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Systems-based approach to public electric vehicle supply equipment expansion: An international policy analysis

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1 Introduction

The adoption of electric vehicles (EVs) is widely acknowledged as a key strategy for reducing fossil fuel dependence and decarbonising passenger transport. However, the rollout of adequate EV Supply Equipment (EVSE) remains a decisive factor in enabling this transition, with range anxiety continuing to hinder uptake (Mastoi et al., 2022). Despite efforts from public and private organisations, deployment has been slow and fragmented. Policy incoherence, limited resources, and conflicting priorities in local government mobility agendas have been highlighted as major obstacles (Tilly et al., 2025). Scaling EVSE requires addressing multiple interdependent factors, yet few studies adopt a holistic perspective. This research addresses this gap by examining EVSE expansion through a systems lens, focusing on the interconnections between policy, power networks, and consumer behaviour.

EVSE growth is influenced by market and technological dynamics (Helmus et al., 2022). Advances in batteries and faster charging may reduce the number of chargers needed (Madaram et al., 2024), while network constraints limit siting options and reduce accessibility (Ahmad et al., 2022). At the same time, low EV operating costs and low-cost charging can induce more driving, potentially increasing congestion and infrastructure strain (Orsi, 2021). Particularly, urban EV users include commuters, taxis, fleets, and car-sharing operators, each with diverse charging requirements (Visaria et al., 2022). Therefore, a robust public charging network is essential for equity and accessibility (Perera, Hewage, & Sadiq, 2020). Policymakers must manage these trade-offs by designing policy mixes that encourage adoption while avoiding inefficiencies and ensuring long-term sustainability (Liu et al., 2023).

The expansion of EVSE is further constrained by the market ceiling that exists without regulatory intervention (Fang et al., 2020) and the difficulty planners face in forecasting long-term demand (Qadir et al., 2024; Müller et al., 2025). Traditional policy measures have proven inadequate for achieving climate mitigation targets (Heidrich et al., 2017), highlighting the need for more coordinated and adaptive governance. Accelerating EVSE rollout is therefore critical not only to meet rising demand but also in reducing range anxiety, improving accessibility, and tackling spatial inequities in infrastructure provision (Carlton & Sultana, 2024; Manousakis et al., 2023). To ensure effectiveness, demand forecasting must be closely integrated with infrastructure rollout to capture feedback loops between usage and supply. Transitioning from fragmented, ad hoc deployment to systematic, forward-looking planning can enhance network efficiency while supporting social equity (Caulfield et al., 2022; Liu et al., 2025).

Low EV uptake in early diffusion phases deters private investment, creating a fixed-point problem that slows EVSE development (Shi et al., 2021). Rollout is time- and cost-intensive, with location-specific challenges requiring careful alignment with user needs (LaMonaca & Ryan, 2022). Public organisations have taken the lead in driving EVSE expansion to meet environmental goals (Shi et al., 2020), but face regulatory complexity across jurisdictions (Fang et al., 2020). Site identification, permitting, and questions of ownership and operation remain major hurdles, exposing councils to financial and strategic risks (Qadir et al., 2024). Governance and ownership models, including public-private partnerships and private-led approaches, remain underexplored in terms of costs, accessibility, and equity impacts (Bitencourt et al., 2023; Pardo-Bosch et al., 2021). A systems-based perspective is therefore

essential, recognising EVSE not as a patchwork of stations but as an integrated part of energy and transport systems. The interplay between EV adoption, grid capacity, mobility patterns, and consumer behaviour creates feedback loops that influence demand (Kaufmann et al., 2021). Technological improvements may alter travel habits and investment priorities, while regional differences shape adaptation needs. Understanding these dynamics is crucial for avoiding unintended consequences, building resilient networks, and ensuring coordinated policy interventions. By adopting this holistic perspective, this study provides insights for policymakers, planners, and utilities to align EVSE rollout with broader mobility and energy objectives.

2 Methodology

The data were collected using advanced Google search functions, allowing the study to specifically target yet broadly cover EV policies at different government levels in Australia, Canada, the US, the UK, and Germany. The selection of these countries was driven by their varying degrees of EV adoption, the absence of adequate public charging infrastructure, and the diversity in their approaches to EVSE expansion, providing a rich context for exploring rollout strategies. The policy documents were located by employing a search query in the following format: “keyword” site: (government domain) filetype: (type of file)”. The data collection was conducted during the first two weeks of August 2024. The gathered policies were recorded as (name of city, region, or country), (year of publication), (title), (keyword). This enabled the elimination of duplicates afterward due to search string overlaps. The remaining policies were screened for initial categorisation into policy type (e.g., strategy, action plan), scope (e.g. public, private EVSE) and version. Draft versions and outdated policies were not considered. In total, 108 policy documents were considered for this analysis.

This study employs thematic analysis to examine qualitative data extracted from EVSE policies, involving the identification and interpretation of patterns within the dataset (Xu & Zammit, 2020). In the coding phase, concise keywords were assigned to data segments, transforming complex textual data into a more accessible theoretical framework. Keywords considered relevant for the scope of this study emerged throughout the screening and coding phase and include terms such as location, type, and ownership. The subsequent step involved organising codes into coherent groups to identify overarching patterns and relationships. Subcategories (e.g., public-private partnerships, community engagement) were identified throughout the coding process and facilitated analysis. This research uses a description-focused coding strategy. NVivo software was used for coding and analysis.

3 Main findings

The rapid uptake of household and public EVSE places increasing strain on power networks, particularly during peak demand periods when simultaneous charging occurs. Without managed charging or incentives for off-peak use, utilities risk higher costs from grid augmentation. Strategies such as dynamic load management, smart charging, and daytime incentives could reduce system stress while enhancing security. Coupling EV adoption with rooftop solar, batteries, and smart chargers further optimises supply and demand. Early collaboration with utilities is essential to assess grid capacity, while streamlined permitting processes and transparent data sharing between councils and energy providers improve deployment timelines. Ultimately, the coordinated adoption of smart charging, V2G, and renewable integration transforms EVSE from a source of network risk into an asset that strengthens grid flexibility, reduces costs, and supports long-term decarbonisation goals.

Robust data collection and transparent sharing underpin effective EVSE planning, operations, and equity outcomes. Monitoring device- and network-level energy use enables better decisions on investment, policy evaluation, pricing, and resource allocation, while helping utilities and users align charging with system and cost benefits. Data should cover usage patterns, delivered energy, real-time station status, pricing, and operational performance, while protecting personal information through anonymisation and clear privacy disclosures.

Accessible and standardised datasets help identify charging gaps, optimise site placement, and monitor long-term trends. Partnerships with private EVSE operators can reduce public data management burdens while still providing essential insights. Comprehensive EVSE data governance helps authorities track adoption, optimise investment, ensure user satisfaction, and build resilient charging networks that meet both energy and transport system objectives.

Public awareness and education are critical for scaling EVSE use, ensuring equitable access, and addressing knowledge gaps. Municipalities often adopt a mix of strategies, from public events and partnerships to targeted outreach via signage, online platforms, and local organisations. Accessibility tools such as real-time maps showing location, charger type, cost, and availability enhance user confidence, while asset databases support future planning. Simplified guides, brochures, and retrofit pathways provide practical assistance to site hosts and contractors, reducing barriers to deployment. Councils also work with landowners to identify priority sites and highlight funding opportunities, while innovative programs such as EV home-charger rentals lower retrofit costs and expand access for renters. National initiatives and knowledge hubs further ensure consistent best practices across jurisdictions, supporting coordinated procurement and planning. Collectively, these approaches build trust, reduce uncertainty, and create more inclusive EVSE networks.

Local authorities can adopt various delivery models to deploy EVSE, balancing financial sustainability, user needs, and market growth.

Table 1: EVSE delivery models

Delivery model	Description	Benefits	Risks	Examples
Public sector (own-and-operate)	Council funds, installs, and manages chargers with full control over tariffs and revenue.	Full control; flexibility; avoids disputes.	High costs; ongoing maintenance; risk of underuse or obsolescence; long payback.	Low-demand or high-cost areas (Ceredigion, UK, 2022)
Concession model	Council provides enabling works; private CPOs invest, operate, and share profits.	Lower upfront costs; shared risks; private expertise; scalable.	Reduced council returns; liability disputes; costs recovered from users.	Council car parks, rural sites (Horsham, UK, 2020)
Private independent model	Private investors fund, install, and operate chargers, often leasing space.	No public investment; lowest council risk; minimal oversight.	Limited council control or revenue; focus on profitable sites only.	Hotels, retail, motorways (Cumberland, AU, 2023)

A mixed-model approach allows councils to balance commercially attractive sites with less viable residential or rural areas, expanding equitable coverage and ensuring flexibility as technology evolves. To mitigate risks, contracts should include protective measures like performance bonds or guarantees against operator exit. Emerging models such as “Charging as a Service” and community-led initiatives further diversify opportunities. Ultimately, no single model fits all contexts; instead, experimentation and partnerships across multiple delivery approaches allow councils to expand coverage sustainably, adapt to changing technology, and build resilience in a rapidly evolving EVSE market.

Selecting optimal EVSE locations requires integrating technical, social, and environmental factors to maximise access, equity, and long-term scalability. Considerations include land use compatibility, proximity to transport hubs, traffic and parking patterns, and the protection of sensitive areas such as wetlands, floodplains, or heritage zones. Grid capacity and constructability are critical, alongside opportunities for renewable integration and futureproofing for higher charging speeds. Key site types include public residential areas, workplaces, destinations, and transport hubs, each serving distinct user needs and enhancing convenience, modal integration, or incidental charging. Geographic information systems (GIS)

are widely recommended to support data-driven analysis, identify gaps, and guide planning. Equitable distribution is vital, particularly in multi-unit dwellings and high-demand urban areas where private charging is limited. By strategically siting chargers near amenities, workplaces, or community hubs, municipalities can stimulate adoption, support local economies, and reduce range anxiety.

Different EVSE types serve varied charging needs, and an appropriate mix of slow, fast, rapid, and ultra-rapid chargers is essential for meeting user expectations while optimising infrastructure investment.

Table 2: EVSE types

Charging types	Descriptions	Benefits	Examples
Slow	Typically, 3-6 kW; used for overnight or long-duration charging (6-12 hours), e.g., residential or workplace parking.	Ideal for overnight or workplace charging; low-cost and flexible deployment.	Residential areas, private parking lots, public workplace lots (Bracknell Forest Council, UK, 2022; Halifax Regional Municipality, CA, 2021)
Fast	Rated at 7-22 kW; AC charging. Recharges a 40kW battery in 1-6 hours.	Convenient for topping up while parked; lower cost than rapid chargers; easy to deploy.	Supermarkets, gyms, shopping centres, hotels, transport hubs (UK Government, 2023; Bracknell Forest Council, UK, 2022)
Rapid	AC (43 kW) or DC (50-150 kW); charges EVs to 80% in 20-60 minutes. Designed for short dwell times and quick turnaround.	Fast charging for high-traffic locations; attracts users through quick turnaround. High commercial viability.	Motorway services, major routes, rapid charging hubs (Ceredigion County Council, UK, 2022; Devon County Council, UK, 2024)
Ultra-rapid	DC chargers providing 100kW+ power; charges EVs in 20-40 minutes (or as fast as 3-5 minutes for a day's driving).	Enables fast, long-range travel; mimics ICE refuelling; preferred by users (76% of all charging sessions).	Corridor travel hubs, urban clusters, and forecourts near food/drink outlets (City of Vancouver, CA, 2016; City of York Council, UK, 2023)

Emerging innovations include lamp post retrofits, in-road charging, battery swapping, and V2G systems, all of which could transform infrastructure efficiency and resilience. Selecting appropriate charger types depends on site feasibility, power supply, dwell time, and user demand. A diversified charging mix, supported by innovative technologies, not only improves accessibility and convenience but also reduces the total infrastructure required while future-proofing EVSE systems.

Financially sustainable and user-friendly charging fee structures are essential for efficient EVSE operation. The three most common schemes are time-based pricing, which discourages overstaying and optimises turnover; energy-based pricing, which ensures fairness across vehicle models; and hybrid models, which combine both to balance equity and efficiency. Data-driven fee structures can also align with local policy goals, such as supporting retail turnover or incentivising off-peak charging. Transparency is crucial, as unclear pricing undermines user confidence and grid management benefits. Experience shows that time-of-use (TOU) rates are particularly effective in shifting charging to off-peak hours, with pilot projects demonstrating up to 85% user compliance. Payment accessibility is another priority, with widespread acceptance of contactless cards, mobile apps, and digital wallets ensuring inclusivity. Emerging innovations, such as vehicle-recognition billing, aim to streamline transactions further. Well-designed fee and payment systems thus balance financial sustainability, user convenience, and grid optimisation, fostering trust in public charging networks and supporting wider EV adoption.

4 Discussion

EVSE expansion requires public organisations to carefully plan and deploy varied charger types across multiple locations and ownership models. This endeavour is highly complex, as the lack of development in one aspect, such as limited grid capacity, can render other components of the system, such as EVSE development, infeasible. For example, it has recently been highlighted that 50-80% of potential EV charging sites have limited or no grid connections (Evison, 2025). Therefore, coordination between chargepoint developers and the grid operators is necessary to ensure stability and efficiency (Bitencourt et al., 2023). Achieving this requires effective resource and information flow between key stakeholders. Here, public sector involvement remains crucial for orchestrating collaboration efforts and continuously assessing consumer preferences to sustain EV adoption and prevent overinvestment in infrastructure misaligned with future needs.

Feedback loops are an important indicator of system dynamics and can be either positive (more EV users through expanded public EVSE) or negative (less use due to unavailability of chargers and high prices). Charging behaviour can inform key stakeholders, creating feedback loops that guide decisions and help tailor EVSE deployment to local conditions, even with limited system data. However, some system behaviours are hardly possible to predict and demonstrate the required flexibility and adaptability by public organisations responsible for the EVSE rollout. Hence, it is necessary to implement flexible EVSE that can adapt to future technology changes and consumer preferences and leave room for scaling EVSE to meet evolving demand as EV adoption grows (Wu et al., 2024).

Meeting EV charging needs can be approached through destination charging, public fast charging stations, and workplace charging options, catering to diverse user preferences (Funke et al., 2019). Choosing the right mix for public EVSE is key given that chargers positively impact EV ownership (Burra et al., 2024). The same applies to EVSE for micromobility, like e-bikes, which can support a more sustainable transport system by encouraging micromobility use and shifting travel away from private cars (Corti et al., 2024). While this study focuses on light-duty passenger vehicles and associated EVSE, future research could extend its scope to include heavy-duty EVs and micro-mobility solutions. These vehicle classes have their specific infrastructure needs which are likely to have an impact on planning and deployment. In addition, the study does not explore the implementation challenges faced by utilities, private investors and EV users. Incorporating diverse stakeholder perspectives through interviews or participatory approaches would refine policy recommendations and support the EVSE rollout.

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