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Technology Primer: The impact of electric vehicle charging infrastructure on residential grid systems

Analysts - Beatriz Minamy

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Introduction

The rapidly increasing adoption of electric vehicle charging infrastructure is placing growing pressure on local grid infrastructure — particularly transformers, feeders and distribution systems not originally designed for high-power, distributed loads. Domestic charging makes up 85% of all EV installations and will likely remain dominant throughout the decade, according to S&P Mobility's EV charging infrastructure 2024 forecast. This reinforces the urgency of adapting residential grids. This report focuses on residential charging; nonresidential infrastructure such as fleets, bus depots, logistics hubs and heavy-duty vehicles will be covered in a separate report.

The Take

While vehicle-to-grid (V2G) offers strong potential to enhance grid flexibility, its mass deployment remains limited — many energy distributors remain in early stages of readiness and view it as a mid- to long-term objective, while others are moving ahead. Centralized energy management systems (EMS) are essential to unlock V2G's benefits, enabling controlled bidirectional flows that protect infrastructure and optimize delivery. However, fragmented standards, favorable regulations, government incentives and supply chain complexity continue to hinder scalable implementation. These challenges are compounded by the rise of distributed-energy-resource ecosystems that, while enhancing resilience, demand interoperability, aggregation and coordinated control. Supporting V2G at scale requires alignment and integration at the grid edge across the entire ecosystem — not just energy distributors, government bodies, grid operators, aggregators, original equipment manufacturers, tech vendors and regulators — underscoring the need for cross-sector collaboration to realize the promise of bidirectional energy systems.

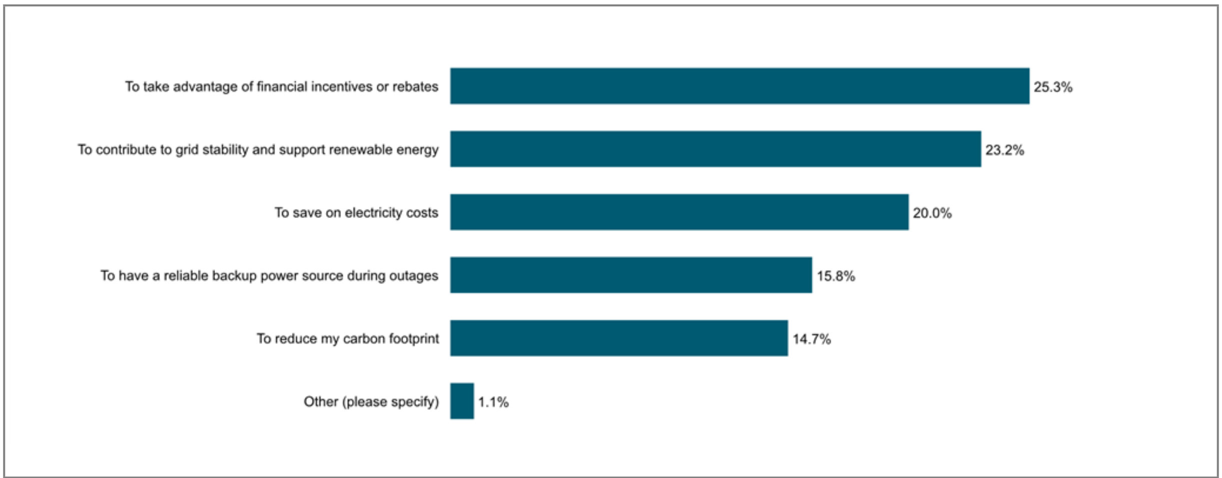
Residential grid impact overview

Residential electricity demand is undergoing a shift, with homes and high-rise apartment buildings evolving into dynamic energy hubs. Increasingly, these households are equipped with Level 2 EV chargers, typically rated at 11 kW or 22 kW, which provide significantly faster charging than standard outlets. In parallel, the adoption of photovoltaic (PV) systems and home battery energy storage systems enables households to generate, store and manage their own electricity. Together, these technologies form a growing network of distributed energy resources (DERs). When coordinated through energy management systems, DERs can operate as residential microgrids — localized systems capable of interacting with or operating independently from the main grid.

Among DERs, rooftop solar PV contributes the most power to the residential grid, often generating surplus electricity during daylight hours that can be exported back to the grid. Home batteries, while essential for load shifting and backup, do not generate power and have limited discharge duration. V2G offers promising flexibility and capacity, but remains in the early deployment phase. Yet, momentum is building: According to 451 Research's Voice of the Enterprise data, automotive organizations see V2G as a technology that will deliver near-term value within their connected-vehicle and IoT strategies. This reflects growing readiness among EV OEMs and tech vendors, even as energy distributors, grid operations, and regulators lag due to interoperability, policy and grid maturity gaps. These disparities risk slowing the pace of DER integration and highlight the need for coordinated cross-sector innovation.

End-user interest is also rising: Our data shows that over 80% of EV and hybrid vehicle owners express interest in enabling V2G at home. The top motivations include financial incentives or rebates (25%), contributing to grid stability and supporting renewable energy (23%), and reducing electricity costs (20%) (Figure 1). This signals a strong consumer pull that could accelerate adoption — if ecosystem barriers are addressed.

Figure 1: Primary reasons for using V2G technology with EVs



Source: 451 Research's VoCUL: Endpoints & IoT, Mobility – Connected Hybrid & Electric Cars 2024 (population representative).
Q. What would be your primary reason for using V2G technology with your electric vehicle?
Base: Respondents whose primary vehicle is electric/plug-in hybrid (n=95).
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The sentient grid is the next step. By combining real-time IoT data, AI and two-way communication, it transforms static infrastructure into an intelligent, self-optimizing system.

Residential microgrids become active grid participants — balancing loads, enabling dynamic pricing, and accelerating the shift to a resilient, low-carbon and sustainable energy future.

Barriers to residential grid readiness for EV charging

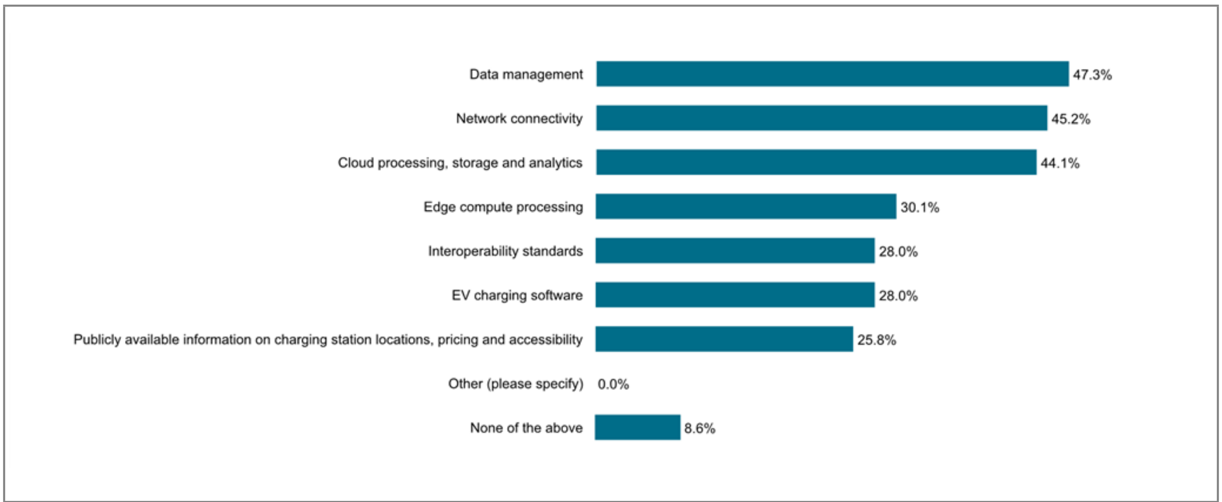
The key challenge lies in ensuring that local grids can accommodate this new energy demand without compromising stability, efficiency or equity. By adding DERs, the grid has evolved from a unidirectional into a bidirectional system during the last decade, but the ongoing additions of new devices and assets are adding complexity to managing loads at the grid edge. This requires not only physical infrastructure upgrades but also digital transformation — enabling interoperability, aggregation and coordinated control across a growing network of residential microgrids and grid-interactive technologies. Below are the most pressing barriers that must be addressed to support this transition effectively:

- **Aging infrastructure in legacy neighborhoods:** Old electrical infrastructure often lacks the capacity or flexibility to support modern energy demands, including EV charging. This is especially true in brownfield developments — previously built areas where infrastructure may be outdated, undersized or degraded. Older underground cables may even still have paper insulation, which could ignite with the power demand of electric vehicle charging infrastructure (EVCI). These zones often require more extensive upgrades to accommodate EV adoption, making them critical targets for modernization efforts. Upgrading these networks requires significant capital investment and long-term planning.
- **Transformer and feeder capacity:** Most residential transformers were not designed to handle the sustained high loads introduced by Level 2 EV chargers. When multiple homes in a neighborhood charge EVs simultaneously, transformers can overheat, leading to reduced lifespan, service interruptions or even failures. Similarly, feeder lines may require upsizing to accommodate the aggregated demand.
- **Voltage regulation challenges:** High concentrations of EV chargers can cause voltage drops or fluctuations, especially at the end of distribution lines. These variations can affect power quality and damage sensitive household electronics. Utilities must invest in voltage regulation equipment and advanced monitoring systems to maintain stability.
- **Panel and wiring upgrades in homes:** Installing Level 2 chargers often necessitates upgrades to a home's electrical panel and internal wiring. This can be costly and complex, especially in older buildings. These upgrades are a barrier to adoption and must be considered in policy and incentive design.
- **Grid connection delays and costly workarounds:** Charge point operators (CPOs) face delays in grid connections due to slow permitting and regulatory processes. To bypass grid constraints, some deploy battery-integrated charging stations, but these high-cost solutions often lack a viable business case in low-EV-density areas.
- **Regulatory and policy gaps:** While some regions are advancing EV-friendly regulations, implementation remains inconsistent. For example, Switzerland's "right to charge" law and the EU's Energy Performance of Buildings Directive are steps forward, but enforcement and retrofitting challenges persist. In addition, several global regulatory frameworks are shaping the future of residential EV charging:
    - **United States:** The Energy Department's vehicle grid integration strategy outlines a national framework emphasizing interoperability, cybersecurity and customer-centric design.
    - **United Kingdom:** Smart charging regulations now require all new home chargers to support off-peak charging and remote access, aligning with grid flexibility goals.
    - **European Union**: The Action Plan for Grids, the Grid Package and the upcoming Electrification Action Plan (expected Q1 2026) reflect growing policy momentum. The EU has acknowledged grid connection delays as a key bottleneck in its automotive strategy — an issue that has slowed EV charging deployment across the region.

- **Interoperability issues:** The absence of standardized communication protocols at the low-voltage level hinders integration with grid systems and energy management platforms. This limits visibility and coordination across the distribution network and grid edge, where effective DER integration depends on interoperability and consistent data exchange — capabilities that are still not widely implemented.
- **Data access and forecasting gaps:** Utilities, municipalities and CPOs often lack access to granular EV charging data due to regulatory silos and inconsistent data sharing frameworks. This limits their ability to forecast demand accurately, plan grid upgrades and deploy services like V2G or dynamic pricing. Without transparent real-time data, grid operators are forced to rely on outdated assumptions, increasing the risk of under- or over-investment in residential infrastructure.

According to 451 Research's Voice of the Enterprise data, automotive organizations identify data management (47%), network connectivity (45%), cloud processing (44%) and interoperability (28%) as foundational to the success of EV charging infrastructure. These components are not just technical enablers — they are strategic levers for scaling DERs and unlocking grid flexibility. (Figure 2)

Figure 2: Fundamental components for EV charging infrastructure



Source: 451 Research's Voice of the Enterprise: Internet of Things, The OT Perspective, Technology Decisions 2024
Q. Which of the following components, if any, are fundamental to the success of your EV charging infrastructure? Please select all that apply.
Base: Automotive respondents (n=93).
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Trends in residential EVCI

Electric vehicle charging infrastructure is evolving from a passive load into a dynamic grid asset. In residential and urban contexts, emerging technologies and deployment models are reshaping how EV charging interacts with the power system. Key trends are included in Figure 3.

Figure 3: Maturity and grid impact of key residential EVCI trends

Trend	Maturity status	Grid impact
Bidirectional charging (V2G)	Early stage/PoC	V2G is being tested in pilot programs across Europe, the US and Asia, but widespread deployment is limited by regulatory, technical and commercial

		readiness. Enables EVs to discharge electricity back to the grid, supporting peak shaving and frequency regulation. Requires advanced control systems.
Ultra-fast home chargers (upper limit of Level 2 chargers 22 kW)	Growing adoption	Increasingly available in residential markets, especially in new builds and high-end homes, but grid readiness varies. Reduces charging time, but increases instantaneous demand, potentially overloading local transformers and feeders.
Wireless charging	Emerging	Still in early commercial stages, with limited residential deployment due to lack of standardization and cost. Offers convenience, but lower efficiency increases cumulative grid demand.
Battery swapping	Emerging	Mostly used in fleet mobility-as-a-service applications (e.g., China and India). Decouples charging from grid demand, reducing peak load clustering. Requires standardization and logistics coordination.
Renewables and storage integration	Moderate adoption	PV and home battery pairing with EV chargers is growing, but coordination with grid services is still evolving. Reduces grid dependency and enables grid services like voltage support and peak shaving when coordinated.
Smart charging and grid-aware behavior	Widespread adoption	Time-of-use pricing and smart charging mandates are already in place in several countries (e.g., UK, Netherlands), and many utilities offer incentives or require smart chargers. Flattens demand curves and reduces peak loads through time-of-use pricing and grid-responsive systems.
Grid-conscious retrofits of fuel stations	Growing adoption/PoC	These are being piloted in grid-constrained urban areas, often with public-private partnerships, but are not yet mainstream. Enable fast charging in grid-constrained areas using battery-buffered systems and solar canopies.
Smart buildings as Grid Nodes	Moderate adoption	Increasingly common in new developments and retrofits, especially where EMS platforms are integrated. However, full grid interactivity is still limited to advanced projects. Dynamically adjust EV charging based on grid signals, supporting demand response and grid balancing.

Source: S&P Global Market Intelligence 451 Research.
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To manage the EV charging energy demand effectively, a coordinated multi-stakeholder strategy is essential — one that includes utilities, distribution system operators (DSOs), policymakers, OEMs, CPOs, technology companies, building developers and consumers.

Figure 4: Actionable insight for scaling EVCI deployment and grid readiness

Stakeholder	Actionable insight	Real-world use case
Charge point operators	Deploy EMS-integrated smart chargers and participate in V2G pilots. Enable demand-side flexibility and grid services.	Enel X partnered with utilities in California to deploy smart chargers that respond to grid signals and participate in demand-response programs. SCALE project brings together 29 partners — including CPOs, DSOs, OEMs and cities — to deploy and test interoperable smart charging and V2G/V2X solutions across multiple European cities.
Technology vendors	Develop integrated EMS/BMS platforms and energy management ecosystems that support open communication standards.	Siemens AG's Total Integrated Power framework supports integration of EV charging with building energy systems and grid infrastructure during design phase, and its Xcelerator portfolio enables real-time load management and predictive maintenance. Schneider Electric SE's EVlink Smart Wallbox and EcoStruxure platform enable smart charging that responds to time-of-use tariffs and integrates with solar, storage and home automation systems.
Energy distributors	Integrate EV load profiles into	UK Power Networks uses EV adoption forecasts and smart meter

and distribution system operators	grid planning and invest in predictive infrastructure upgrades.	data to dynamically update hosting capacity maps and prioritize grid upgrades. In Europe, DSOs piloting AI-based forecasting, real-time grid monitoring and regulatory alignment — such as through the ETIP SNET CIRED 2025 forum — are advancing predictive EV integration in countries like Austria, Italy and Greece.
Policymakers and regulators	Mandate EV-ready building codes and incentivize smart charging adoption.	The California Green Building Standards Code (CALGreen) requires new residential buildings to be EV-capable, with conduit and panel capacity for future EV supply equipment (EVSE) installation. Utilities like PG&E Corp. and Southern California Edison offer rebates for smart charger installations. The EU's Energy Performance of Buildings Directive (EPBD) requires new or renovated residential buildings with over three parking spaces to pre-cable 50% for EV charging and include at least one smart charger, with many countries offering grants or tax incentives.
Automotive OEMs	Equip vehicles with V2G capabilities and co-develop cybersecurity protocols.	Nissan Motor Co. Ltd.'s LEAF model supports V2G and has been used in pilot programs in Denmark and Japan to provide grid services. Volkswagen AG is rolling out bidirectional charging capabilities in its ID. series, with V2G pilots underway in Germany.
EVSE manufacturers (OEMs of charging equipment)	Design grid-interactive, secure and interoperable charging hardware.	Alfen offers OCPP-compliant chargers with dynamic load balancing and solar/storage integration. Eaton's "Home as a Grid" concept enables circuit-level control and demand response.
Building developers and property managers	Design for shared charging infrastructure and plan for electrical upgrades.	Greystar integrated shared EVSEs and upgraded electrical panels in new multiunit developments across Europe to meet tenant demand. In the NL, developers of multiunit dwellings are implementing shared EV charging hubs in line with the EU's EPBD, using smart load balancing and pre-cabling to reduce retrofit costs and support equitable access.
Training institutions and industry alliances	Launch certification programs for EVSE installation, EMS/BMS integration, and cybersecurity.	In the US, the Interstate Renewable Energy Council offers certified training for EVSE installers and EMS technicians. In Europe, DEKRA launched the world's first cybersecurity certification program for EVSE, based on international standards like ETSI EN 303 645 and IEC 62443.
Governments and nongovernment organizations	Deploy modular and mobile charging in underserved areas to ensure equity.	EVmatch and local governments deployed mobile charging units in rural Colorado to serve low-income and remote communities. Germany's NOW GmbH (National Organisation Hydrogen and Fuel Cell Technology) co-funded mobile EV charging pilots in underserved rural areas as part of its Clean Mobility program, supporting equitable access to charging infrastructure.
Consumers	Adopt smart chargers and participate in demand-response programs.	OhmConnect users in California receive incentives for shifting EV charging to off-peak hours via smart charger integration. In the Netherlands, Jedlix partners with EV manufacturers and grid operators to reward users for smart charging. EV owners receive financial incentives for charging during periods of high renewable energy availability or low grid demand, helping balance the grid and reduce emissions.

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