV charging is often assumed to simply scale up electricity demand.

b) COMPLEXITY:
Future EV charging could change the shape of demand, depending on when and where charging occurs.



c) INTEGRATION:
EV charging can impact power system planning and operations, particularly with high shares of variable renewable energy.

d) FLEXIBILITY:
Optimizing EV charging timing and location could add flexibility to help balance generation and demand.

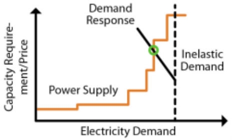
New class of models needed to assess the integration opportunities of EVs on the power system

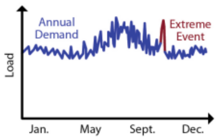
Source: [*Muratori and Mai, 2020*]

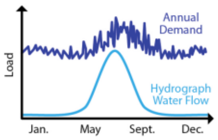
EVs can support the grid in multiple ways providing values for different stakeholders, including non-EV owners

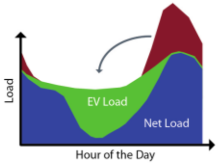
Smart electric vehicle-grid integration can provide flexibility – the ability of a power system to respond to change in demand and supply – by charging and discharging vehicle batteries to support grid planning and operations over multiple time-scales

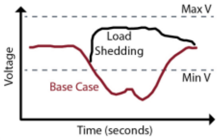
	Generation Capacity and Transmission/ Distribution Planning	Resilience To Extreme Events	Seasonal Planning (Hydro/Long-Term Storage Dispatch)	Commitment and Dispatch Decisions	Balancing and Power Quality	Support End Consumers
Power System Application	**Generation Capacity and Transmission/ Distribution Planning**	**Resilience To Extreme Events**	**Seasonal Planning (Hydro/Long-Term Storage Dispatch)**	**Commitment and Dispatch Decisions**	**Balancing and Power Quality**	**Support End Consumers**
Time scale	*Multi-year*	*Years (planning), hours (real-time response)*	*Months*	*Days to Hours and Sub-Hours*	*Seconds to sub-seconds*	*Years (planning), hours (real-time response)*
Vehicle-Grid Integration value	Ability to reduce peak load and capacity requirements and defer distribution systems upgrades if reliable EV charging flexibility is available	Load response to natural events (heat waves, tornados) or human-driven disasters, load postponement over days, and support microgrid management and grid restoration (V2G)	No role for EVs	Leverage EV charging flexibility to support supply dispatch and load-supply alignment (tariff management), variable renewables integration, operating reserves, energy arbitrage (V2G)	Provide voltage/frequency regulation and support distribution system operations	Tariff management (e.g., mitigate retail demand charges), complement other distributed energy resources (smart load, generation and storage), and minimize equipment aging/upgrades

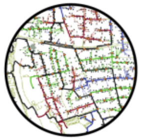










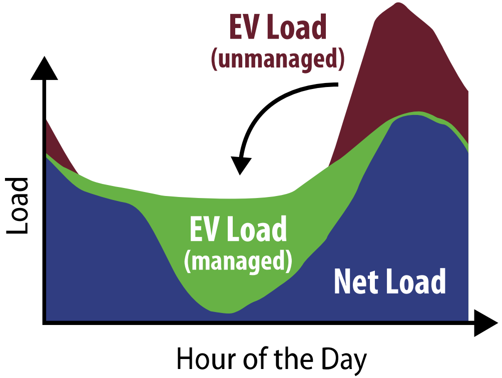


Source: Muratori *et al.* 2021. The rise of electric vehicles—2020 status and future expectations. Progress in Energy.

An Opportunity for Grid Integration

As electric vehicle (EV) adoption continues to grow, effective management of these flexible loads offers a unique opportunity to **support power systems during normal and extreme conditions**, with the potential to benefit EV users and other electricity consumers alike.

Value of Electric Vehicle Managed Charging



Managed EV charging can support grid planning and operations

Reduce Bulk Power Systems Investment Costs
20–1350 $/EV/year

Reduce Bulk Power Systems Operating Costs
15–360 $/EV/year

Reduce Renewable Energy Curtailment
23–2400 kWh/EV/year

Reduce Distribution Systems Investment Costs
5–1090 $/EV/year

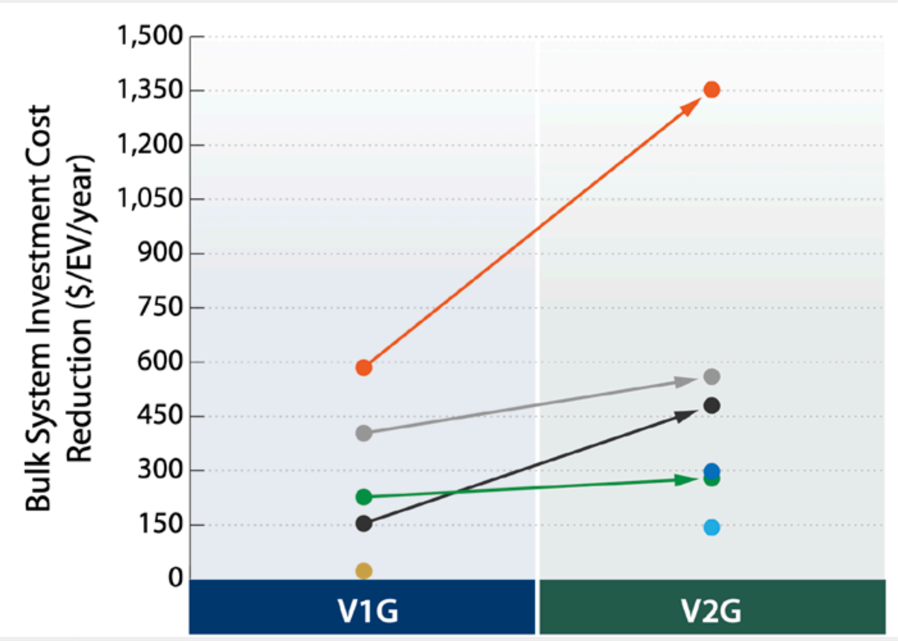
Increase Distribution Systems EV Hosting Capacity
30–450%

Source: Anwar et al. 2022. Assessing the value of electric vehicle managed charging: a review of methodologies and results. Energy & Env. Science.

Reducing bulk system investment costs

- Managed charging is shown to consistently provide **hundreds of dollars in investment cost savings per EV each year**.

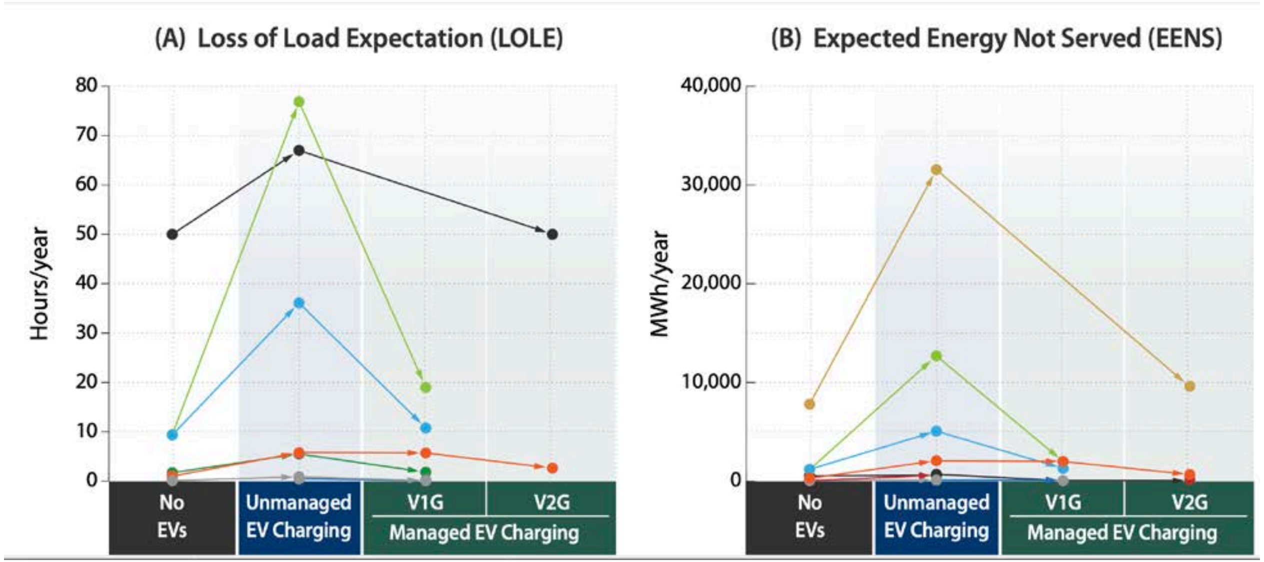
- **V2G capability tends to enable greater investment cost reductions** compared to V1G; however, the extent of these benefits depends on system characteristics, EV adoption assumptions and EV flexibility modeling, and **enablement costs** (usually not explicitly considered in these studies).



Source: Anwar et al. 2022. [Assessing the value of electric vehicle managed charging: a review of methodologies and results](). Energy & Env. Science.

Impact on Reliability

Unmanaged EV charging invariably worsens **bulk power system reliability** (frozen system, no expansion assumed), while managed charging can offer reliability close to the case without EVs (again, without any system expansion)



Source: Anwar et al. 2022. [Assessing the value of electric vehicle managed charging: a review of methodologies and results](). Energy & Env. Science.

Concluding Remarks

EVs are not a burden for the grid, but a resource: managed charging can provide major benefits across multiple timescales, especially for high-renewable systems

- **Benefits change** for different power systems, charging strategies, and over time
- **Benefit-cost analyses** largely missing, especially for complex solutions (e.g., V2G)

Needs:

- More nuanced **demand-side modeling** to assess EV charging needs and flexibility
- Comprehensive **analyses across the entire power system** to explore tradeoffs across multiple aspects and cost/benefit to **inform evolving regulations and the design of future power markets**
- **Technologies, business models, and multi-sector collaborations required to untap this potential and engage/compensate EV users**
- Assessing **role/value of charging infrastructure** in enabling and supporting managed charging

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Questions?

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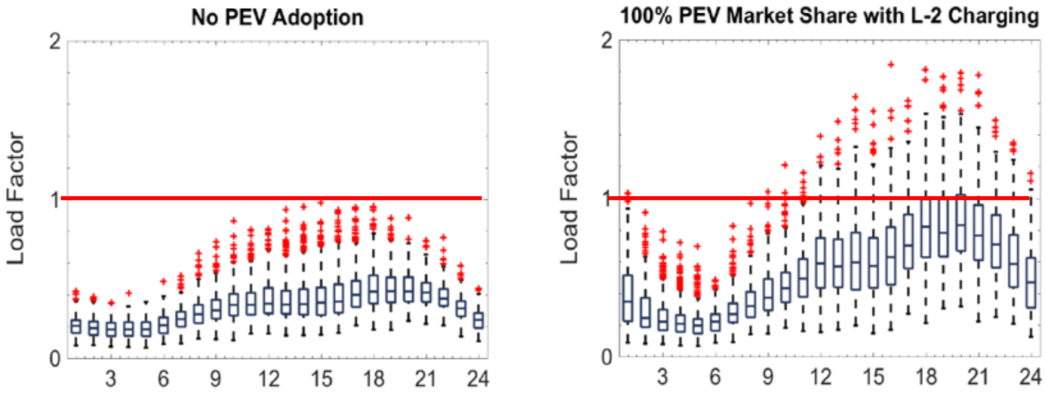
Supplemental

Impact of Uncoordinated EV Charging

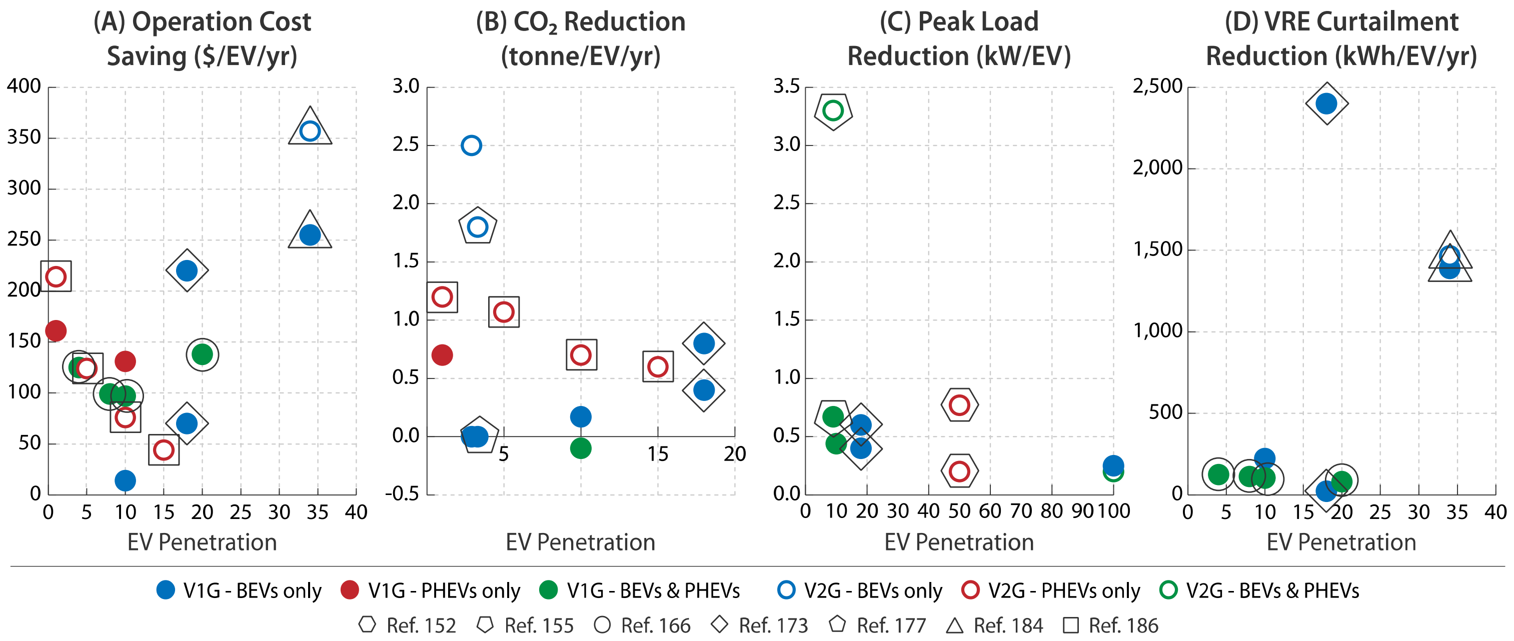
Residential EV charging represents a significant increase in household electricity consumption that can require upgrades of the household electrical system and unless properly managed it may lead to exceeding the maximum power that can be supported by distribution systems, especially for legacy infrastructure and during high demand times.

- **Clustering effects** in EV adoption and **higher power** charging exacerbates these issues
- Effective planning, smart EV charging, and distributed energy storage systems can help to cope with these potential issues.
- Key to **consider EVs in system upgrades**



Source: Muratori, M., 2018. [Impact of uncoordinated plug-in electric vehicle charging on residential power demand]. Nature Energy, 3(3), pp.193-201.

An Opportunity for Grid Integration



Source: Anwar et al. 2022. Assessing the value of electric vehicle managed charging: a review of methodologies and results. Energy & Env. Science.