Barriers and Opportunities to Energy Sharing Between Vehicles and Buildings During an Emergency, and Vehicles and Grids at Other Times

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Disclaimer

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The cover photo was generated by ChatGPT

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Abbreviations

Abbreviation	Full Term	Explanation
AC	Alternating Current	An electric current that periodically reverses direction; the standard form of electricity supplied by power grids.
BC	British Columbia	A province in Canada.
CCS	Combined Charging System	A fast-charging standard for electric vehicles that supports both AC and DC charging.
DC	Direct Current	An electric current that flows in one direction; used in batteries and many electronic devices.
DERs	Distributed Energy Resources	Small-scale, decentralized energy sources such as solar panels, batteries, and EVs that can supply electricity locally.
DSO	Distribution System Operator	An entity responsible for managing and operating the electricity distribution network.
EV	Electric Vehicle	A vehicle powered fully or partially by electricity stored in batteries.
FCEV	Fuel Cell Electric Vehicle	An EV powered by hydrogen fuel cells that generate electricity through an electrochemical reaction.
GHG	Greenhouse Gas	Gases such as carbon dioxide (CO_2) and methane that trap heat in the atmosphere, contributing to climate change.
ICE	Internal Combustion Engine	A conventional engine that burns fossil fuels (e.g., gasoline, diesel) to produce power.
PEV	Plug-in Electric Vehicle	A broad category of EVs that can be charged from an external power source, including battery EVs and hybrid EVs.
SOC	State of Charge	The level of charge in a battery, usually expressed as a percentage of total capacity.
TOU	Time-of-Use	An electricity pricing scheme where rates vary depending on the time of day to reflect demand patterns.
UK	United Kingdom	
US	United States	
V2B	Vehicle-to-Building	A bidirectional charging concept where EVs supply power to buildings.
V2G	Vehicle-to-Grid	A system where EVs exchange electricity with the grid, supporting load balancing and grid services.

V2H	Vehicle-to-Home	The use of EVs to provide backup or supplemental power to a household.
V2L	Vehicle-to-Load	The ability of EVs to power appliances or equipment directly.
V2X	Vehicle-to-Everything	A general term for bidirectional energy and communication flows between EVs and various systems (grid, buildings, devices).
VPPs	Virtual Power Plants	Aggregated networks of distributed energy resources coordinated to function like a single power plant for grid services.

Executive Summary

The increasing adoption of electric vehicles (EVs) and the urgent need to decarbonize both the transportation and building sectors have given rise to innovative solutions that maximize energy efficiency, resilience, and sustainability. One such innovation is vehicle-to-everything (V2X) technology, which allows energy to flow in both directions between EVs, the electric power grid, and buildings. In this context, vehicle-to-building (V2B) and vehicle-to-grid (V2G) systems are gaining attention as tools that can transform EVs into mobile energy storage assets capable of supporting both local energy needs and broader grid services.

This project, conducted in partnership with BC Housing through the UBC Sustainability Scholars Program, investigates the barriers and opportunities associated with energy sharing between EVs and buildings during emergencies, and EVs and the grid during normal operations. BC Housing's commitment to sustainability, climate resilience, and energy equity provides a strong foundation for exploring how these technologies could be integrated into future residential housing developments across British Columbia (BC). The research combined a comprehensive literature review, a jurisdictional and policy scan, and interviews with experts from utilities, academia, government, and technology sectors to ensure robust and practical insights.

Key Findings

- *Opportunities in BC:* V2X can enhance resilience by providing backup power during emergencies, reduce operational costs through demand management, and support climate goals by increasing the use of BC's clean electricity. Community-scale applications could strengthen equity by extending benefits to underserved populations.
- *Barriers in BC:* Implementation is constrained by high upfront costs, limited availability of V2X-ready EVs and chargers, lack of interoperability standards, regulatory uncertainty, and risks of unequal access for low-income and multi-unit housing residents.
- *Expert insights:* Stakeholders emphasized the importance of aligning utilities and housing providers, starting with small-scale pilots, and ensuring equity so vulnerable communities benefit from innovation.
- *Jurisdictional lessons:* Global pilots provide models for BC.
  - Japan has advanced V2H/V2B as part of disaster resilience planning, showing how V2X can strengthen community hubs.
  - Denmark and the UK have demonstrated V2G for grid services through utility–equipment manufacturer partnerships, highlighting the importance of interoperability and supportive tariffs.

- California has integrated V2X into climate and electrification strategies, backed by funding and regulatory support, which illustrates how policy certainty accelerates adoption.

➢ *Implications for BC:* V2X technologies align closely with provincial goals for clean energy, resilience, and affordable housing. By integrating V2X into climate and energy strategies, BC can reduce dependence on fossil fuels, improve preparedness for outages, and foster a more equitable energy transition.

Recommendations for BC

To enable large-scale V2X adoption, coordinated provincial action is required:

- Develop a provincial V2X roadmap that links clean transportation, building decarbonization, and emergency preparedness.
- Update building codes and permitting to require V2X-ready capacity in new multi-unit and community developments.
- Expand CleanBC and utility rebate programs to cover bidirectional chargers, with higher incentives for social housing and resilience hubs.
- Establish regulatory clarity on EVs as distributed energy resources, including standards for interconnection, aggregator participation, and compensation.
- Fund pilot and demonstration projects to generate local data on emissions benefits, battery performance, and community resilience impacts.

Recommendations for BC Housing

As a leading provider of affordable housing, BC Housing can accelerate adoption and demonstrate benefits by:

- Launching pilot projects in multi-unit residential buildings and community facilities to test V2B and V2G applications.
- Collaborating with utilities (BC Hydro, FortisBC) to design supportive tariffs, cost-sharing models, and resilience-focused programs.
- Integrating V2X-readiness into BC Housing’s design guidelines, including wiring, panel capacity, and charging infrastructure in new builds and retrofits.
- Prioritizing equity by targeting pilots in affordable housing, Indigenous communities, and underserved regions.
- Building awareness and capacity among tenants, building operators, and staff to support successful adoption and long-term management.

V2X offers BC and BC Housing a compelling opportunity to advance resilience, affordability, and sustainability. By acting early, through supportive provincial frameworks and targeted pilots in housing, BC Housing can lead in demonstrating how V2X technologies strengthen community preparedness, reduce costs, and ensure equitable participation in BC’s clean energy transition.

This executive summary provides a concise overview of the research process, key findings, and strategic insights. The full report provides a more in-depth analysis of each dimension explored in the project.

Introduction

British Columbia (BC) is at the forefront of a transformative shift in its energy landscape, spurred by growing environmental concerns, technological advancements, and policy imperatives. This transformation is marked by the increasing shift toward electric-powered transportation and the proliferation of renewable energy systems, particularly solar photovoltaics (CleanBC, 2019; BC Hydro, 2023). As the province aims to reach stringent climate objectives and foster a low-carbon economy, there is a growing emphasis on integrating decentralized, smart, and resilient energy solutions across all sectors.

The rapid rise in electric vehicle (EV) adoption, driven by both consumer demand and government incentives, has introduced a new dynamic into the energy system. EVs are no longer viewed solely as transportation assets but are increasingly recognized as distributed energy resources (DERs) with the potential to store and supply electricity (IEA, 2022). This dual functionality presents an opportunity to rethink how buildings and vehicles interact with the power grid, creating synergies that enhance overall system efficiency and resilience.

One promising innovation in this space is Vehicle-to-Everything (V2X) technology, a broad concept that encompasses vehicle-to-grid (V2G), vehicle-to-building (V2B), and other modes of bi-directional energy exchange. These technologies enable EVs to discharge stored energy to various endpoints, including homes, commercial buildings, and the wider electrical grid (Mwasilu et al., 2014; Liu et al., 2018). Through intelligent energy management systems and bidirectional charging infrastructure, V2X can help balance energy generation and consumption, optimize renewable energy usage, and provide backup power in times of disruption, and many other grid services, such as peak demand reduction.

Background

To situate the project, this section provides background on the evolving role of EVs, the concept of V2X, its benefits, why it is relevant for BC Housing, and the project objectives.

The Evolving Role of Electric Vehicles in Energy Systems

EVs are no longer just a greener substitute for traditional internal combustion engine (ICE) vehicles; they are becoming integral components of a smarter, more flexible energy system. Globally, EV adoption is accelerating, and in 2023, over 14 million new EVs were sold, marking a 35% growth compared to the year before (IEA, 2024). This rapid growth presents both opportunities and challenges for grid operators, utilities, housing providers, and policymakers.

One of the most transformative opportunities lies in V2X technologies, which enable EVs can both consume electricity from the grid and feed energy back into buildings, other vehicles, or the grid itself. These bidirectional energy exchanges position EVs as mobile energy storage units, effectively functioning as DERs. With proper integration, EVs can support grid stability, reduce peak demand, and improve resilience in emergencies (Cano et al., 2020).

V2X: Vehicle-to-Everything Energy Sharing

V2X is a suite of emerging technologies that enable bidirectional energy flow between EVs and external systems such as the electric grid, buildings, homes, and individual loads, as shown in Figure 1. By unlocking the energy storage potential of EV batteries, V2X offers innovative pathways for grid support, energy resilience, and sustainable electrification.

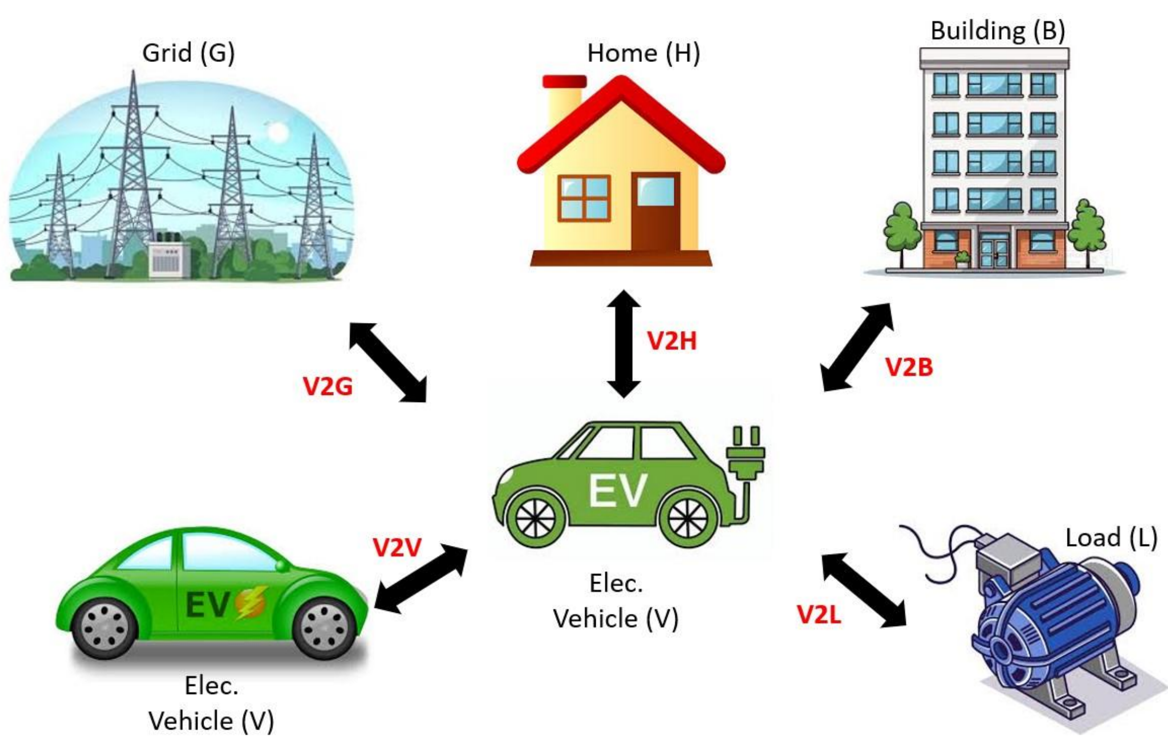

Figure 1: V2X energy sharing

- *Vehicle-to-Grid (V2G)*

V2G technology permits EVs to feed electricity back into the grid, effectively transforming them into DERs. Aggregated fleets of EVs are capable of delivering various services to the grid, including frequency regulation, peak shaving, load balancing, voltage support, and demand response (Noel et al., 2019; Claude et al., 2020). These functions help utilities reduce dependence on fossil-fuel-based peak plants, defer costly grid infrastructure upgrades, and enhance the integration of renewable energy (Kalsoom et al., 2023).

- *Vehicle-to-Building (V2B) and Vehicle-to-Home (V2H)*

V2B and V2H technologies facilitate the discharge of EV battery power directly into building or home loads. These functions are particularly valuable during grid outages, extreme weather events, or peak demand periods. V2B is increasingly recognized for its role in enhancing energy resilience and supporting critical infrastructure such as healthcare centers or emergency shelters (Gough et al., 2021; Zhou & Cao, 2020). On a smaller scale, V2H has gained traction in countries like Japan, where households frequently face natural disasters and power disruptions.

In residential or commercial settings, V2B and V2H systems can be merged with on-site renewable generation, such as rooftop solar and battery storage, to form a flexible, self-sustaining energy ecosystem. These systems can optimize local energy usage, reduce grid dependency, and improve overall energy autonomy.

- *Vehicle-to-Load (V2L)*

With V2L, EVs can directly power standalone devices or equipment, without connecting to a building or grid. This functionality is ideal for mobile, off-grid, or emergency situations, such as providing electricity for construction site equipment or supporting disaster relief operations in areas without grid access.

Implementing V2X technologies requires:

- Bidirectional chargers: Hardware that can both charge and discharge energy from EVs.
- Communication Protocols: Standards guaranteed seamless interoperability between vehicles, chargers, and energy systems (Appendix A) (Cano et al., 2020).
- Smart energy management systems: Software platforms that coordinate energy flow based on real-time signals, user preferences, and energy pricing.

Benefits of V2X Integration

The integration of V2X technologies offers substantial technical, economic, social, and environmental benefits as shown in Figure 2. These advantages extend beyond individual EV owners to include utilities, housing providers, and broader energy systems, particularly as jurisdictions aim to decarbonize electricity grids, improve resilience, and manage infrastructure costs.

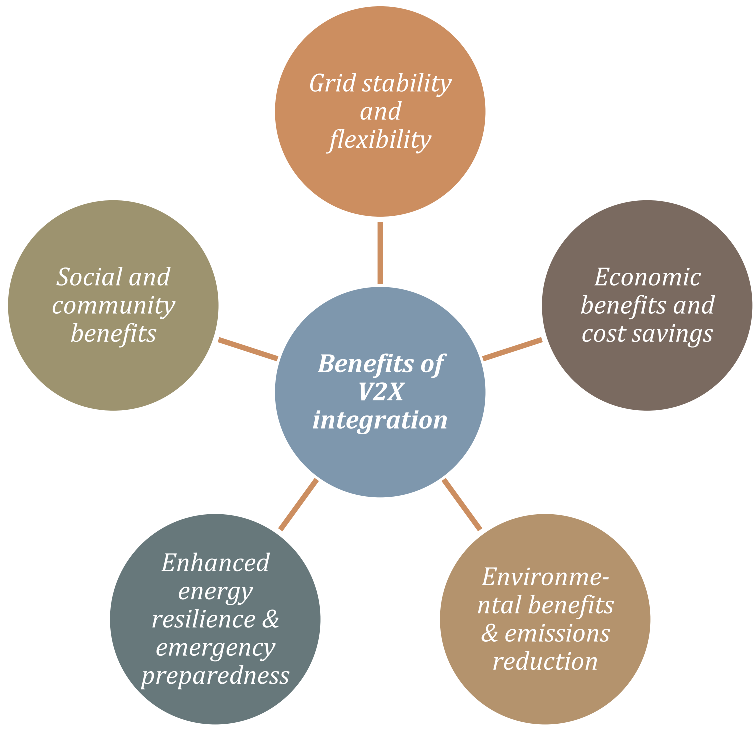

Figure 2: Benefits of V2X integration

- *Grid stability and flexibility*

One primary benefit of integrating V2X technology is its potential to enhance grid stability and flexibility. By enabling bidirectional power flow, EVs can serve as decentralized energy storage units, mitigating the variability associated with fluctuating renewable energy sources such as solar and wind. EVs can store surplus energy generated during times of low demand and discharge energy during peak demand, supporting frequency regulation, load balancing, and voltage control (Lopes et al., 2011; Cano et al., 2021). This capability is particularly vital in systems with high renewable energy penetration where traditional grid assets may be insufficient to manage fluctuations effectively (Bai et al., 2022).

- *Economic benefits and cost savings*

V2X technologies offer cost-saving opportunities for utilities and consumers alike. For grid operators, V2X enables demand response, peak shaving, and grid support without the need for extensive investments in new infrastructure (Noel et al., 2019; IRENA, 2019). Consumers, especially fleet operators or residents in multi-unit residential buildings, can take advantage of energy arbitrage by charging when prices are low and discharging when prices are high, generating revenue or reducing electricity bills (Peterson et al., 2013). For institutions like BC Housing, V2X offers a mechanism to manage electricity demand charges and support long-term cost savings in energy-efficient building operations.

- *Environmental benefits and emissions reduction*

V2X supports decarbonization by enhancing the embedding of renewable energy into the electrical grid. By facilitating local storage of solar or wind energy and enabling its strategic discharge during carbon-intensive periods, V2X can significantly reduce reliance on fossil fuel-based peak power plants and lower greenhouse gas (GHG) emissions (Liu et al., 2018; Baars et al., 2021). This is notably impactful in regions like BC, where a strong clean electricity mix can be better leveraged for building and mobility emissions reduction through V2X integration (IRENA, 2020).

- *Enhanced energy resilience and emergency preparedness*

V2X enhances resilience by providing mobile, flexible power sources during grid outages. V2H and V2B technologies allow EVs to supply electricity to homes or critical facilities during emergencies such as wildfires, storms, or earthquakes (Sovacool et al., 2022; Nissan, 2021). This is especially valuable in remote or underserved areas, or for vulnerable populations dependent on reliable electricity for medical or essential needs.

- *Social and community benefits*

V2X presents opportunities to foster energy equity and community resilience. Community-based V2X hubs can support shared mobility, energy access, and localized backup power, especially for multi-family buildings or lower-income households (Brown et al., 2022). V2X also enables community participation in the energy transition by democratizing grid services through vehicles, increasing public awareness, and building trust in renewable energy and smart grid technologies (Schmalfuß et al., 2018). Additionally, the deployment of V2X infrastructure may generate new job opportunities in clean technology manufacturing, installation, and system management.

Why V2X Matters to BC Housing?

BC Housing plays a key role in supporting the development, maintenance, and operation of affordable housing across the province. With a strong commitment to sustainability, climate resilience, and social equity, the organization is well-positioned to be a leader in integrating innovative energy solutions into residential communities (BC Housing, 2022).

The potential benefits of V2X technologies align closely with BC Housing's mandate and values:

- ✓ *Improved resilience:* By enabling EVs to act as auxiliary power during electrical interruptions, V2X can provide essential energy access for vulnerable populations, particularly during extreme weather events or emergencies (DOE, 2021).
- ✓ *Cost management:* V2B and V2G systems can help lower peak electricity consumption and move loads to off-peak times, lowering utility bills and operational costs in multi-unit residential buildings (Noel et al., 2019).
- ✓ *Emission reductions:* V2X supports broader decarbonization goals through efficient utilization of clean electricity and minimizing dependence on backup diesel generators (IEA, 2022).
- ✓ *Energy equity:* Access to V2X-enabled infrastructure in affordable housing can democratize the benefits of smart energy technologies, ensuring low-income residents remain included in the energy transition (Sovacool et al., 2022).

By exploring V2X applications in its portfolio, BC Housing has an opportunity to lead by example, pilot cutting-edge technologies, and help shape best practices for sustainable housing in BC and beyond.

Project Rationale and Scope

This project seeks to evaluate the challenges and opportunities of implementing V2B and V2G technologies in BC. The overarching goal is to understand how two-way energy exchange between EVs, buildings, and the grid can support a more resilient, efficient, and low-carbon built environment.

Key objectives of the project include:

- ➢ Reviewing the current state of V2B and V2G technologies, including technical capabilities, market readiness, and pilot deployments in other jurisdictions.
- ➢ Identifying regulatory, economic, and technical barriers to implementation in BC.
- ➢ Conducting expert interviews to understand the current policy and technical environment.
- ➢ Identifying opportunities and providing actionable recommendations to support strategic planning, future pilot projects, and long-term investment in V2B and V2G-enabled infrastructure.

The methodology combines an extensive review of the literature (including academic and grey sources), environmental scans of policy frameworks and case studies, and expert interviews. The insights derived from this research are intended to support provincial efforts to advance sustainable, resilient, and equitable energy systems.

Methodology

This study adopted a mixed-methods research design to investigate the implementation challenges and opportunities of V2G and V2B integration within BC, as shown in Figure 3. The use of multiple sources and analytical approaches enabled a more comprehensive understanding of the technical, policy, and socio-economic dimensions of V2G and V2B deployment in BC.

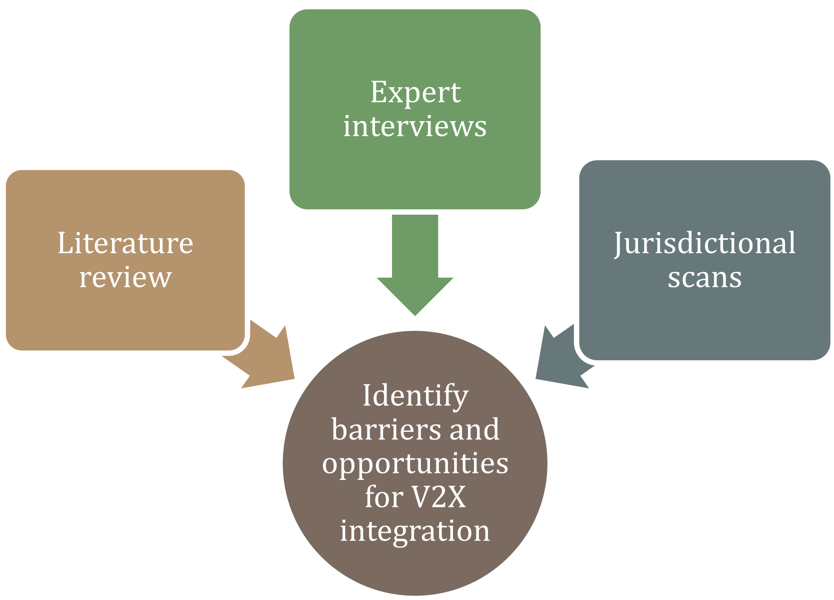

Figure 3: Research approach of the study

Literature Review

A structured review of the literature formed the foundation of the research. More than 70 documents, including peer-reviewed journal articles, industry white papers, technical standards, utility reports, and government policy documents, were reviewed and categorized across different thematic areas such as technical design and infrastructure requirements, cost-benefit analyses and business models, grid and building integration strategies, policy, regulatory, and market enablers, and social and environmental consequences.

Each source was assessed for relevance, credibility, and geographic applicability to the BC context. The review enabled the identification of key enabling technologies (e.g., bidirectional chargers, energy management systems), use-case typologies (e.g., resilience, cost savings), and outstanding knowledge gaps.

Jurisdictional Scan

A comparative scan of different jurisdictions was conducted to identify how other regions are approaching the adoption of V2X technologies. Jurisdictions were selected based on criteria such as policy leadership (e.g., California, Netherlands), technology pilots (e.g., Japan, UK), and climate and grid similarity to BC (e.g., Quebec).

For each jurisdiction, the factors such as regulatory frameworks supporting V2G and V2B participation, incentive programs for EV users, utilities, and housing providers, demonstration and pilot projects involving multi-unit residential settings, lessons learned, and implementation barriers were examined. Data sources included government portals, regulatory filings, utility documentation, and project evaluation reports.

Expert Interviews

To complement the literature review and validate emerging insights, semi-structured interviews were carried out with diverse stakeholders, such as academics specializing in smart grids and EV-grid integration, utility representatives with experience in DER and demand-side management programs, government and regulatory officials involved in clean transportation and building decarbonization policy, and non-profit and industry actors engaged in pilot projects or V2X advocacy.

A total of 14 interviews were completed between May and August 2025. Participants were selected based on subject-matter expertise, and interviews followed a consistent protocol while allowing for adaptive follow-up questions. Thematic coding of interview transcripts was conducted to extract common perspectives, innovative practices, and region-specific considerations.

Synthesis and Triangulation

Insights from the three methodological components were synthesized through triangulation, enabling validation and cross-verification. This approach enhanced the rigor of the study by ensuring that literature findings were grounded in real-world experience, expert perspectives informed the relevance of international models, and jurisdictional scan results were contextualized for local application. The final recommendations were developed based on converging evidence.

Findings

This section includes the detailed findings of the literature review, jurisdictional scans, and expert interviews.

Barriers to V2X Adoption

While V2X technologies hold strong potential, several challenges hinder their widespread adoption. These barriers fall into five categories: technical, economic, policy and regulatory, environmental, and social.

Technical Barriers

- *Lack of availability and accessibility of infrastructure*

One of the foremost technical barriers to V2X implementation is the limited availability and accessibility of essential infrastructure. For EVs to participate in V2G or V2B services, widespread deployment of reliable, bidirectional charging infrastructure is necessary. However, many regions still face a shortage of public charging stations, especially those equipped for bidirectional power flow. This scarcity contributes to range anxiety, the concern that EV drivers may not find a charging point when needed, which discourages EV ownership and, by extension, participation in V2X programs (IEA, 2023; Zhang et al., 2022).

Beyond EV charging, the broader technical ecosystem needed for V2X, such as vehicle aggregators, energy management systems, and smart bidirectional chargers, remains in the early stages of development and deployment. Many jurisdictions lack access to certified, interoperable equipment that is critical for enabling two-way energy flows (Kalsoom et al., 2023; Cano et al., 2020). Furthermore, integration strategies that align these technologies with grid operations are still evolving, which limits the scalability of V2X applications. As a result, the limited availability and accessibility of both hardware and system-level infrastructure remain a significant hurdle to the growth of V2X energy sharing models (Zhou & Cao, 2020; El Idrissi et al., 2023).

- *Compatibility and interoperability*

The absence of interoperability and standardization in EV charging infrastructure continues to be a major technical hurdle for the broad adoption of V2X technologies. EV drivers often experience issues with charger compatibility across different charging locations, often resulting in limited access, inconvenient charging experiences, or even complete incompatibility between specific EV models and certain charging hardware (Zhang et al., 2022). These limitations diminish the user experience and restrict mobility options, especially in areas where station coverage is already sparse.

Regional and national disparities in charging regulations, communication protocols, and hardware standards further exacerbate this issue. Without harmonized standards, it is difficult for policymakers, utilities, and manufacturers to align efforts toward large-scale V2X deployment (Kalsoom et al., 2023). This lack of alignment not only impedes rapid infrastructure rollout but also threatens the feasibility of advanced applications like bidirectional energy exchange, demand response, and grid services.

Efforts are underway to address this barrier. Standards, which enable secure, bidirectional communication between EVs and charging stations, with the Combined Charging System (CCS), offering compatibility for both alternating current (AC) and direct current (DC) charging, represent promising steps forward (Cano et al., 2020). However, adoption remains inconsistent across manufacturers and regions, with varying degrees of functionality and compatibility. To fully unlock the potential of V2G and V2B technologies, urgent efforts are needed to enforce interoperability standards across the entire EV ecosystem, from vehicle hardware to grid-connected infrastructure.

- *Grid challenges*

The increasing adoption of EVs introduces significant challenges to existing electrical grids, particularly in terms of load management, infrastructure resilience, and local distribution capacity. As EV penetration grows, so does the collective electricity demand from residential, commercial, and public charging stations. This surge in demand, if unmanaged, could overwhelm grid capacity, lead to local overloads, and compromise system stability (Zhang et al., 2022).

Even when employing coordinated charging strategies, high concentrations of EVs in localized areas, such as residential neighborhoods or urban centers, can exacerbate grid congestion and degrade power quality (Gough et al., 2021). These issues are particularly acute during peak hours when simultaneous charging by multiple vehicles imposes sharp increases in load. Without proactive infrastructure upgrades and intelligent demand response mechanisms, such scenarios risk increasing the frequency of outages or voltage irregularities.

Moreover, existing grid systems were not originally intended to support the bidirectional flow of electricity required by V2G and V2B systems. This mismatch complicates efforts to integrate EVs as decentralized energy assets and requires investment in smart grid technologies, transformer upgrades, and advanced communication protocols (Cano et al., 2020). Strategic planning, decentralized energy management systems, and time-of-use pricing models are essential to ensuring that EV integration enhances rather than destabilizes the grid.

- *Communications challenges*

A key challenge in smart charging systems is ensuring that all components—EVs, chargers, and the grid—can communicate effectively. Currently, these devices often use different digital "languages" (protocols), which makes connecting them smoothly difficult (Van Kriekinge et al., 2023). This can require significant engineering effort, especially for small businesses entering the market.

Even when devices use the same protocol, differences in implementation—such as variable names, measurement units, or data structures—can create additional complications. Frequent firmware updates may also require ongoing adjustments to keep devices synchronized, adding to maintenance demands. In some setups, dual communication channels may be needed, which can occasionally conflict and create further integration challenges.

Therefore, standardized communication protocols and alignment with the latest versions are essential to reduce complexity, improve interoperability, and support scalable deployment of smart charging systems.

- *Lack of user engagement*

The effectiveness of smart charging schedulers depends heavily on receiving accurate data from drivers regarding their energy requirements. While a web interface can be developed to collect these preferences, eliciting precise and consistent input from users remains a significant challenge. Many drivers are unaccustomed to actively specifying their charging needs, often expecting the process to start automatically without additional interaction. Addressing this issue requires the development of user engagement strategies that encourage drivers to provide accurate energy preferences via the web interface, thereby enhancing the scheduler's performance and reliability (Van Kriekinge et al., 2023).

- *Lack of vehicle data available at the charger*

In the current landscape of AC chargers, the dominant communication protocols do not support data exchange between the charger and the EV (Van Kriekinge et al., 2023). Consequently, at the start of a charging session, essential data, including battery capacity, charging level, and maximum charging capability, remains unknown. This informational gap restricts the ability to implement optimal charging schedules. To estimate the maximum charging power, the local controller must allow the EV to charge at full power for a certain period. Furthermore, having access to the EV's capacity and charging level would enable the scheduler to better anticipate inaccuracies in driver-provided inputs by providing clearer insight into the vehicle's charging constraints. The lack of this data exchange capability thus impedes the development and deployment of more efficient and informed smart charging strategies (Van Kriekinge et al., 2023).

- *Minimum charging power to be applied*

Currently, most AC chargers have a technical limitation for charging currents (Van Kriekinge et al., 2023). However, many smart charging schedulers in the literature do not explicitly consider this operational constraint. Ignoring this limitation can lead to significant challenges in managing large fleets of chargers, especially under dynamic and diverse charging scenarios. Therefore, it is essential for smart charging scheduling algorithms to integrate such practical constraints to ensure accurate, reliable, and efficient control over the charging process.

- *Intolerance of (some) vehicles to session interruptions*

A further challenge arises when the smart charging scheduler opts to pause a charging session for reasons such as prioritizing another EV or waiting for solar photovoltaic generation to increase (Van Kriekinge et al., 2023). The difficulty is that certain EVs or chargers cannot seamlessly resume charging after such interruptions. To mitigate this issue, specialized solutions have been developed to enable the reliable resumption of charging sessions following interruptions. These mechanisms are critical to maintaining flexibility and reliability in charging management, allowing systems to respond effectively to dynamic conditions within the charging infrastructure (Van Kriekinge et al., 2023).

- *Phase imbalances*

Smart charging schedulers typically operate using power-based values that align with forecasts of energy supply and demand (Van Kriekinge et al., 2023). However, in practice, chargers function by controlling current setpoints and may be configured as either single-phase or three-phase systems. It is therefore critical to account for phase imbalances during the optimization process to avoid overloading any individual phase, particularly when chargers share a phase with the building's existing electrical load. To address this challenge, additional constraints must be integrated into the smart charging algorithms, guaranteeing the secure, reliable, and smooth functioning of the charging infrastructure while managing the complexities associated with current setpoints and potential phase imbalances.

- *Complexity of charging*

Implementing intelligent charging strategies often requires sophisticated equipment capable of managing both charging rate and duration (Deilami et al., 2011; Yilmaz and Krein, 2013). This introduces significant design considerations involving programming, software integration, data transmission, optimization algorithms, and real-time monitoring of electricity market prices. Such complexities manifest on both the EV and grid sides of the system.

The complexity intensifies further when bidirectional chargers are employed, enabling power flow in both directions. Integrating bidirectional converters along with advanced control strategies and optimization algorithms to regulate battery charging and discharging adds another layer of intricacy (Morstyn et al., 2018; Han et al., 2015). In these scenarios, the charging rate is dynamic, continuously adjusted based on optimization outcomes. This dynamic control demands high communication bandwidth and rapid control response times, making battery management a highly complex task (Morstyn et al., 2018).

- *Complexity of power electronic interfaces*

The smart charging and discharging process requires a power electronics interface to connect the EV to the grid. This interface is relatively simple when operating solely in charging mode, typically involving a unidirectional converter, a diode bridge, and unidirectional power flow (Yilmaz and Krein, 2013). However, complexity significantly increases when both charging and discharging modes are active. It requires advanced electronic switches and control mechanisms that can safely manage power both ways. These components add cost and complexity to bidirectional chargers but are what make V2X possible. (Yilmaz and Krein, 2013).

- *Requirement of control and digital communication*

Effective communication is fundamental to implementing smart EV charging and discharging strategies, necessitating advanced communication infrastructure connecting EVs, chargers, aggregators, and the power grid (Vukadinovic et al., 2020). Standards and specifications provided by key institutions, such as the IEEE (IEEE, 2018), the Society of Automotive Engineers (SAE), and the Open Charge Alliance's Open Charge Point Protocol (OCPP) (Open Charge Alliance, 2021), form the foundation for interoperable communication.

The communication complexity increases significantly compared to uncoordinated charging due to the need to support bidirectional power flow enabled by V2G technologies (Lopes et al., 2011). This bidirectional interaction requires advanced control algorithms capable of managing dynamic power flows and ensuring grid stability. Furthermore, the lack of complete interoperability and standardized communication protocols across diverse charging infrastructures hinders seamless integration and scaling of smart charging systems.

- *The necessity of collecting and storing data*

Effective management of smart charging systems hinges on the continuous collection and storage of extensive data sets. Critical information, such as charging sessions, user preferences, vehicle state-of-charge, grid conditions, and energy pricing, must be recorded accurately to enable real-time decision-making and long-term analysis (Wang et al., 2019; Gharba et al., 2021). Data storage facilitates historical trend analysis, performance evaluation, and predictive modeling, which are essential for optimizing charging schedules, forecasting demand, and enhancing grid stability (Sauter and Kessel, 2020).

Moreover, data retention supports compliance with regulatory requirements, cybersecurity measures, and auditing processes (Xie et al., 2022). However, the increasing volume and variety of data introduce challenges related to data management infrastructure, privacy protection, and ensuring interoperability across multiple stakeholders (Reddy and Kumar, 2021). Developing robust, secure, and scalable data collection and storage frameworks is therefore vital to ensure the effective implementation and operation of smart charging ecosystems.

- *Cybersecurity and data privacy risks*

Integrating intelligent EV charging solutions into electrical grids introduces significant cybersecurity and data privacy risks. Privacy concerns stem from the collection of user data, including charging behaviors and personally identifiable information, that must be protected from unauthorized access (Amin et al., 2013; Liu et al., 2020). Cybersecurity threats encompass the potential for malicious actors to manipulate charging data, disrupt operations, or gain unauthorized control over smart charging infrastructure (Chaudhary et al., 2021). Such vulnerabilities can compromise grid stability by altering charging patterns, potentially leading to widespread energy disruptions (Gupta et al., 2019). Standards such as IEEE 1609 provide security frameworks designed to protect these systems from such threats (IEEE, 2016).

Insecure communication protocols and software vulnerabilities exacerbate these risks, underscoring the need for robust security protocols, including data encryption, access controls, routine software updates, and continuous monitoring (Yan et al., 2019; Wu et al., 2022). Additionally, compliance with privacy regulations and user education programs is vital to safeguarding user data and ensuring trust in smart charging systems (Kshetri, 2017).

- *Potential battery degradation*

EV batteries naturally lose capacity over time due to two main processes:

  - Calendar aging – degradation that occurs simply with time, influenced by storage conditions and state of charge.
  - Cycling aging – degradation caused by charging and discharging, influenced by depth of discharge, power rates, and operational stress (Dubarry et al., 2012; Keil & Jossen, 2016).

Excessive charging or discharging—especially frequent deep discharges or high-power charging—can accelerate wear, shortening the battery's overall lifespan (Birkl et al., 2017). Standard uncoordinated charging is usually gentle on batteries, while smart charging or V2G operations may increase stress by using higher power levels (up to ~7 kW) during peak periods (Zhang et al., 2018; Liu et al., 2020).

Even though smart charging strategies can benefit the grid, they may slightly increase battery cycling and associated wear. However, research shows that intelligently managed V2G operations generally cause minimal extra degradation (Guo et al., 2018; Neubauer & Pesaran, 2011). Still, consumer confidence is limited due to the lack of long-term real-world data and standardized warranties for V2G impacts (Liu et al., 2020).

Properly managed charging can balance grid benefits with battery longevity. Emerging battery technologies may reduce degradation risks further, but additional research and development are needed for widespread adoption.

- *Situations with limited charging time*

In coordinated charging and discharging operations, limited charging time can impose two primary constraints on achieving the desired state of charge (SOC) in EVs. The first constraint occurs when increasing charging power to meet SOC targets causes the total power demand on the distribution bus to exceed its limits. This surge can create peak loads that negatively affect the power grid, transformer capacity, and voltage stability (Mwasilu et al., 2014; Wang et al., 2019). The second constraint arises when charging power is deliberately optimized to remain within transformer and grid capacity limits, which may prevent EVs from reaching their desired SOC levels within the available time. This limitation can lead to user dissatisfaction, as the residual SOC may be insufficient for longer trips (Han et al., 2015).

These challenges highlight the inherent trade-offs in smart charging strategies, underscoring the need for careful optimization and coordination to balance grid constraints with user requirements (Li et al., 2020).

Potential Reforms for BC

To address technical challenges, BC Hydro and FortisBC could require the adoption of international communication standards (e.g., ISO 15118 and OCPP, see Appendix A) in new interconnection approvals. This would improve interoperability across chargers, vehicles, and aggregators. Pilot programs supported by the province could also test vehicle and charger interoperability under BC conditions, reducing uncertainty for future large-scale deployment.

Economic Barriers

- *High capital costs of bidirectional chargers and infrastructure*

One of the primary deterrents to V2X deployment is the substantial upfront investment required for bidirectional chargers and associated infrastructure. Although prices are gradually declining, these systems remain prohibitively expensive without subsidies or incentives (Van Kriekinge et al., 2021). The complexity and costs escalate further when incorporating advanced power electronics, communication protocols, and optimization systems necessary for smart charging and discharging functionalities (Yilmaz and Krein, 2013).

- *Uncertainty around long-term financial returns*

The uncertainty regarding long-term economic benefits deters investment. While "value stacking" strategies, combining benefits such as demand charge reduction, backup power, and ancillary grid services, can improve financial viability, such opportunities heavily depend on regulatory frameworks and market accessibility (Lopes et al., 2011). In residential and multi-unit residential buildings, the cost-benefit balance is particularly challenging without targeted funding, as housing providers face added burdens from maintenance, equipment certification, and fluctuating utility tariffs (Zhou et al., 2020).

- *Grid network upgrades*

The existing power grid infrastructure often requires significant upgrades to accommodate the additional load and bidirectional power flows associated with EV fleets (Mwasilu et al., 2014; Wang et al., 2019). These upgrades include investment in power electronics, sensors, smart meters, and data communication systems (Yilmaz and Krein, 2013; Vukadinovic et al., 2020). The high costs of upgrading transformers, cables, and control systems pose a considerable barrier to scalability (Lopes et al., 2011).

- *Charging infrastructure upgrades*

Establishing a widespread and effective charging network demands significant financial resources for installation, operation, and maintenance (Neaimeh et al., 2017). While unidirectional chargers require relatively less investment, the shift to bidirectional charging notably increases costs and complexity, necessitating advanced hardware, communication, and control systems (Van Kriekinge et al., 2021). Rapid technological advances risk rendering existing infrastructure obsolete, especially in budget-constrained communities, creating potential stranded investments (Neaimeh et al., 2017; Zhou et al., 2020).

- *Additional operational and maintenance costs*

Beyond initial capital expenditure, ongoing operational costs, including labor, materials, and maintenance, add to the economic burden (Wang et al., 2019). Lifecycle costs, including end-of-life management, recycling, and replacements, must be factored into economic assessments to avoid underestimating total expenditures (Liu et al., 2020).

- *Battery degradation and replacement costs*

Frequent cycling from V2X charging and discharging can speed up battery wear, shortening battery life and increasing replacement costs (He et al., 2019; Zhang et al., 2018). Degraded batteries reduce vehicle range and efficiency, leading to higher operational costs and user concerns regarding financial viability (Guo et al., 2018).

- *Differences in tariff schemes*

Network tariffs vary by region and time, significantly impacting the economics of EV charging (Sioshansi, 2012). Time-of-Use and critical peak rate structures incentivize off-peak charging but can paradoxically cause new peak loads when many EVs charge simultaneously (Li et al., 2020). Capacity-based tariffs, which charge based on contracted demand, can be a barrier to fast-charging infrastructure essential for broader EV adoption (Farhangi, 2010).

Potential Reforms for BC

To mitigate economic barriers, CleanBC and utility rebate programs could be expanded to include bidirectional chargers, with higher incentive tiers for affordable housing and multi-unit residential buildings. Utilities could also pilot innovative tariff structures, such as resilience credits or time-varying buyback rates, to improve the business case for V2X. These measures would reduce upfront costs and create predictable value streams for early adopters.

Policy and Regulatory Barriers

- *Nascent and fragmented policy landscape*

In most regions, including Canada, there is a lack of comprehensive interconnection standards, energy export rules, and tariff structures tailored for V2X participation (Dallinger et al., 2017; Lopes et al., 2011). Many electricity pricing schemes, such as flat-rate or demand-charge tariffs, disincentivize energy export by providing little to no financial compensation to EV users for grid services (Sioshansi, 2012). This lack of supportive policies hampers market signals needed to encourage investment in V2X technologies.

- *Misalignment across regulatory domains*

The absence of coordination between building codes, transportation planning, and energy regulations further slows V2X adoption, especially in multi-unit residential buildings and metropolitan areas (Mwasilu et al., 2014; Zhou et al., 2020). The unclear role and regulatory recognition of aggregators in energy markets also restricts the scaling of V2X solutions, limiting their ability to aggregate and monetize grid services.

Early policy efforts such as BC's Zero Carbon Step Code demonstrate emerging interest, yet comprehensive regulatory frameworks are still needed to support large-scale V2X integration (BC Ministry of Energy, 2023).

- *Legal status as flexibility providers*

EVs face significant legal and administrative challenges regarding their recognition as grid flexibility providers (Lopes et al., 2011). Bidirectional EV systems must comply with regulations applicable both to energy consumers and producers, requiring formal authorization as DERs capable of providing ancillary services (Dallinger et al., 2017). The legal and regulatory status of V2G installations often remains ambiguous and needs alignment with energy storage systems to prevent regulatory inconsistencies, such as double taxation on exported energy (Sioshansi, 2012). Clarity in these legal frameworks is crucial for incentivizing investment and ensuring fair treatment of EVs in energy markets.

- *Inconsistent and inadequate regulations*

Regulatory inconsistency, both within and across regions, poses a barrier to seamless V2X adoption (Lopes et al., 2011). Grid codes vary nationally and regionally, leading to challenges for original equipment manufacturers and operators of EV fleets that operate across borders. This inconsistency complicates compliance and increases costs, potentially slowing market growth.

With growing integration of DERs, including EVs providing ancillary services like frequency regulation, enhanced synchronization between distribution and transmission operators becomes essential (Mwasilu et al., 2014). While such coordination improves operational reliability and asset utilization, it introduces additional computational, communication, and regulatory complexities that must be addressed to facilitate effective V2X integration (Dallinger et al., 2017).

Potential Reforms for BC

Policy and regulatory barriers could be addressed by updating the BC Building Code to require V2X-ready electrical capacity in new multi-unit and commercial developments, building on existing EV-readiness provisions. The BC Utilities Commission could clarify rules for EVs and aggregators to participate in demand response and ancillary service markets, ensuring compensation for exported electricity. Incorporating V2X into provincial emergency preparedness frameworks would also recognize its role as a resilience asset.

Environmental Barriers

- *Dependency on clean electricity sources*

The carbon intensity of the electrical grid plays a major role in the environmental benefits of V2X. In regions relying mainly on fossil fuels, such as coal or natural gas for electricity production, V2X-enabled energy discharges during peak demand periods may inadvertently increase carbon emissions (Cao et al., 2017; Knezović et al., 2020). Without alignment to clean and renewable energy sources, the net effect of V2X on GHG emissions may be minimal or negative.

- *Renewable energy intermittency*

The fluctuating nature of renewables such as wind and solar complicates the reliable delivery of clean electricity needed for EV charging (Gao et al., 2016; Denholm et al., 2015). When renewable energy output is low, reliance on conventional fossil-fueled generation can increase, limiting the environmental advantages of V2X strategies (Denholm et al., 2015; He et al., 2018).

- *EV battery-related environmental concerns*

Frequent cycling associated with V2X operation accelerates battery degradation, potentially reducing the functional life of EV batteries and increasing the demand for replacements (Zhang et al., 2018; Guo et al., 2018). Battery manufacturing involves the extraction of critical minerals such as lithium, cobalt, nickel, and rare earth elements, often associated with significant social and environmental impacts, such as habitat disruption, water contamination, and human rights issues (Swain, 2017; Harper et al., 2019). Furthermore, inadequate recycling infrastructure raises concerns about the end-of-life management of batteries, as inappropriate disposal methods can lead to hazardous waste and environmental contamination (Gaines et al., 2014; Harper et al., 2019). A comprehensive lifecycle approach is vital to address these sustainability challenges (Harper et al., 2019).

- *Environmental impacts of infrastructure upgrades*

The expansion of charging infrastructure and associated facilities incurs environmental costs across their lifecycle, from material extraction and manufacturing to installation and maintenance (Denholm et al., 2015; Wang et al., 2019). Rapid technological evolution can render existing infrastructure obsolete, and improper disposal of outdated equipment may further exacerbate environmental harm (Zhang et al., 2018). Proactive lifecycle management and recycling initiatives are essential to minimize the ecological footprint of infrastructure upgrades (Gao et al., 2016).

Potential Reforms for BC

To address environmental concerns, the province and utilities could fund demonstration projects that track lifecycle emissions and battery degradation under V2X operation in BC's clean electricity context. These projects would generate local data on sustainability impacts and inform policies to encourage responsible scaling. Recycling and second-life battery initiatives could also be integrated into CleanBC's circular economy strategy, reducing environmental risks over time.

Social Barriers

- *Safety*

Public perceptions around EV safety are influenced by crash tests, battery incidents, and media coverage. Battery-related safety concerns, including thermal runaway, fire hazards, and accident risks, are prominent among consumers (Sovacool et al., 2018). These concerns are exacerbated when integrating smart charging and V2X, where bi-directional flows may raise fears about system reliability and personal safety. Mitigating these risks requires robust engineering, transparent safety standards, and public awareness. Enhancing trust entails consistent communication about safety certifications, emergency response protocols, and thermal management systems (Hardman et al., 2017).

- *Resiliency and range anxiety*

Concerns over driving range remain a major obstacle to EV adoption and V2X participation. This fear, stemming from uncertainties about battery depletion, limited charging infrastructure, and unpredictable driving conditions, discourages drivers from allowing energy discharge for grid services (Noel et al., 2019). Longer charging times compared to refueling conventional vehicles also contribute to perceptions of inconvenience. V2X can amplify these fears, especially if discharging occurs without assurances of adequate reserve range. Solutions include user-controlled charging preferences, predictive range estimation, and location-aware charging service maps (Wolbertus et al., 2018).

- *Equitable access and distributive impacts*

Ensuring equitable access to V2X technologies is critical to avoid exacerbating existing disparities in energy and mobility. Low-income households face multiple barriers, including limited access to EVs, insufficient charging infrastructure in their neighborhoods, and higher sensitivity to electricity cost fluctuations. Residents of multi-unit buildings encounter additional challenges: shared or limited parking, lack of individually metered electrical connections, and inadequate grid upgrades to support bidirectional charging (Carley et al., 2021; Chen et al., 2023).

Beyond access, the distribution of V2X benefits and burdens can vary across communities. Incentive and regulatory designs, such as time-of-use pricing, demand-response programs, or emergency energy-sharing rules, may favor households with flexible schedules, home EVs, or dedicated charging infrastructure, while low-income, rental, or multi-unit building residents may participate less or not at all. During grid stress or outages, communities without V2X-enabled resources may experience prolonged disruption, whereas those with access could benefit from backup power or shared energy. Without careful consideration, these factors could reinforce existing social and economic inequities, limiting the broader societal benefits of V2X technologies.

- *Behavioral changes*

Transitioning to V2X and smart charging necessitates behavioral adaptation at both individual and institutional levels. EV owners must change routines related to charging schedules, travel planning, and participation in energy markets (Gnann et al., 2018). Utilities and local governments must reorient policies to facilitate decentralized energy interactions. Public education campaigns, peer influence, and digital platforms that promote behavioral nudges, such as gamification, have proven effective in improving participation rates (Noppers et al., 2015).

- *EV owner participation*

Active engagement from EV owners is a cornerstone of smart charging success. Yet many remain skeptical due to concerns about cost, charging time, battery wear, and privacy (Wolbertus et al., 2020). These concerns reduce willingness to engage in grid support or demand response programs. Research suggests that owner participation improves significantly when there are clear economic incentives, customizable settings, and user-friendly platforms that make participation seamless (Xu et al., 2021). Trust can be further enhanced by providing transparency on how and when the vehicle will be used for grid services.

- *Lack of awareness*

Awareness of V2X and grid services remains low, even among EV drivers and industry professionals (Sovacool et al., 2022). Many users are unaware that their vehicle could serve as a flexible grid asset or how participation could generate benefits. Addressing this gap requires multi-channel outreach strategies, combining financial incentives, real-time feedback, community demonstrations, and digital education tools. Gamification and community-based programs have also shown potential to boost understanding and engagement (Noel et al., 2020).

Potential Reforms for BC

To overcome social barriers, updates to the BC Building Code could require shared charging infrastructure and V2X-ready wiring in new multi-unit developments, while utilities could introduce equity-focused tariffs designed to include affordable housing residents. Targeted subsidies for social housing providers to install V2X infrastructure would ensure that resilience and cost savings extend to vulnerable populations. Public awareness campaigns and tenant engagement programs could also help build trust and understanding of V2X benefits.

While the preceding discussion has explored technical, economic, policy, social, and environmental challenges in detail, Table 1 summarizes the key barriers to V2X adoption in BC. This synthesis provides a foundation for understanding why reforms and targeted interventions are needed.

Table 1: Summary of key barriers to V2X in BC

Category	Barrier	BC Relevance
Technical	• Lack of standardized communication protocols (e.g., ISO 15118, OCPP 2.0.1 not widely adopted). • Limited availability of certified bidirectional EVs and chargers. • Grid integration challenges: panel upgrades, metering, and sub-metering in buildings. • Cybersecurity risks in charger–vehicle–grid communications.	Risks stranded assets, higher infrastructure costs, and potential system vulnerabilities if standards and security are not addressed.
Economic	• High upfront cost of bidirectional chargers and required electrical upgrades. • Uncertain and fragmented revenue models; value stacking not yet proven in BC. • Limited scale of pilots reduces confidence in financial returns. • Concerns over battery degradation increase uncertainty around long-term ownership costs.	Creates affordability barriers for multi-unit residential buildings (MURBs), municipalities, and low-income households; deters private investment.
Policy / Regulatory	• Building codes and permitting processes do not yet require or enable V2X-ready infrastructure. • No clear framework for aggregator participation in BCUC-regulated markets. • Regulatory lag and slow approval processes limit scaling. • Lack of clarity on roles/responsibilities between utilities, aggregators, and housing providers.	Slows pilot adoption and creates uncertainty for investors and housing providers.
Social / Equity	• Low-income households face barriers: limited EV access, higher cost sensitivity, lack of charging infrastructure in neighborhoods.	Without targeted inclusion strategies, V2X could widen energy inequities and

	• MURB residents face shared/limited parking, inadequate wiring, and insufficient grid upgrades. • Distributive impacts: resilience and cost benefits during outages/grid stress may not reach all communities. • Consumer trust concerns: vehicle warranties, data privacy, and lack of awareness.	reduce public confidence.
Environmental	• Limited real-world data on battery degradation under V2X duty cycles. • Uncertain lifecycle impacts, including manufacturing, recycling, and second-life battery use.	Creates uncertainty about sustainability benefits and slows trust in environmental claims.

Despite these challenges, V2X technologies also create significant opportunities across technical, economic, environmental, policy, and social dimensions. These opportunities are summarized in the following section.

Opportunities for V2X Adoption

V2X technologies present a wide range of opportunities that benefit EV owners, electricity providers, policymakers, and society at large. These opportunities span across technical, economic, environmental, policy, and social domains, with emerging trends accelerating their realization.

Technical Opportunities

- *Enhanced grid integration and renewable energy support*

V2X enables bidirectional power exchange and communication between EVs and the grid, enabling EVs to offer ancillary services such as peak shaving, voltage support, and frequency regulation. These capabilities improve grid reliability and support higher penetration of intermittent renewable sources like solar and wind (Liu et al., 2021; Tan et al., 2016; Denholm et al., 2020). Standardized communication protocols, such as ISO 15118, are facilitating interoperability across charging systems, EVs, and grid infrastructure (IEC, 2019; Liu et al., 2021). A global trend toward adopting CCS further enhances V2X compatibility, promoting a unified and flexible ecosystem for bidirectional charging (Element Energy, 2022).

- *Decentralized energy storage and system resilience*

V2X-equipped EVs function as mobile, distributed energy storage units, improving energy system resilience by providing localized backup power during outages and enabling demand-side flexibility (Noel et al., 2019). This is particularly beneficial for areas vulnerable to grid disruptions caused by extreme weather or other emergencies.

- *Improved system efficiency and reduced grid upgrades*

Managed V2X charging and discharging strategies can reduce grid peak demand, postpone the need for expensive infrastructure upgrades, and improve overall energy performance (Liu et al., 2021; Noel et al., 2019).

Economic Opportunities

- *Multiple revenue streams and value stacking*

V2X allows EV owners and fleet operators to generate income through participation in demand response and ancillary service markets. This concept of value stacking, offering multiple services with a single asset, is especially relevant for housing providers managing centralized fleets or shared charging in multi-unit buildings (Kristoffersen et al., 2011; Element Energy, 2022; Torregrossa et al., 2023).

In BC, V2X systems could combine several value streams. Table 2 provides example scenarios.

Table 2: Example value stacking scenarios for BC

Value stream	Scenario	EV contribution	Annual monetary value
Energy cost savings	20-EV fleet in a Vancouver multi-unit building; peak demand ~300 kW	Each EV shifts 2–3 kWh/day from peak to off-peak	$500–$1,000 per EV; $10,000–$20,000 total
Demand response and ancillary services	Participation in grid support during peak events. e.g., $0.05–$0.10/kWh for exported energy during peak events	Each EV exports 1–2 kWh during peak events	$36–$73 per EV; $730–$1,460 total for 20 EVs
Emergency backup energy	Mid-size BC Housing site with communal kitchen and elevators	2 EVs provide 10 kWh each during a 4-hour outage	$200–$500 avoided operational disruption per outage
Renewable integration	50 kW PV system on a community center paired with 5 EVs	Each EV stores 5–8 kWh/day of excess solar	$1,500–$2,000 avoided grid purchases annually

Total aggregate benefit per EV: $2,000–$4,000 annually (depending on site, fleet size, and local tariffs)

By combining these streams, building operators, fleet managers, or municipalities in BC could realize aggregate economic benefits of $2,000–$4,000 per EV annually, depending on system size, building type, and local tariffs. Tailoring value stacking strategies to BC's electricity rates, incentives, and building archetypes can make V2X deployment more financially attractive and scalable.

- *Energy cost savings and bill optimization*

V2X enables users to recharge EVs in off-peak periods and supply energy back during times of high demand, reducing electricity bills and demand charges (Liu et al., 2021; Kristoffersen et al., 2011). This dynamic pricing strategy also enhances grid efficiency.

- *Growing industry investment*

Original equipment manufacturers are increasingly integrating V2X capabilities into EVs. For example, the Ford F-150 Lightning supports V2H/V2B backup power functions, while automakers like Porsche and Tesla are actively piloting V2G functionalities (EnergyHub & RMI, 2022; IEA, 2023). These developments signal growing confidence in the commercial viability of V2X technologies.

- *Aggregators and virtual power plants (VPPs)*

Energy aggregators are emerging as critical enablers of V2X by bundling EV batteries into VPPs that can deliver grid services at scale (EnergyHub & RMI, 2022). This aggregation model enhances the system-level benefits of V2X and opens up new market opportunities.

Policy and Regulatory Opportunities

- *Alignment with clean energy and transportation goals*

V2X supports national and regional climate targets by enabling electrification, renewable integration, and distributed energy solutions. Jurisdictions such as California and the Netherlands have begun to incorporate V2X into decarbonization strategies and transport electrification roadmaps (Noel et al., 2019; Torregrossa et al., 2023).

- *Supportive regulations and utility programs*

Utilities are developing compensation mechanisms for exported V2X power and launching pilot programs to reward grid-beneficial EV behavior (BC Hydro, 2023; Liu et al., 2021). These pilots lay the groundwork for more formal participation of EVs in energy markets.

- *Government incentives and funding programs*

Financial support from governments is making V2X more accessible. Examples include Canada's Zero Emission Vehicle Infrastructure Program (ZEVIP) and California's Low Carbon Fuel Standard (LCFS), which support both infrastructure and operational costs (Natural Resources Canada, 2023; California Energy Commission, 2021). At the federal level, policies like the U.S. Inflation Reduction Act (IRA) also offer substantial backing for V2X-enabling technologies (IEA, 2023).

- *Integration with building codes and urban planning*

Municipalities can accelerate V2X adoption by incorporating V2X-readiness into new building codes and urban development plans, particularly for multi-unit dwellings and smart cities (Noel et al., 2019; BC Hydro, 2023).

Environmental Opportunities

- *Renewable energy utilization and emissions reduction*

By storing surplus renewable electricity and discharging it during peak demand, V2X reduces dependence on fossil fuel-driven peak plants and improves renewable energy utilization (Tan et al., 2016; Denholm et al., 2020; Liu et al., 2021). This contributes directly to GHG reduction goals.

- *Emergency power and fossil fuel displacement*

During power outages, V2X-capable EVs can act as low-emission backup power sources for homes and critical services, reducing dependence on diesel generators (Noel et al., 2019).

- *Reduced infrastructure-related emissions*

By avoiding or delaying major grid expansions, V2X minimizes the emissions associated with manufacturing and installing additional infrastructure (IEA, 2023; Liu et al., 2021).

Social Opportunities

- *Community empowerment and energy access*

V2X can support community-based energy systems in remote or underserved areas by enabling shared storage solutions and improving local resilience (IEA, 2023; Liu et al., 2021).

- Behavioral change and public engagement

Through programs that encourage flexible energy use, V2X fosters greater consumer awareness of electricity consumption and climate-conscious behavior (Gough et al., 2017; EnergyHub & RMI, 2022).

- *Advancing climate justice and social inclusion*

V2X programs targeted at low-income and marginalized communities can democratize access to clean energy and transportation. By providing financial savings, backup power, and mobility, V2X contributes to more equitable energy transitions (IEA, 2023; EnergyHub & RMI, 2022).

Table 3 provides a high-level synthesis of the most promising opportunities, paired with their potential benefits in the BC context.

Table 3: Summary of key opportunities for V2X in BC

Category	Opportunity	BC Potential
Technical	• Adoption of open global standards (e.g., ISO 15118, OCPP 2.0.1, IEEE/CSA) to ensure interoperability. • Growing availability of V2X-compatible EVs and chargers (e.g., Nissan Leaf, Ford F-150 Lightning). • Advances in power electronics are improving charger efficiency and reducing costs. • Improved cybersecurity frameworks tailored to V2X.	Positions BC to align with international best practices, lower costs, and avoid stranded investments while maintaining consumer trust.
Economic	• Value stacking across services (peak shaving, frequency response, backup power, arbitrage). • Business model innovation (utility aggregation, cooperative/community ownership, municipal fleet-sharing). • Scaling pilots to fleets, campuses, and housing providers. • Targeted funding, grants, and tax incentives to reduce capital barriers.	Strengthens the business case for municipalities, housing providers, and fleets while unlocking private sector investment.
Policy / Regulatory	• Integration of V2X into CleanBC programs, BC Building Code, and resilience planning. • Policy certainty to reduce risk and attract investment. • Alignment with Technical Safety BC, CSA, NRCan, and NRC to harmonize standards and support pilots. • Recognition of V2X in emergency preparedness for critical infrastructure (e.g., shelters, health facilities).	Creates an enabling environment for cross-sector adoption and ensures resilience is part of BC's policy agenda.
Social / Equity	• Embedding V2X in affordable housing, emergency shelters, and community hubs. • Publicly visible pilots (schools, fire halls, community centers) to build trust and awareness. • Early engagement of municipalities, Indigenous communities, nonprofits, and housing providers in co-developing solutions. • Subsidies and targeted programs for underserved communities.	Ensures benefits are shared broadly and supports a just transition by addressing equity and distributive justice.
Environmental	• Pairing V2X with renewable generation and community microgrids. • Enhancing GHG reduction through load shifting and renewable utilization. • Supporting the circular economy through EV battery recycling and second-life use.	Strengthens BC's climate goals while improving resilience in both urban and remote communities.

Examining how other regions are approaching V2X integration provides important lessons for BC. The following jurisdictional scan highlights global strategies, pilot projects, and regulatory approaches.

Jurisdictional Insights

The implementation of V2X technologies, including V2G, V2B, and V2H, varies significantly across jurisdictions, influenced by regional energy policies, grid infrastructure maturity, vehicle adoption rates, and regulatory frameworks. While countries like Japan and Denmark have pioneered early demonstration projects, others, including the United States and the United Kingdom, are advancing V2G through utility-led pilots, original equipment manufacturer collaborations, and evolving grid regulations.

As EV adoption accelerates globally, the capability of bidirectional charging to enhance grid stability, decrease emissions, and defer costly infrastructure upgrades becomes increasingly relevant. Based on findings from a U.S. Department of Energy study, electrification of transportation and building sectors could increase electricity consumption by as much as 38% by 2050, placing significant pressure on existing grid systems (Mai et al., 2018). In this context, V2X offers a flexible and decentralized approach to energy management, capable of supporting renewable integration and load balancing at various scales (Lund & Kempton, 2019).

Jurisdictions differ in how they are responding to this opportunity. Some have introduced supportive regulations and market incentives, while others are still addressing technical, economic, and institutional barriers. The following sections provide a comparative analysis of V2X initiatives in selected countries, highlighting the diversity of implementation pathways, challenges, and lessons learned.

United States

The United States has demonstrated strong momentum in exploring V2X capabilities, primarily through state-level pilot projects, research programs, and early-stage commercial developments. However, the absence of a unified national regulatory framework remains a critical barrier to widespread implementation (Neubauer et al., 2012; DOE, 2021).

Pilot projects and technological demonstrations

Several pioneering V2G pilot projects have emerged across the country, particularly in California. In July 2022, a five-year pilot involving eight electric school buses was launched in the San Diego Gas & Electric (SDG&E) service area, in partnership with Pacific Gas and Electric (PG&E) and Southern California Edison. The buses, connected using Nuvve’s V2G software, participated as part of the Emergency Load Reduction Program (ELRP) managed by the California Public Utilities Commission, aggregating battery capacity to support grid reliability during outages (SDG&E, 2022). Similarly, the University of California, San Diego piloted INVENT, a V2G campus initiative supported by the California Energy Commission, which installed 50 bidirectional charging stations and integrated them with its shuttle fleet (Nuvve, 2017).

Private sector engagement has been significant. Nissan's Energy Share initiative in 2018 partnered with Fermata Energy to implement V2G at Nissan North America’s Tennessee headquarters (Fermata, 2020). Fermata later received the first UL 9741 safety certification for a bidirectional EV charging system in North America, an important step toward commercial readiness (Underwriters Laboratories, 2020).

Texas has also contributed to early V2G development. Southwest Research Institute (SwRI) pioneered the first V2G aggregation system certified by the Electric Reliability Council of Texas (ERCOT), capable of autonomous grid frequency response by modulating vehicle charging (SwRI, 2014). This was initially supported through the Department of Defense’s SPIDERS program, highlighting federal interest in resilient energy infrastructure (Burns & McDonnell, 2013).

Policy developments and legislative landscape

Although state initiatives, particularly in California, have been instrumental, the national policy landscape remains fragmented. The BIDIRECTIONAL Act introduced in the U.S. Senate in 2022 aimed to establish a federal program supporting the deployment of V2G-enabled school buses. Despite its promise, the bill stalled in committee, reflecting the broader challenge of building federal consensus on V2G (U.S. Senate, 2022).

Nevertheless, electrifying school buses has gained momentum. Leading manufacturers such as Blue Bird and Lion Electric are actively showcasing the advantages of bidirectional technology for the grid. Electrification of U.S. school buses, historically consuming over $3.2 billion in diesel annually, offers substantial potential for emissions reductions and grid balancing (U.S. PIRG, 2020; Lion Electric, 2021).

Research and simulation tools

Research institutions continue to play a key role in modeling V2G deployment and evaluating its impact. Lawrence Berkeley National Laboratory designed the V2G-Sim platform, which simulates spatial-temporal driving behavior and grid interaction. Simulations indicated that controlled V2G could provide significant benefits such as peak shaving and mitigation of the “duck curve,” while incurring minimal battery degradation (Sheppard et al., 2020).

Challenges and opportunities

Despite the technical and environmental promise, several challenges remain. At Intersolar & Energy Storage North America 2025, experts highlighted the need for standardized protocols, consistent utility engagement, and more effective consumer communication. Without standardized implementation models and clear financial incentives, V2G risks remaining in the pilot phase (Intersolar NA, 2025).

California stands out as a frontrunner, with supportive electricity tariffs, grid modernization investments, and sustained funding for V2X pilots creating a conducive ecosystem. However, broader adoption across the U.S. will require harmonized policies, robust interoperability standards, and market mechanisms that reward grid services provided by EVs (Prasad et al., 2021).

Japan

Japan has positioned itself as a key innovator in V2X technologies, driven by national imperatives for energy security, disaster resilience, and carbon neutrality. While full-scale V2G deployment remains in the pilot stage, the country has made notable progress with V2H and V2B systems, particularly in the wake of the 2011 Fukushima disaster.

Pilot projects and technological demonstrations

Japan's first V2G pilot project began in November 2018 in Toyota City, Aichi Prefecture, through a collaboration between Toyota Tsusho Corporation, Chubu Electric Power Co., and V2G aggregator Nuvve Corporation. The project tested two bidirectional charging stations linked to a V2G aggregation server to examine electricity supply-demand balancing and grid impacts (Nuvve, 2018). Nissan, a global leader in EV development, has been at the forefront of Japan's V2G initiatives. The Nissan LEAF, equipped with bidirectional charging capability, has been central to numerous pilot programs, positioning the company as a key driver of V2G readiness in Japan (Nissan, 2022).

Looking ahead, Nissan has announced its intention to provide cost-effective bidirectional charging options for certain EV models starting in 2026, enabling both grid export and residential energy use (Nissan, 2023). These efforts are underpinned by a broader national goal to modernize aging electricity infrastructure; Japan has committed approximately $71.1 billion toward grid upgrades to better integrate renewable energy and support bidirectional flows (METI, 2023).

Policy developments and legislative landscape

While Japan has seen strong progress in V2H adoption, V2G remains in the testing and demonstration phase, with no fully commercialized systems to date. The legal and regulatory frameworks needed to scale V2G, particularly those concerning compensation mechanisms for exported power, grid interconnection standards, and aggregator participation, are still under development. However, Japan's disaster-resilience policies have actively supported V2B and V2H technologies, providing an enabling environment that may eventually expand to accommodate V2G (IEA, 2022).

Government and industry collaboration continues to be a key feature of Japan's V2X development. Initiatives often emerge from integrated partnerships involving utilities, automakers, and municipalities, with a focus on enhancing energy reliability in emergencies and improving the flexibility of the national grid.

Research and simulation tools

Japan's research focus has leaned more toward applied demonstration projects than simulation modeling tools like those developed in the United States. Several Japanese universities and technical institutes are exploring grid interaction modeling, battery life-cycle implications, and optimization algorithms for bidirectional energy flow. Much of this work remains proprietary or unpublished compared to the more open-access platforms seen in jurisdictions like the U.S. or Europe.

Nonetheless, Japan's robust testbed environments, often enabled through public-private partnerships, function as living laboratories for V2X integration and provide real-time data on performance, load balancing, and emergency response, especially in V2B and V2H contexts.

Challenges and opportunities

Japan's experience illustrates both the promise and complexity of V2X integration. On the one hand, strong leadership from original equipment manufacturers (e.g., Nissan), post-disaster energy policy alignment, and growing consumer interest in backup power capabilities make Japan a fertile ground for V2G. On the other hand, the lack of a mature regulatory framework for commercial V2G services and limited standardization of charging protocols pose ongoing barriers.

Nonetheless, Japan's approach, rooted in long-term infrastructure planning and disaster resilience, provides valuable insights for jurisdictions seeking to integrate V2X into broader energy and emergency management strategies. The widespread commercial deployment of V2H, and soon V2G, could position Japan as a global model for distributed energy systems that are flexible, consumer-centric, and disaster-resilient.

Denmark

Denmark has long been recognized worldwide for expertise in wind energy integration, and V2G technology is viewed as a strategic approach for balancing the intermittency of renewable generation. Through a sequence of research and demonstration projects, including Edison, Nikola, and Parker, Denmark has developed one of the most mature jurisdictional portfolios in V2G research, laying important groundwork for future commercial deployment.

Pilot projects and technological demonstrations

The foundation of Denmark's V2G journey began with the Edison Project, which ran from 2009 to 2013 on the island of Bornholm. This publicly funded initiative aimed to explore how plug-in electric vehicles (PEVs) could store excess wind energy when the grid could not absorb it and feed it back during peak demand or low wind availability. The consortium included Ørsted (formerly DONG Energy), IBM, Siemens, EURISCO, Østkraft, the Technical University of Denmark (DTU), and the Danish Energy Association. The project supported Denmark's ambitious goal to generate 50% of its electricity from wind by 2020 and served as a testbed for the necessary V2G infrastructure (Edison Project, 2013; The Guardian, 2013).

Following Edison, the Nikola Project launched in 2014 as a laboratory-based demonstration at DTU's Risø Campus. Partnering with Nuvve and Nissan, Nikola focused on validating V2G technologies and grid interactions in controlled environments. This led directly to the Parker Project (2016–2018), a more ambitious field trial that used a fleet of EVs with bidirectional chargers to test real-world applications in Copenhagen. The Parker Project's partners, DTU, Insero, Nuvve, Nissan, and the local distribution system operator Frederiksberg Forsyning, explored commercial viability and technical impacts of V2G services, including peak shaving, frequency regulation, and local grid support across various car brands (Nikola Project, 2016; Parker Project, 2018).

Policy developments and legislative landscape

While Denmark has made significant technological progress through its national research programs, regulatory and commercial frameworks for V2G services remain under development. Government subsidies for zero-emission vehicles have supported early adoption, but explicit incentives for V2G services, such as dynamic electricity tariffs or grid services compensation, are still limited (Energinet, 2020). Denmark's progressive renewable energy policies and early regulatory openness to distributed energy resources have enabled system operators and researchers to engage meaningfully in V2G experimentation. Nonetheless, pilot projects have underscored the need for legal clarity around aggregator roles, grid interconnection standards, and market access rules for mobile energy storage assets like EVs.

Research and simulation tools

Denmark's V2G research emphasizes practical, system-level demonstrations rather than simulation-only approaches. University-industry-government collaborations, particularly involving DTU, have developed hardware-in-the-loop (HIL) simulation and control testing platforms that simulate grid conditions. These environments have strengthened pilot projects' technical validity and applicability for larger-scale deployment (DTU, 2019). Data from projects like Parker have been instrumental in evaluating grid frequency regulation capabilities, revenue models for EV fleets, and interoperability among manufacturers.

Challenges and opportunities

Denmark's V2G initiatives highlight the feasibility of using flexible EV resources to balance high shares of renewable energy, supported by strong public-private partnerships. However, economic barriers such as the cost of bidirectional chargers and regulatory challenges including aggregator licensing and fair market participation remain hurdles to scaling V2G services beyond pilots. Despite these hurdles, Denmark's long-term commitment to a carbon-neutral energy system and its experience from Edison, Nikola, and Parker projects position it as an exemplary testbed with lessons applicable across Europe and globally.

United Kingdom

The United Kingdom has emerged as one of the most proactive countries in promoting V2G technology, leveraging robust government-backed initiatives and public-private partnerships. Since 2011, the UK government has implemented various programs to assist in the adoption of PEVs, positioning V2G as a key enabler of flexible and decentralized energy systems.

Pilot projects and technological demonstrations

Numerous V2G pilot projects have been launched across the UK to test the technical feasibility, consumer benefits, and grid impacts of bidirectional charging. In 2016, Nissan and Italian utility Enel initiated one of the UK's first V2G trials using 100 bidirectional chargers paired with Nissan Leaf and e-NV200 electric vans (Nissan, 2016). The project aimed to demonstrate how EVs could support grid stability by feeding stored electricity back to the network during peak periods.

EDF Energy revealed a collaboration with Nuvve Corporation in 2018 to deploy as many as 1,500 V2G chargers across its business customer sites and its own facilities, targeting 15 MW of aggregate storage capacity (EDF-Nuvve, 2018). Parallel to this, the Vehicle-to-Grid Britain (V2GB) consortium published a comprehensive report in 2019 that analyzed the potential of V2G services in decarbonizing transport and supporting the grid (V2GB, 2019).

Additionally, the University of Warwick's WMG center collaborated with Jaguar Land Rover to evaluate the long-term effects of V2G charging on battery degradation. Their two-year study revealed that, under typical driving conditions, certain V2G charging patterns could extend battery life more effectively than conventional charging strategies (Warwick, 2020).

Policy developments and legislative landscape

The UK has demonstrated strong political will in developing a regulatory framework for V2G. The UK's energy regulatory authority, the Office of Gas and Electricity Markets (OFGEM), is actively working on regulatory adjustments to enable the broader implementation of V2G. This includes addressing licensing requirements, market participation rules for aggregators, and access to balancing services markets for distributed energy assets like EVs (OFGEM, 2022).

Although V2G implementation still faces economic and technical challenges, such as the high cost and complexity of obtaining approval for bidirectional chargers above 3.5 kW, the UK benefits from a relatively mature grid connection standard for certified charging systems. The growing experience with flexible electricity tariffs, especially time-of-use and dynamic pricing, is also improving the business case for V2G.

Road to Zero strategy and Transport Decarbonisation Plan by the UK government have further underscored its long-term commitment to integrating V2G within a smart, low-carbon energy ecosystem. As part of these efforts, V2G is expected to be commercially introduced in 2025, with Nissan planning to roll out affordable V2G technology in the UK and then expand to broader European markets from 2026 onward (Nissan Europe, 2023).

Research and simulation tools

In addition to pilot projects, the UK has invested significantly in modeling and analytical studies to understand the potential of V2G at scale. Institutions such as Imperial College London, the University of Oxford, and the University of Warwick have developed simulation tools to forecast grid impacts, quantify emissions savings, and evaluate cost-benefit scenarios under different V2G deployment models. The V2GB study remains a cornerstone of this research landscape, offering scenarios for mass deployment and evaluating V2G's role in system flexibility and decarbonization.

Challenges and opportunities

Despite strong momentum, the UK's V2G market still faces structural challenges. Chief among them are the high upfront costs of V2G-capable chargers, limited availability of compatible EVs, and the complexity of integrating mobile energy assets into existing market mechanisms.

Additionally, consumer education and engagement remain crucial to encourage participation in V2G schemes.

However, the UK's established expertise in grid flexibility, smart charging, and dynamic tariffs, combined with strong regulatory foresight and public funding, positions it well for large-scale V2G rollout. Continued collaboration among automakers, utilities, regulators, and academic institutions is expected to accelerate commercial deployment over the coming years.

Germany

Germany views V2G technology as a viable tool to enhance the flexibility and resilience of its energy system, especially as the country continues to phase out nuclear power and lower its fossil fuel dependency. Given its ambitious renewable energy targets and regional imbalances in energy generation and demand, V2G is seen as a complementary mechanism to manage grid congestion and maximize the usage of variable renewable energy sources like solar and wind.

Pilot projects and technological demonstrations

One of Germany's flagships V2G pilot initiatives was carried out by The Mobility House in collaboration with Nissan and transmission system operator TenneT. In this demonstration, Nissan Leaf vehicles charged using wind energy from northern Germany and discharged energy back to the grid when demand is highest. The project deployed ten charging stations equipped with software-based smart energy redistribution controls. The findings demonstrated that electric mobility could help flexibly handle the intermittency of renewable energy sources and reduce dependence on fossil fuel peaker plants.

In another initiative in 2020, German utility E.ON partnered with gridX to develop a V2H solution. This pilot was implemented in a private household and integrated a 5.6 kWp rooftop photovoltaic system, three home batteries totaling 27 kWh, and a 40 kWh Nissan Leaf connected to a DC bidirectional charger. The goal was to optimize self-consumption of solar energy and explore the potential of EVs as household energy buffers. Although focused on V2H, the results indicated strong relevance for broader V2G applications in residential settings.

Despite these promising technical demonstrations, V2G in Germany remains in the pre-commercial stage, with no commercially available services for end consumers as of 2024.

Policy developments and legislative landscape

Germany's legal and regulatory framework for V2G is still under development. While the technical feasibility of bidirectional charging has been validated, widespread rollout is hindered by inadequate clear policy direction and standardized procedures for grid integration. The fragmented nature of the German electricity market, which includes hundreds of small and medium-sized distribution system operators (DSOs), complicates the uniform rollout of V2G across the country.

One major bottleneck is the limited progress in the national smart meter rollout. As of 2024, fewer than 10% of households are equipped with certified smart meters, which are essential for enabling dynamic tariffs, real-time load control, and participation in flexibility markets, prerequisites for V2G services. In contrast to countries like the UK or France, Germany's decentralized energy governance makes coordinated action more difficult.

Nevertheless, the need for grid services such as redispatch, the adjustment of generation to avoid congestion, has grown with the increasing penetration of renewables. V2G offers the potential to contribute to these redispatch efforts, providing distributed, flexible capacity that can be dispatched locally to relieve grid bottlenecks.

Technical and market readiness

From a technical perspective, many challenges related to communication protocols and charger functionality have already been addressed. Progress in smart charging standards and interoperability has paved the way for more complex bi-directional energy services. However, the absence of a comprehensive market design for distributed flexibility assets means that EV owners and aggregators currently have limited financial incentives to participate in V2G.

Germany is also behind in terms of certifying V2G-compatible chargers and setting up processes for market participation of aggregated EV fleets. Industry stakeholders have called for a clearer regulatory framework that supports the certification of V2G equipment, streamlines grid connection procedures, and ensures fair compensation for flexibility services.

Challenges and opportunities

Germany's high share of renewable energy and the regional imbalance between wind generation in the north and utilization centers in the south make V2G particularly attractive for improving grid reliability. The combination of growing EV adoption, household photovoltaic systems, and battery storage could offer significant benefits for both consumers and the grid, especially in suburban and rural areas.

However, V2G development is currently hindered by a lack of standardized regulation for bidirectional energy flows, slow energy system digitalization (e.g., smart meter rollout), fragmented distribution grid structure with varying DSO capabilities, and the absence of clear market participation mechanisms for V2G aggregators

Despite these barriers, several automotive original equipment manufacturers and energy companies in Germany continue to explore future business models for V2G, especially in conjunction with solar-plus-storage residential systems and fleet electrification.

The Netherlands

The Netherlands has positioned itself as a European leader in experimenting with and deploying V2G technologies. Driven by a progressive policy environment, strong public-private partnerships, and a well-developed EV infrastructure, the country has launched numerous pilot projects exploring V2G's technical, commercial, and grid-related potentials. Integration of V2X into broader smart grid and energy flexibility strategies has significantly advanced the country's deployment and understanding of bidirectional charging.

Pilot projects and technological demonstrations

One of the most prominent and large-scale V2G implementations in the Netherlands is the project at Amsterdam's Johan Cruijff ArenA (JCA). Since 2019, this initiative has connected bidirectional vehicles to an existing 3 MW battery storage system composed of 148 repurposed Nissan Leaf batteries and a 1 MW rooftop photovoltaic system. The energy management system, developed by The Mobility House, enables intelligent control of EV charging and discharging. Visitors to the stadium can opt to allow their vehicles to supply power to the stadium during events, providing a real-world demonstration of V2G capabilities in a commercial and public infrastructure setting (The Mobility House, 2019).

The cities of Arnhem and Utrecht have also emerged as hubs for V2G experimentation. Utrecht, in particular, has established a city-wide V2G ecosystem in collaboration with Hyundai, deploying IONIQ 5 vehicles capable of bidirectional charging. These projects are supported by local governments, DSOs (e.g., Stedin), and technology partners, and have focused on optimizing grid interaction, maximizing self-consumption of renewable energy, and evaluating user participation models.

In addition to battery electric vehicles, Dutch researchers have explored V2G applications for hydrogen fuel cell electric vehicles (FCEVs). Delft University of Technology conducted pioneering research beginning in 2016. Their work involved both techno-economic modeling and experimental testing. A Hyundai ix35 FCEV was adapted to provide up to 10 kW DC power without compromising its roadworthiness. Working with Accenda, the team designed a power conversion system to interface the vehicle with the grid and demonstrated its potential to provide grid services such as frequency reserves (Oldenbroek et al., 2018).

Policy developments and legislative landscape

Despite the impressive number of pilot projects, the Netherlands has not yet implemented a nationwide regulatory framework to enable the commercial scaling of V2G. While local governments and project-specific exemptions have supported pilot deployments, persistent regulatory barriers remain. These include issues around grid codes for bidirectional energy flows, the role of EVs as DERs, and financial mechanisms for aggregating and compensating flexibility services from EVs.

That said, the country's electricity system is relatively advanced in terms of digital infrastructure, and smart meters are widely deployed. This enables experimentation with dynamic pricing, demand response, and user participation in local flexibility markets. The Dutch government has also included V2G as part of its National Climate Agreement (Klimaatakkoord), indicating political support for the upcoming incorporation of the technology into the primary energy infrastructure.

Additionally, the Netherlands has actively participated in international and EU-funded research initiatives, such as the SEEV4-City project, which explored how V2G and other smart charging solutions can support cities in reducing carbon emissions and balancing local electricity networks.

Technical and market readiness

The Netherlands benefits from a well-developed EV charging infrastructure, a high density of EVs per capita, and a strong ecosystem of grid operators, energy technology companies, and research institutions. Many of the technical hurdles to V2G deployment—such as charger compatibility, communication protocols, and data management—have been addressed in pilot settings. However, moving from pilot to scale remains challenging due to a lack of standardized certification for V2G chargers and vehicles, unclear market models for aggregator participation, and grid congestion issues in some regions that limit V2G potential without major upgrades. Nevertheless, the Dutch energy transition strategy heavily emphasizes decentralization, consumer empowerment, and flexible grid management, conditions that favor future V2G expansion.

Challenges and opportunities

The Netherlands is well-positioned to lead in V2G adoption due to strong governmental and municipal support for smart mobility, dense EV penetration, and advanced public charging infrastructure, and pioneering pilot projects demonstrating technical viability and user acceptance.

Key barriers include the need for consistent national regulation, integration of V2G into balancing and ancillary services markets, and streamlined DSO engagement processes. As grid flexibility becomes increasingly essential, V2G is anticipated to have a critical role in enhancing the resilience and sustainability of the Dutch electricity system.

Australia

Australia is gradually embracing V2G technology, with notable progress in research, pilot testing, and regulatory development over the past few years. While early-stage challenges remain, particularly around regulatory harmonization, product availability, and limited EV model compatibility, Australia’s trajectory is one of increasing momentum, driven by strong academic contributions and recent advancements in national standards.

Pilot projects and technological demonstrations

Since 2020, the Realising Electric Vehicle-to-grid Services (REVS) project led by the Australian National University (ANU) has significantly propelled V2G research efforts in the country. The project investigates the technical reliability, economic viability, and grid benefits of V2G at scale (Bruce et al., 2020). As part of this work, the ANU spun off the Battery Storage and Grid Integration Program, which continues to evaluate how EVs are capable to supply grid services such as load shifting, frequency regulation, and energy arbitrage.

Australia’s first commercial V2G charger became available for purchase in 2022. However, rollout has been slow due to a fragmented regulatory environment, where each state’s power authority must certify products independently, even after federal approval. As of 2023, V2G compatibility is limited to a narrow set of vehicles, such as the Nissan Leaf and select Mitsubishi plug-in hybrids. This limitation has constrained pilot project diversity and consumer adoption.

Despite these hurdles, several demonstrations have been launched. For instance, a trial in the Australian Capital Territory (ACT) involved using V2G to support public fleet electrification and grid resilience. These demonstrations have emphasized the potential for public sector fleets to serve as early adopters, given their predictable usage patterns and centralized charging.

Policy developments and legislative landscape

A major milestone in Australia’s V2G readiness occurred in November 2024, following Standards Australia's approval of a national bidirectional charging standard. This followed several years of consultation and technical analysis. This approval cleared the path for manufacturers and charging companies to have their products registered with the Clean Energy Council, making bidirectional charging possible (Australian Government, 2024).

This standardization step is expected to accelerate charger certification and deployment, improve interoperability, and build investor and consumer confidence. However, implementation still depends on jurisdictional coordination across Australia's states and territories, where differing grid requirements and compliance processes have delayed the uniform rollout of V2G-compatible hardware.

Australia's energy market structure, which includes a high penetration of rooftop solar and a growing focus on DERs, provides fertile ground for V2G integration. Yet, regulatory clarity on how V2G can participate in frequency control ancillary services and other energy market mechanisms remains limited.

Technical and market readiness

From a technological standpoint, Australia has made significant strides with pilot systems and standards. However, the market remains constrained by a very limited number of V2G-capable EV models (primarily the Nissan Leaf), high costs and low availability of certified V2G chargers (e.g., Wallbox Quasar 1), and patchy regulatory approvals across states (e.g., only conditional approval in South Australia as of 2024).

Looking ahead, the anticipated launch of Wallbox Quasar 2 and broader EV model compatibility may ease hardware-related constraints. Meanwhile, software development and data analytics capabilities for grid integration are strong, particularly among research institutions like ANU and CSIRO, and companies engaged in DER aggregation.

Challenges and opportunities

Australia presents a promising but still maturing landscape for V2G. Key opportunities include high levels of residential solar PV and flexible DER integration strategies, public fleet electrification policies at the federal and state levels, and research excellence in grid services and storage integration.

Challenges include fragmented jurisdictional regulations delaying charger certification and deployment, limited consumer awareness and high up-front technology costs, and a lack of market access mechanisms for small-scale distributed flexibility providers.

Nevertheless, with national standards now approved and a wave of second-generation V2G hardware expected, Australia is well-positioned to enter a new phase of V2G development focused on scalability and market integration.

France

France has emerged as a leader in the commercial deployment of V2G technology in Europe, building on a foundation of pilot projects and a strong government vision for EV-grid integration.

With the introduction of consumer-facing V2G offerings and supportive regulation, France has transitioned from experimentation to implementation more rapidly than many of its peers.

Pilot projects and technological demonstrations

France began testing V2G as early as 2018, focusing on both islanded grids, such as those in overseas territories, and urban energy flexibility pilots. These early efforts were coordinated in partnership with energy companies, research institutes, and vehicle manufacturers, including EDF, Enedis, and Renault. One of the key goals was to use bidirectional EV charging to stabilize grid operations, especially in locations with high shares of intermittent renewable energy (Avere France, 2020).

For instance, the FlexMob'île project on Belle-Île-en-Mer combined EVs, solar generation, and smart charging to reduce diesel reliance. Similarly, urban pilots such as GridMotion explored how parked EVs in residential areas could provide peak shaving and load shifting.

France became the first country globally to make V2G commercially available to individual EV drivers. In October 2024, Renault Group, its mobility brand Mobilize, and the energy company The Mobility House launched a commercial V2G program centered around the new Renault 5 EV. Through this initiative, customers can use the PowerBox Verso, a bidirectional AC charging station, to charge and discharge their vehicle's battery based on dynamic energy market signals (Renault Group, 2024). This allows the vehicle to participate in demand-response and grid-balancing markets.

This rollout represents a significant technological milestone. The Renault 5 is one of the first mass-market EVs in Europe designed with factory-integrated bidirectional charging capabilities. Importantly, the system operates using AC (rather than DC) bidirectional charging, reducing equipment complexity and cost for end users. The commercial service is enabled through a tailored energy contract that allows users to sell stored electricity back to the grid.

Policy developments and legislative landscape

France's regulatory landscape is particularly favorable for V2G, due in part to proactive efforts by the national grid operator (RTE), energy regulator (CRE), and standards bodies. By 2023, the country had implemented the key legal and technical provisions necessary for bidirectional energy flow from EVs to the grid. This includes certification procedures for bidirectional chargers, clear grid interconnection rules, and market participation guidelines for distributed energy resources (RTE, 2023).

V2G technology has been formally recognized in national energy planning strategies, including the Multiannual Energy Plan (Programmation Pluriannuelle de l'Énergie- PPE), which identifies EVs as a strategic flexibility resource. Additionally, France's market design reforms under the Clean Energy Package have incorporated provisions that allow aggregators to combine flexibility from small-scale assets such as EVs, which has created a pathway for commercial V2G aggregation.

Challenges and opportunities

France's experience illustrates the importance of coordinated innovation between automakers, grid operators, and regulatory agencies. The following characteristics define France's V2G progress. Some of the opportunities are strong OEM leadership from Renault with commercial V2G-capable EVs, simplified AC-based bidirectional charging solutions, reducing cost barriers, robust regulatory support allowing EVs to participate in ancillary service markets, and national policies explicitly targeting V2G integration into grid flexibility plans.

However, challenges exist, such as currently limited to select vehicles (primarily Renault 5), consumer participation depends on clear financial incentives and awareness, and bidirectional hardware (like PowerBox Verso) is still emerging and may face early supply chain limitations.

France's success serves as a model for other jurisdictions looking to accelerate the commercialization of V2G by aligning regulatory clarity, technology readiness, and market access mechanisms.

Poland

Poland's engagement with V2G technology is still in its nascent stages, primarily led by pilot-scale testing initiatives rather than commercial or regulatory implementation. Nevertheless, the country has taken important foundational steps that signal growing interest in V2G as part of its broader e-mobility and renewable energy strategy.

Pilot projects and Pilot projects and technological demonstrations

One of the most notable milestones in Poland's V2G journey is the launch of the Solaris Charging Park in Bolechowo, inaugurated on September 29, 2022. This state-of-the-art facility, developed by Solaris Bus & Coach, is designed to test both charging and discharging operations for EVs, particularly electric buses produced by the company. The Park includes multiple types of charging infrastructure, plug-in, pantograph (top-down and bottom-up), and inductive systems, and serves as a proving ground for bidirectional charging systems under real-world conditions (Solaris, 2022).

While Solaris has not yet commercialized full V2G offerings, the Charging Park's infrastructure is equipped for bidirectional energy flow, enabling it to support future integration of energy-return capabilities into the Polish grid.

The facility also supports research and development collaboration between Solaris and energy utilities to explore how large vehicle batteries (especially from e-buses) can support frequency regulation and demand-side management services. Although these functions are not yet active at scale, the groundwork for such services is being laid.

Policy developments and legislative landscape

Poland currently lacks a dedicated regulatory framework that supports the commercial deployment of V2G technology. The absence of bidirectional grid interconnection standards, aggregator market access rules, and incentive structures limits the scalability of current projects.

However, Poland is a signatory to the European Union's Clean Energy for All Europeans Package, which encourages member states to enable DER engagement in energy and balancing markets. As such, Poland is expected to adopt enabling provisions in the coming years, especially as the EU works to harmonize regulations around EV-grid integration across the internal market (European Commission, 2022).

Moreover, the Energy Policy of Poland until 2040 (EPP2040) identifies electromobility and decentralized energy sources as strategic sectors, which could create future alignment between national energy goals and V2G implementation.

Challenges and opportunities

Poland's progress toward V2G remains largely exploratory, but early initiatives such as Solaris's Charging Park reflect growing institutional and industrial interest in the potential of EVs as grid assets.

Opportunities include industrial leadership from Solaris in testing bidirectional charging for heavy-duty EVs, integration of V2G into broader energy flexibility strategies in line with EU policies, and potential for municipal fleet electrification to drive V2G demand (especially for buses).

Nevertheless, the lack of national regulatory standards for V2G implementation, the limited number of V2G-capable vehicles currently operating in Poland, and the need for stronger coordination between energy sector regulators and transport stakeholders are some existing challenges.

Poland's progress suggests that while the country is not yet a front-runner in V2G commercialization, it is positioning itself to take advantage of bidirectional charging technologies as part of its long-term energy transition.

Canada

Canada's approach to V2G deployment remains cautious and fragmented, with activities primarily led by provincial pilot projects and academic research. Despite the country's vast clean electricity resources and high potential for grid decarbonization, V2G implementation is slowed by regulatory uncertainty, a lack of harmonized interconnection standards, and limited market signals for grid services provided by EVs.

Pilot projects and technological demonstrations

Canada's V2G landscape has been shaped mainly by demonstration projects supported by federal or provincial agencies. In Ontario, one of the earliest V2G pilots was launched by Hydro One, Plug'n Drive, and Ontario Power Generation (OPG) in partnership with Natural Resources Canada (NRCan), which used Nissan Leafs and bidirectional chargers to assess the potential for grid support services (Hydro One, 2017).

In BC, BC Hydro collaborated with researchers from the University of British Columbia (UBC) on integrating V2G with campus microgrids and renewable generation (UBC Clean Energy Research Centre, 2020). The project involved testing the feasibility of using EV batteries to smooth solar generation intermittency and reduce peak load on the campus distribution system.

The province of Québec, which has one of the cleanest electricity grids in the world thanks to hydroelectricity, has shown strong EV uptake but lags in formal V2G trials. However, Hydro-Québec is investing in smart grid upgrades and has signaled interest in leveraging EVs as flexible grid assets in future planning documents (Hydro-Québec, 2021).

Nationally, Canada's Electric Vehicle Infrastructure Demonstration (EVID) program, sponsored by NRCan, has supported research on V2G-enabling technologies, including charger interoperability and communication protocols.

Policy developments and legislative landscape

Canada lacks a federal-level regulatory framework explicitly supporting bidirectional charging, and energy policy is primarily a provincial jurisdiction. As such, there is no consistent standard or process across provinces for certifying V2G chargers, interconnecting them with the grid, or compensating services like frequency regulation or demand response from EVs.

In 2022, the Canadian Standards Association (CSA Group) began exploring standards related to EV-grid integration through its Strategic Steering Committee on Performance, Energy Efficiency and Renewables (SCOPEER) committee, which includes bidirectional charging in its scope. However, implementation remains voluntary and varies by utility.

The absence of aggregated demand response markets in most provinces also impedes V2G value stacking. Without compensation mechanisms or clear pathways for EVs to participate as DERs, private sector momentum has been limited.

Challenges and opportunities

High clean electricity penetration (especially in BC, Québec, Manitoba) makes V2G emissions benefits more marginal but supports grid flexibility goals. Also, existing university-industry collaboration (e.g., UBC, McMaster) offers a strong research base. Moreover, another opportunity is the potential integration with remote and Indigenous communities using diesel generation, where V2G could offer cost savings and emissions reductions.

However, lack of national regulatory coordination and grid interconnection standards for V2G, limited availability of certified bidirectional chargers and compatible EVs, and fragmented electricity governance across provinces hinder market development.

Canada’s V2G pathway is shaped by provincial diversity and regulatory complexity. Progress will depend on developing interoperable standards, enabling aggregation of EVs into energy markets, and aligning V2G incentives with decarbonization and grid modernization goals.

While international pilots illustrate technical feasibility, BC faces distinct challenges and opportunities. Its clean electricity grid maximizes the decarbonization potential of V2X, but barriers such as aging infrastructure in multi-unit residential buildings and regulatory uncertainty must be addressed. Lessons from Japan, Denmark, and California underscore the importance of strong policy alignment, utility engagement, and equity-focused program design — all directly relevant to BC’s context.

Cross-Cutting Patterns and Implications for BC

Cross-Cutting Patterns from Jurisdictions

The jurisdictional scan and global pilot data show that while V2X development varies widely, several clear patterns emerge:

1. Regions advancing fastest have strong policy and regulatory support.

- The UK leads in the number and diversity of pilot projects, supported by government funding, dynamic tariffs, and supportive regulation.
- Japan has prioritized V2H and V2B adoption to strengthen resilience following disasters.
- Denmark has advanced V2G services to help balance its high share of wind generation.

2. Early applications cluster around a few key services.

Data from V2GHub (2025) shows that pilot projects globally are concentrated in six service categories: time shifting, frequency response, distribution services, arbitrage, emergency backup, and reserve. Figure 4 illustrates the global distribution of pilots across these categories, while Table 4 highlights the top five contributing countries.

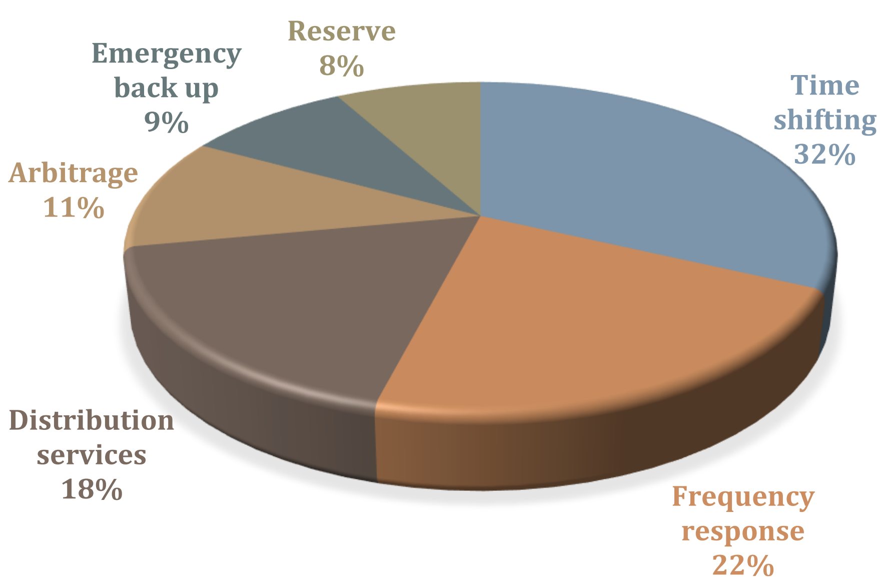

Figure 4: Global distribution of V2X pilot projects by services (V2GHub, 2025)

Table 4: Top five countries contributing to V2X pilot projects across different services (V2GHub, 2025)

Services	Top 5 countries
Time shifting	United Kingdom, United States, Netherlands, Korea, France
Frequency response	United Kingdom, United States, Germany, Netherlands, France
Distribution services	United Kingdom, United States, Netherlands, Denmark, Sweden
Arbitrage	United Kingdom, Korea, Germany, Netherlands, France
Emergency backup	United States, Netherlands, United Kingdom, Spain, Japan
Reserve	Korea, United Kingdom, Switzerland, Spain, Italy

This indicates that certain services, especially frequency regulation, demand response, and emergency backup, are emerging as global entry points for V2X.

3. Enablers are consistent across leading regions.

- Incentives and compensation programs from utilities and governments.
- Clear standards for interconnection and communication.
- Strong partnerships between automakers, utilities, and housing or community organizations.

4. Persistent barriers remain globally.

- High capital costs of bidirectional chargers.
- Fragmented or unclear regulations.
- Concerns among EV owners about cost, battery wear, and convenience.

These issues appear across nearly all jurisdictions, reinforcing that technical progress must be matched with supportive policy and consumer engagement.

Implications for BC

These international experiences point to several practical implications for BC Housing and its partners:

- *Resilience as a first mover advantage*. Like Japan, BC is vulnerable to wildfires, floods, and heat events. Positioning V2X as an emergency preparedness tool can create strong public and policy support while directly benefiting vulnerable tenants.
- *Grid flexibility in a renewable-rich system*. Similar to Denmark, BC's grid is clean but faces peak demand challenges. V2X could provide distributed storage to help manage loads and defer costly upgrades.
- *Policy alignment is critical*. As seen in the UK, clear tariffs, interconnection rules, and recognition of EVs as grid resources are essential. BC will need collaboration with BC Hydro, FortisBC, and the BC Utilities Commission to unlock market participation.
- *Equity must be central*. Drawing on California's use of school buses and the Netherlands' community pilots, BC Housing can ensure that affordable housing residents benefit directly from resilience and cost savings.
- *Partnerships drive success*. Across all leading jurisdictions, projects succeed when utilities, automakers, governments, and housing providers collaborate. BC Housing is well-positioned to play a convening role in such partnerships.

In summary, global patterns suggest that BC's V2X pathway should begin with small, resilience-focused pilots in affordable housing, supported by utilities and regulators. By aligning with proven service types (emergency backup, demand response, and peak management) and emphasizing equity, BC Housing can establish itself as a leader in resilient and inclusive V2X adoption.

In addition to the literature and jurisdictional scan, expert interviews provided practical perspectives on the opportunities and barriers for V2X in BC. The next section summarizes the key themes raised by interviewees.

Insights from Expert Interviews

To complement the literature review and analysis, fourteen semi-structured interviews were conducted with experts across government agencies, utilities, housing authorities, clean technology organizations, academics, and engineering firms. These interviews offered grounded insights into the real-world barriers and opportunities associated with energy sharing between vehicles and buildings during emergencies and between vehicles and the grid during non-emergency periods. Thematic analysis of the interviews yielded several recurring insights summarized below.

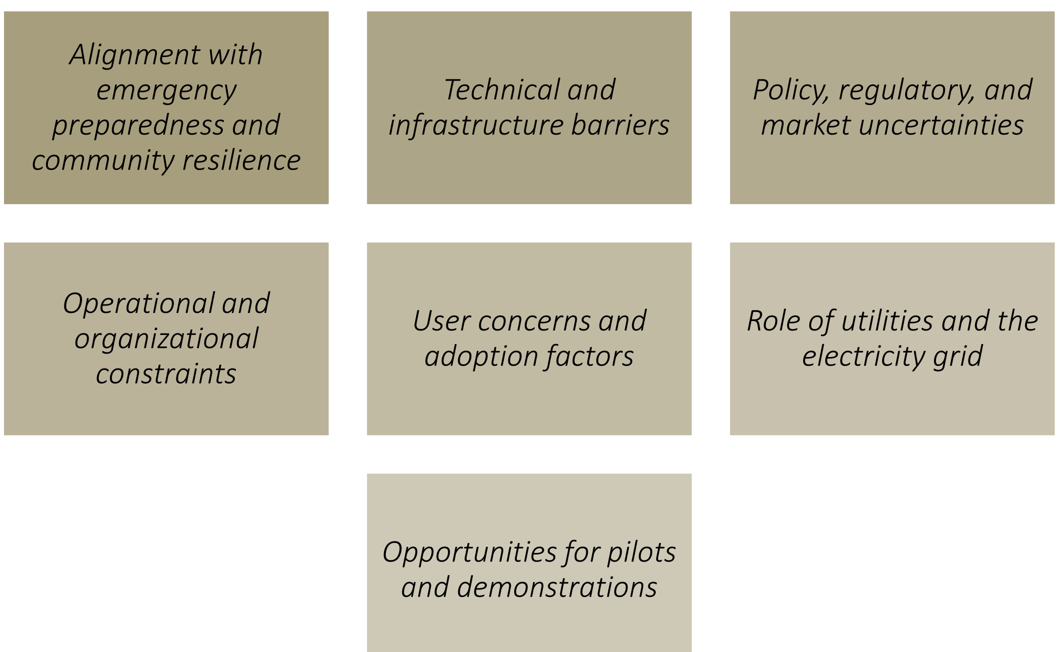

Figure 5: Key insights for BC from expert interviews

Alignment with emergency preparedness and community resilience

Several interviewees emphasized that V2X systems could enhance emergency preparedness, especially when targeted at critical infrastructure such as community centers, health facilities, and emergency shelters. These buildings can serve as resilience hubs if equipped with backup energy options. Bidirectional EVs were seen as a potentially valuable complement to stationary batteries and solar photovoltaic systems. In particular, V2X could help meet the energy needs of vulnerable residents during power outages caused by extreme weather events, wildfires, or earthquakes.

"During wildfires or heat events, if a building can remain powered for 6 to 12 hours using EVs, that could mean the difference between safety and harm for vulnerable populations."

However, interviewees also noted that V2X should not be considered a replacement for dedicated backup generators in facilities that provide essential services. Instead, EV energy sharing could support non-critical loads or extend the operation of other backup systems.

Interviewees pointed out that resilience planning must consider the trade-offs between mobility and stationary energy use. For example, using an EV battery to power a building during an outage may limit the vehicle's ability to evacuate residents or access other essential services. Despite this, some communities have already used EVs for resilience in informal ways, such as powering water pumps or communication devices during grid outages. These real-world use cases highlight the feasibility of V2X under specific conditions.

Technical and infrastructure barriers

All interviewees acknowledged the technical immaturity of V2X deployments, particularly V2B applications. Key barriers included:

- Limited availability of bidirectional chargers and compatible EV models. Most current EVs do not support bidirectional charging, and where they do, manufacturer support may be limited to specific applications (e.g., V2L but not V2G).
- Lack of standardization and interoperability, making system integration complex. The shift toward the CCS is ongoing, but not all EVs or chargers are compatible. Interviewees emphasized the need for harmonized standards to support large-scale V2X deployment.
- Communication challenges across devices and platforms (e.g., Modbus, OCPP, MQTT). Interviewees noted that system integration is made difficult by the number of proprietary or incompatible communication protocols utilized by diverse parts of the energy system.
- System complexity for building operators raises concerns about usability, safety, and maintenance. Operators of affordable or supportive housing buildings may not have the technical capacity or budget to manage complex V2X systems.

One expert from the housing sector noted:

"If it's too complicated to operate, it becomes a problem for our building operators and tenants."

Another expert emphasized the lack of smart infrastructure and control systems to support large-scale integration:

"Until we solve the control systems and communication issues, V2X will remain a boutique solution, not a grid-scale one."

Interviewees also highlighted concerns around panel sizing and load calculations in multi-unit residential buildings. Developers and electricians may be uncertain about how to size electrical infrastructure to accommodate future V2X loads. Misunderstandings about these requirements could result in overbuilt or underprepared systems, leading to unnecessary costs or limited functionality.

Policy, regulatory, and market uncertainties

The regulatory landscape for V2X is still evolving. Experts cited the following concerns:

- Ambiguity around interconnection standards and the legality of using EVs as energy export devices. In many jurisdictions, there is no clear framework for EVs to serve as DERs.
- Liability and insurance concerns, especially in residential or publicly owned buildings. Interviewees questioned who would be responsible in the event of equipment failure or a safety incident during V2X operation.
- Lack of clear compensation mechanisms or market structures to reward EV owners for grid services. Without time-varying rates or incentives for energy exports, EV owners have little financial motivation to participate in V2G programs.
- Fire safety and building code limitations, particularly around battery storage within buildings or underground parking structures. Some interviewees flagged the need for further collaboration between electrical code committees, fire departments, and building officials to resolve these issues.

One expert noted:

"There's no functioning market for EV battery services right now. Until that exists, we're not rewarding the people who could provide real value."

A housing sector representative also raised concerns about risk management:

"If we're introducing technology, it has to work when it matters—and be backed by clear regulations."

Operational and organizational constraints

From the perspective of housing providers and building operators, interviewees highlighted several practical issues:

- EV fleet availability: Most residential or supportive housing sites do not have dedicated EV fleets parked on-site. Even when staff vehicles or community EVs are available, their usage patterns may not align with emergency needs.
- Emergency load prioritization: Life-safety loads are already backed up through existing systems (e.g., diesel generators or battery storage). V2B integration must be coordinated with these systems and may only be appropriate for non-critical loads.
- Budget constraints: Public sector organizations, including housing authorities, face capital and operational budget limits. V2X systems must demonstrate clear value for money and cost-effectiveness.
- Maintenance responsibilities: Some organizations rely on third-party contractors for electrical work. Interviewees questioned whether these contractors would be trained or willing to support complex V2X systems.

One interviewee remarked:

"We need to understand the value proposition. Does V2B help us reduce diesel usage, lower emissions, or provide backup when the grid is down?"

Another expert shared a concern that innovations like V2B may impose unexpected costs on building operators unless financial and technical support is provided.

User concerns and adoption factors

Common concerns included potential battery degradation, vehicle readiness for trips, safety risks, and added complexity for users and operators. Simplifying user experience with automated controls that guarantee minimum charge levels and seamless energy management is critical to fostering adoption and trust.

Role of utilities and the electricity grid

BC's mostly single-utility context offers opportunities for coordinated V2X program development, but the absence of time-of-use pricing limits economic incentives. Lessons from distributed solar integration provide useful models for tariff design and technical standards.

Opportunities for pilots and demonstrations

Despite barriers, many experts viewed targeted V2X pilots as a promising way forward. Suggestions included:

- Partnering with community centers or post-disaster shelters for resilience-focused pilots.
- Deploying V2G demonstrations with fleet operators where operational control is centralized.
- Leveraging existing solar and battery projects and adding V2X as a layer of functionality.
- Using public or commercial parking lots as test beds for V2G, especially where EVs remain parked for long durations (e.g., airport parking).

Interviewees emphasized that pilot projects must be co-designed with communities, building operators, and technical experts to be successful. Multiple experts advocated for a phased approach that starts with well-supported pilot projects before scaling:

"Pilot projects could help us de-risk the technology and understand how to make it work in real-world contexts."

Some interviewees also suggested using demonstration sites to collect real-time data on load profiles, charging behaviors, and emergency energy needs. This data could support the development of business cases and guide future investments.

Long-term vision and system integration

Several experts stressed that V2X should be considered within the context of a comprehensive energy system transformation:

- Integrated energy systems where EVs, solar photovoltaic, batteries, and buildings work together seamlessly. V2X could complement other DERs rather than operate in isolation.
- Smart controls and automation to optimize energy flows and reduce burden on users. Interviewees called for intelligent platforms that simplify system operation and maximize efficiency.
- Equitable design to ensure marginalized communities benefit from these technologies. Experts warned against allowing innovative energy technologies to widen existing gaps in energy access.

One expert concluded:

"The future is not just solar or EVs or batteries—it's all of them working together, intelligently."

Another noted that the success of V2X depends on creating governance and ownership models that reflect community needs and values.

In summary, the interviews revealed cautious optimism about the role of V2X technologies in enhancing resilience and grid flexibility. While significant barriers remain, particularly on the regulatory, technical, and operational fronts, there is strong interest in collaborative, well-designed pilot projects to test and scale V2X solutions in BC's building and energy sectors. Interviewees called for improved coordination across housing agencies, utilities, standards bodies, and community groups to align efforts and unlock the full potential of V2X systems.

Summary

This report presents a comprehensive investigation into the potential of V2X technologies to support sustainable, resilient, and equitable energy systems in BC, with a focus on V2B and V2G applications. By enabling bidirectional energy flow between EVs, buildings, and the grid, V2X transforms EVs into DERs capable of supporting peak load management, enhancing renewable energy integration, and offering standby power during power interruptions.

The research examines the technical, economic, policy, environmental, and social dimensions of V2X integration in buildings and the grid, combining insights from a literature and jurisdictional review with findings from expert interviews. In the BC context, V2X aligns with provincial goals for climate resilience, low-carbon electrification, and energy equity, particularly in social housing, municipal infrastructure, and emergency-prone regions.

Key Findings and Implications for BC:

Technologically, the findings reveal that V2X-capable hardware and communication protocols are maturing, and under managed charging conditions, battery degradation is minimal. Experts confirmed that integration with solar PV, microgrids, and stationary storage is both feasible and valuable for enhancing local energy resilience. However, a lack of standardized equipment certification, cybersecurity protocols, and interoperability remains a challenge, particularly in the Canadian context.

Economically, V2X systems still face high capital costs and uncertain return on investment, particularly for residential applications. However, opportunities exist for BC in fleet-based deployments and emergency preparedness use cases, where value-stacking, such as combining revenue from grid services, backup power, and dynamic pricing, can improve the business case. Interviewees emphasized the need for clear ownership models, utility collaboration, and better tariff structures to make V2X financially viable.

From a policy and regulatory standpoint, Canada lags behind global leaders such as Japan, the Netherlands, and California, where enabling frameworks and pilot programs have accelerated V2G deployment. In BC, despite favorable conditions, such as a clean electricity mix and rising EV adoption, V2X scale-up is constrained by fragmented regulatory oversight, a lack of interconnection rules, and slow smart meter rollout. Experts also highlighted the absence of regulatory support for aggregators and flexible market participation as a critical barrier.

Environmentally, V2X supports emissions reductions by maximizing renewable energy utilization and reducing reliance on diesel generators during grid outages. Socially, the research identifies equitable access, user education, and trust as essential to successful adoption. Concerns around data privacy, usability, and the risk of excluding low-income communities must be addressed through inclusive design and policy.

The interviews brought out real-world perspectives from stakeholders across sectors, underscoring the importance of demonstration projects to validate V2X in the BC context. Municipalities, public sector fleets, and social housing projects are seen as ideal early adopters due to their public service missions and alignment with sustainability goals. Experts also emphasized the role of community resilience as a powerful motivator for V2B integration, especially in rural or emergency-prone regions in BC.

Ultimately, this report affirms that V2X represents a transformative opportunity for BC and Canada. But realizing its full potential will require coordinated leadership across government, utilities, the private sector, and civil society. The findings lead to targeted recommendations on policy reform, pilot deployment, equity-driven planning, and stakeholder collaboration, all aimed at accelerating the transition toward sustainable and resilient communities.

Recommendations

Based on a comprehensive analysis of V2X integration in buildings and the grid, augmented by expert interviews, this section presents a set of strategic recommendations to overcome persistent barriers and unlock the full potential of V2X technologies in BC. These recommendations emphasize technical readiness, regulatory clarity, commercial scalability, and inclusive engagement, grounded in a collaborative, multi-stakeholder approach.

The following checklist organizes actions according to the barrier types identified in this report, highlighting both general strategies and BC-specific reforms to accelerate V2X adoption.

Recommendations Checklist

Policy and Regulatory Reforms

- ☐ Revise the BC Building Code to mandate V2X-ready infrastructure (panels, conduits, inverter-ready circuits) in both new developments and retrofits.
- ☐ Expand CleanBC incentive programs to include bidirectional chargers, with higher rebates for affordable housing and multi-unit residential buildings.
- ☐ The BC Utilities Commission (BCUC) should clarify aggregator and customer participation in demand response and ancillary markets, ensuring fair compensation for exported energy.
- ☐ Enable dynamic pricing and energy trading (time-of-use tariffs, real-time compensation) that reward flexibility and incentivize energy exports from EVs.
- ☐ Recognize emergency energy-sharing as a resilience service, and integrate V2X-equipped buildings into BC's emergency preparedness frameworks.
- ☐ Leverage existing work by CleanBC, Technical Safety BC (TSBC), CSA, NRCan, and NRC to align standards and funding mechanisms.

Technical Standardization, Interoperability, and Cybersecurity

- ☐ Mandate or incentivize open communication standards such as ISO 15118 (vehicle-grid), OCPP 2.0.1 (charger backend), and CSA/IEEE-aligned protocols.
- ☐ Require BC Hydro and FortisBC to adopt these standards in interconnection approvals.
- ☐ Identify and promote V2X-compatible EVs and chargers already market-tested in BC (e.g., Nissan Leaf, Mitsubishi Outlander PHEV, Ford F-150 Lightning with Wallbox Quasar or Fermata systems).
- ☐ Support certification and testing of bidirectional equipment for reliability, interoperability, and cybersecurity through TSBC and national labs.
- ☐ Clarify technology requirements for integration (smart meters, inverter specs, panel upgrades, sub-metering) across BC Housing's portfolio.
- ☐ Invest in cybersecurity standards tailored to V2X systems to safeguard grid assets and consumer data.
- ☐ Promote industry collaboration among automakers, utilities, and digital platform providers to de-risk deployment.

Economic Incentives and Business Models

- ☐ Expand CleanBC and utility rebate programs to cover bidirectional chargers, with additional incentives for non-market housing.

- ☐ Pilot resilience credits or equity-focused tariffs to reward participation from affordable housing developments.
- ☐ Develop targeted pilot projects across archetypes (multi-unit residential buildings, emergency shelters, community hubs, municipal fleets).
- ☐ Define clear success metrics (peak reduction, outage resilience, cost savings) for pilots.
- ☐ Test diverse business models: utility aggregation, third-party service providers, municipal fleet sharing, cooperative ownership.
- ☐ Pilot and evaluate governance models (utility-led, third-party, cooperative, or joint ownership schemes) to clarify roles, responsibilities, and revenue-sharing.
- ☐ Encourage value-stacking models that combine revenues from ancillary services, peak shaving, and resilience.
- ☐ Use public funding and tax incentives to reduce upfront costs and scale early-market adoption.

Environmental Sustainability

- ☐ Fund demonstration projects in BC to track battery degradation, lifecycle emissions, and performance under clean electricity conditions.
- ☐ Integrate battery recycling and second-life use into CleanBC's circular economy strategy.
- ☐ Prioritize pilots that combine renewable energy + V2X, maximizing carbon reduction.
- ☐ Require transparent reporting on the environmental impacts of V2X adoption in housing projects.

Social Equity and Public Engagement

- ☐ Ensure equitable access to V2X by embedding infrastructure in affordable housing and community hubs.
- ☐ Update the BC Building Code to require shared charging/V2X capacity in new multi-unit residential buildings.
- ☐ Design equity-focused tariffs and subsidies that reduce barriers for low-income residents.
- ☐ Require utilities and housing providers to reserve a portion of V2X capacity for emergency backup in vulnerable communities (e.g., seniors, people with medical needs).
- ☐ Launch awareness and tenant engagement programs to build trust, address concerns about warranties and battery degradation, and improve usability.
- ☐ Involve municipalities, Indigenous communities, and nonprofits early in pilot design to ensure inclusive solutions.
- ☐ Showcase V2X in high-visibility public facilities (schools, fire halls, community centers) to build awareness and trust.

Collaborative Research and Learning

- ☐ Expand research into battery degradation, renewable-V2X optimization, and control algorithms in BC's climate and grid context.
- ☐ Model community-scale systems combining solar PV, stationary storage, and V2X to optimize resilience.
- ☐ Translate global pilot lessons (California, Japan, Netherlands) into locally relevant insights.
- ☐ Address key data gaps (e.g., lifecycle cost-effectiveness, ratepayer impacts) through applied research with academic and government partners.
- ☐ Leverage behavioral science insights to understand consumer motivations, trust, and participation in V2X programs.
- ☐ Establish cross-sector knowledge networks among governments, utilities, researchers, and automakers to align strategies.
- ☐ Clarify governance questions (ownership of exported energy, revenue-sharing mechanisms) through pilots and research partnerships.

To complement the checklist, Table 5 summarizes the responsible parties for each barrier category, offering a high-level roadmap for action in BC.

Table 5: Roadmap of responsible parties for V2X adoption in BC

Barrier Category	Key Responsible Parties
Policy & Regulatory	BC Ministry of Housing; CleanBC; BC Utilities Commission (BCUC); BC Hydro; FortisBC; Municipal Governments
Technical	BC Hydro; FortisBC; Technical Safety BC (TSBC); National Research Council (NRC); Automakers; Charging Providers
Economic & Business Models	CleanBC; BC Hydro; FortisBC; Municipalities; Housing Providers; Private Aggregators; Fleet Operators
Environmental Sustainability	CleanBC; Ministry of Environment and Climate Change Strategy; BC Hydro; Research Institutions (e.g., UBC, NRC)
Social Equity & Engagement	BC Housing; BC Ministry of Housing; Utilities; Municipalities; Nonprofits; Indigenous Communities; Housing Providers
Research & Knowledge Sharing	UBC; NRC; CleanBC; BC Hydro; Automakers; Municipal Governments; Industry Associations

A successful transition toward sustainable and resilient energy communities empowered by V2X technologies depends on proactive, coordinated action across multiple fronts. Governments must provide enabling policies and infrastructure funding. Utilities and automakers must ensure technical compatibility and market readiness. Researchers must close data gaps, and communities must be equitably engaged from the outset. With these efforts aligned, V2X can evolve from pilot-stage innovation to a cornerstone of Canada's resilient, flexible, and sustainable energy future.

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Appendices

Appendix A: Technical Standards Overview

Standard	Description	Relevance to V2X
ISO 15118	Vehicle-to-grid communication interface	Enables smart/bidirectional charging
IEEE 2030.5	Smart Energy Profile for DERs	Used in V2G and smart inverter settings
OCPP 2.0.1	Open Charge Point Protocol	Enables interoperability between EVSE and backend systems
IEEE 1609	WAVE (Wireless Access in Vehicular Environments)	Provides cybersecurity protocols for vehicular communications

Appendix B: V2X Pilot Projects

Country	Project Name	Timespan	Chargers	Services	Status of service provided	Link
US	KIA Motors, Hyundai Technical Center Inc., UCI	2016- unknown	6	Time shifting	Proof of concept trial	http://insideevs.com/kia-providing-6-soul-evs-to-university-of-california-irvine-for-v2g-testing/
US	BlueBird School Bus V2G	2017- 2020	8	Freq. Response, Time shifting, Emergency back up	Other	https://electrek.co/2017/07/14/all-electric-school-buses-blue-bird/amp/ https://www.green-technology.org/gcsummit18/images/ZEV-School-Buses.pdf
US	SmartMAUI, Hawaii	2012- 2015	80	Time shifting	Small-scale commercial trial	http://social-innovation.hitachi/en/case_studies/smartgrid_hawaii/index.html & https://www.icef-forum.org/platform/speakers/2017/topic9/session2/ICEF2017_CS3-1_Kazuyuki_Takada_fin.pdf &
US	INVENT- UCSD / Nissan / Nuvve	2017- 2020	50	Freq. Response, Dist. Services, Time shifting	Proof of concept trial	https://ucsdnews.ucsd.edu/index.php/pressrelease/nuvve_and_uc_san_diego_to_demonstrate_vehicle_to_grid_technology http://www.energy.ca.gov/business_meetings/2017_packets/2017-06-14/Item_13_EPC-16-061.pdf
US	US DoD, Smith trucks,	2013- 2014	5	Time shifting, Emergency back up	Proof of concept trial	https://www.army-technology.com/news/newsus-army-receives-bidirectional-electric-vehicle-chargers/
US	US Air Force	2012- ongoing	13	Freq. Response, Reserve, Time shifting, Emergency back up	Small-scale commercial trial	http://www.nacleanenergy.com/articles/22157/v2g-ev-charging AND http://www.electricvehicle.ieee.org/files/2013/03/DoD-Plug-In-Electric-Vehicle-Program.pdf

US	NRG Evgo, UCSD	2015- 2018	9		Proof of concept trial	http://www.utilitydive.com/news/how-nrg-is-testing-the-next-step-of-energy-storage-vehicle-to-grid-integra/409464/
US	NREL Integrate / living lab	unknown-unknown	3		Proof of concept trial	https://www.nrel.gov/news/program/2017/connecting-electric-vehicles-to-the-grid-for-greater-infrastructure-resilience.html
US	PG&E disaster hybrid truck	2014- 2014	1	Emergency back up	Other	http://www.pgecurrents.com/2015/08/25/napa-pge-joins-napa-strong-event-one-year-after-6-0-quake-donates-rapid-response-truck/
US	Grid on wheels (University of Delaware)	2012- 2014	15	Freq. Response	Small-scale commercial trial	http://grid-on-wheels.com/
US	Clinton Global Iniative School Bus Demo	2014-ongoing	6	Freq. Response, Time shifting, Emergency back up	Proof of concept trial	https://www.clintonfoundation.org/clinton-global-initiative/commitments/launching-market-electric-school-buses AND https://green-technology.org/gcsummit16/images/35-ZEV-School-Buses.pdf
US	Distribution System V2G for Improved Grid Stability for Reliability	2015- 2018	2	Dist. Services, Time shifting	Proof of concept trial	EPRI https://www.energy.ca.gov/research/notices/2017-12-05_workshop/presentations/05_EPRI_14-086-DistributionConstrainedV2GServices.pdf
US	UCLA WinSmartEV	unknown-unknown	1	Dist. Services, Time shifting	Proof of concept trial	http://smartgrid.ucla.edu/projects_evgrid.html
US	Massachusetts Electric School Bus Pilot	2015- 2018	unknown		Other	https://www.mass.gov/files/documents/2018/04/30/Mass%20DOER%20EV%20school%20bus%20pilot%20final%20report_.pdf
US	NYSERDA	2016-ongoing	5		Proof of concept trial	http://myemail.constantcontact.com/NYSolar-Smart-September-Newsletter.html?soid=1101960157170&aid=-WValvsvetE

US	Torrance V2G School Bus	2014- 2017	2	Freq. Response, Time shifting	Proof of concept trial	http://www.aqmd.gov/docs/default-source/Agendas/Governing-Board/2014/2014-feb7-010.pdf
US	Fermata Energy V2X pilot	2021- 2021	1	Dist. Services, Time shifting	Proof of concept trial	https://fermataenergy.com/article/electric-vehicle-generates-revenue-and-energy-savings
US	Vehicle-to-Building EV Pilot	2020- ongoing	1	Dist. Services, Time shifting		https://bouldercolorado.gov/projects/vehicle-building-ev-pilot
US	Toyota-Oncor	2022- 2023	unknown		NA	https://pressroom.toyota.com/toyota-announces-collaboration-with-oncor-to-accelerate-ev-charging-ecosystem/
Japan	M-tech Labo	2010- 2013	5	Time shifting, Emergency back up	Proof of concept trial	https://www.evwind.es/2012/06/13/mitsubishi-motors-to-use-electric-vehicles-for-vehicle-to-grid-v2g/19083
Japan	Toyota Tsuho / Chubu Electric / Nuvve	2018- 2019	unknown		Proof of concept trial	http://nuvve.com/2018/06/first-v2g-project-defined-for-japan/ https://www.toyota-tsusho.com/english/press/upload_files/201806011300en.pdf
Japan	V2G Aggregator project-Mitsubishi	2018- unknown	unknown		Proof of concept trial	https://www.mitsubishi-motors.com/en/newsrelease/2018/detail1124.html
Japan	Osaka business park	unknown- unknown	unknown		Proof of concept trial	https://www.level-network.com/wp-content/uploads/2018/02/Tomoko-Blech-CHAdeMO.pdf
Japan	Leaf to home	2012- ongoing	4000	Time shifting, Emergency back up	Other	https://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/vehicle_to_home.html & https://insideevs.com/nissan-leaf-to-home-prepped-for-commercialization-in-u-s-will-be-nissans-primary-focus-at-2017-naias/
Japan	Chubu Electric Power toyota v2g pilot	2018- 2018	2			https://nuvve.com/toyota-tsusho-and-chubu-electric-power-announce-japans-first-ever-v2g-project-using-nuvves-technology/

Japan	METI	2018- 2021	2	Freq. Response, Time shifting		https://nuvve.com/projects/meti/
Denmark	Parker	2016- 2018	50	Freq. Response, Arbitrage, Dist. Services	Service procured commercially	http://parker-project.com
Denmark	Denmark V2G	2016- ongoing	10	Freq. Response	Service procured commercially	https://newsroom.nissan-europe.com/eu/en-gb/media/pressreleases/149186
Denmark	Parker Denmark	2016- 2019	15	Freq. Response, Dist. Services	Small-scale commercial trial	https://parker-project.com/
Denmark	Frederiksberg Forsyning V2G	2016- ongoing	10		Service procured commercially	https://northsearegion.eu/access/news/a-successful-v2g-model-in-a-danish-utility/
Denmark	BOSS (Bornholm Smartgrid Secured)	2019- 2022	unknown			https://nuvve.com/projects/boss-denmark/
Denmark	ACES project	2017- 2020	50	Dist. Services, Time shifting	Small-scale commercial trial	https://nuvve.com/projects/aces-across-continents-ev-services/
UK	SEEV4City	2016- 2020	6	Freq. Response, Arbitrage, Time shifting	Proof of concept trial	http://www.northsearegion.eu/seev4-city/about/ & http://www.northsearegion.eu/media/4384/summary-state-of-the-art-report-seev4-city.pdf
UK	Intelligent Transport, Heating and Control Agent (ITHECA), UK	2015- 2017	1	Freq. Response, Time shifting	Proof of concept trial	http://www.cenex.co.uk/vehicle-to-grid/itheca/ http://www.cenex.co.uk/wp-content/uploads/2016/09/case-study-ITHECA-web.pdf http://www.aston.ac.uk/eas/research/groups/ebri/projects/itheca/
UK	UK Vehicle-2-Grid (V2G)	2016- ongoing	100		Small-scale commercial trial	https://newsroom.nissan-europe.com/uk/en-gb/media/pressreleases/145248
UK	Cenex EFES	2013- 2013	1	Freq. Response, Reserve, Time shifting	Proof of concept trial	http://www.cenex.co.uk/vehicle-to-grid/efes/ https://gtr.ukri.org/projects?ref=131426

UK	Northern Power Grid, The Network Impact of Grid-Integrated Vehicles	2018- 2021	16		Other	http://www.smarternetworks.org/project/nia_npg_014/documents
UK	Electric Nation Vehicle to Grid	2020- 2022	100	Reserve, Dist. Services, Time shifting	Other	https://electricnation.org.uk/
UK	Hitachi Isle of Scilly Smart Islands- No V2G yet	2017- unknown	unknown		Other	http://www.hitachi.eu/sites/default/files/fields/document/press-release/news_release_20170315_isle_of_scilly_hitachi_europe.pdf
UK	V2GO	2018- ongoing	unknown	Freq. Response, Arbitrage, Time shifting		https://www.v2go.org/
UK	E-FLEX-Real-world Energy Flexibility through Electric Vehicle Energy Trading	2018- ongoing	unknown	Freq. Response, Dist. Services, Time shifting		https://www.e-flex.co.uk/v2g
UK	Powerloop: Domestic V2G Demonstrator Project	2018- ongoing	135	Arbitrage, Dist. Services, Time shifting, Emergency back up		https://www.octopusev.com/powerloop
UK	SMARTHUBS Demonstrator	2018- ongoing	unknown			https://www.flexi-solar.com/flexisolar-awarded-uk-government-funding-for-its-v?id=8&showall1=yes&hash=7eb2e9718864a8067e60ed8b45ccaa31e68ec32a9d9
UK	Bus2Grid	2018- ongoing	unknown	Freq. Response, Arbitrage, Time shifting		https://www.sseutilitysolutions.co.uk/insights/press-releases/sse-enterprise-led-consortium-wins-funding-power-smart-electric-buses-future/
UK	EV-elocity	2018- 2022	35	Arbitrage, Time shifting	Other	https://www.ev-elocity.com/
UK	e4Future	2018- 2022	unknown	Freq. Response, Arbitrage, Dist.		https://www.eonenergy.com/v2g.html

				Services, Time shifting		
UK	OVO Energy V2G (Project Sciurus)	2018- 2021	320	Arbitrage	Small-scale commercial trial	https://www.ovoenergy.com/electric-cars/vehicle-to-grid-charger
UK	GenDrive- Engaging households with V2G	2018- 2020	unknown	Time shifting	Proof of concept trial	https://www.gengame.co.uk/
UK	V2Street	2018- 2020	2	Arbitrage, Dist. Services, Time shifting	Proof of concept trial	https://gtr.ukri.org/projects?ref=104224
UK	VIGIL (VehIcle to Grid Intelligent controL)	2020- ongoing	4	Reserve, Dist. Services, Time shifting	Proof of concept trial	https://www.linkedin.com/pulse/vigil-platform-demonstration-successfully-completed-clara-serrano/
UK	V2G EVSE Living Lab	2019- ongoing	2	Time shifting, Emergency back up	Proof of concept trial	https://www.v2g-evse.com/projects/v2g-living-lab/
UK	Milton Keynes Council- Domestic Energy Balancing EV Charging Trial	2020- 2022	4	Time shifting	Proof of concept trial	https://crowd-charge.com/mkc-evchargingproject-info/
UK	Static and Mobile Distributed Energy Storage (SaMDES)	2017- 2021	2	Time shifting, Emergency back up	Proof of concept trial	https://v2g.co.uk/tag/SaMDES
UK	V2X Local Network Fleet Solution	2022- 2023	unknown	Freq. Response, Dist. Services, Time shifting	Other	www.fuuse.io
UK	VEhiCle TO eneRgy communitieS (VECTORS)	2022- 2023	unknown	Dist. Services	Proof of concept trial	https://www.gov.uk/government/publications/v2x-innovation-programme-successful-projects/v2x-innovation-programme-phase-1-successful-projects#vehicle-to-energy-communities
UK	V2X-Flex	2022- 2023	2	Freq. Response, Reserve, Arbitrage, Dist. Services, Time shifting,	Proof of concept trial	https://www.ev.energy/products/v2x

				Emergency backup		
UK	Electric Heavy Goods Vehicles- first roll-out and demonstration of V2X and grid decarbonisation	2024- ongoing	unknown	Freq. Response, Dist. Services		https://www.gov.uk/government/publications/v2x-innovation-programme-successful-projects/v2x-innovation-programme-phase-2-successful-projects
UK	V2VNY Phase 2- optimising AC bidirectional charging for fleet and non-domestic V2V, V2B or V2G applications	2024- ongoing	unknown	Freq. Response, Dist. Services		https://www.gov.uk/government/publications/v2x-innovation-programme-successful-projects/v2x-innovation-programme-phase-2-successful-projects
UK	Papilio3 DC V2X FastHub Demonstration	2024- ongoing	12			https://www.gov.uk/government/publications/v2x-innovation-programme-successful-projects/v2x-innovation-programme-phase-2-successful-projects
UK	Electric Vehicle Fleet Bi-directional Charging (FLEXET)	2024- ongoing	unknown	Freq. Response, Dist. Services, Time shifting		https://www.gov.uk/government/publications/v2x-innovation-programme-successful-projects/v2x-innovation-programme-phase-2-successful-projects
UK	Wireless V2G for fleets (V2Geasy)	2024- ongoing	unknown			https://www.gov.uk/government/publications/v2x-innovation-programme-successful-projects/v2x-innovation-programme-phase-2-successful-projects
Germany	Redispatch V2G	2018- 2021	10		Proof of concept trial	https://www.electrive.com/2018/03/13/tennet-the-mobility-house-nissan-start-v2g-project/
Germany	Honda, The Mobility House, Offenbach	2017- unknown	1		Proof of concept trial	https://www.autobeatdaily.com/blog/post/honda-tests-vehicle-to-grid-charging-system-at-german-site
Germany	INEES Volkswagen, SMA, Lichtblick, Fraunhofer	2012- 2015	20	Freq. Response	Proof of concept trial	https://www.volkswagen-media-services.com/en/detailpage/-/detail/Intelligent-integration--Electric-vehicles-reduce-power-fluctuations-

						/view/3677831/61f6afd1b38119ef1fee028ac6ebe96a?p_p_auth=4M9ClfJz & http://mobilityintegrationsymposium.org/wp-content/uploads/sites/7/2017/11/3A_4_EMob17_298_presentation_T_Degner.pdf
Germany	iZEus (Toyota)	2012- 2014	unknown		Other	https://www.automotiveworld.com/news-releases/toyota-partners-izeus-intelligent-zero-emission-urban-system/ http://www.izeus.de/service/presse-news/news-details/iZEUS_Abschlussevent.html
Germany	Vehicle-to-coffee- The Mobility House	2015-ongoing	1	Time shifting	Proof of concept trial	https://www.mobilityhouse.com/int_en/magazine/press-releases/the-mobility-house-brews-coffee-using-green-electricity-from-an-electric-car.html/
Germany	Vehicle-to-Metal	2019- 2019	unknown		Proof of concept trial	https://www.youtube.com/watch?v=q0_m9DaQ1E8&utm_source=Newsletter+%23EN&utm_campaign=9dcd045df8-EN%3A+Produkt+des+Monats+%2F+JUICE+Plug+%26+Play&utm_medium=email&utm_term=0_70bff88828-9dcd045df8-%5BLIST_EMAIL_ID%5D&ct=t%28EN%3A+Produkt+des+Monats+%2F+JUICE+Plug+&Play%29=&mc_cid=9dcd045df8&mc_eid=%5BUNIQID%5D
Germany	Bidirektionales Lademanagement- BDL	2021- 2022	50	Freq. Response, Arbitrage, Time shifting	Small-scale commercial trial	https://www.bdl-projekt.de
Germany	Nissan Leaf to stabilise the German electricity grid	2018-ongoing	1	Freq. Response	Service procured commercially	https://www.mobilityhouse.com/int_en/magazine/press-releases/v2g-hagen-electric-car-stabilise-electricity-grid.html/
Germany	V2G Redispatch- TenneT, Nissan, The Mobility House, Nissan	2019- 2020	10	Dist. Services	Small-scale commercial trial	https://www.dropbox.com/sh/6u7nw5ln218hvti/AAC-PL123e4CjQMoVUkVoqnqa?dl=0

Germany	BDL- Bidirectional charging management	2019- 2022	50	Freq. Response, Arbitrage, Dist. Services, Time shifting	Small-scale commercial trial	https://www.ffe.de/projekte/bdl/
Germany	BiFlex-Industrie	2023- 2026	unknown		Small-scale commercial trial	https://www.h-ka.de/iaf/projekte/biflex-industrie
Germany	InterBDL	2023- 2026	unknown	Arbitrage, Time shifting	Other	https://www.thu.de/de/org/iea/smartgrids/Seiten/InterBDL.aspx
Netherlands	NewMotion V2G	2016- 2018	10	Freq. Response	Small-scale commercial trial	https://newmotion.com/en/drive-electric/v2g-charging-next-generation-technology
Netherlands	Smart Solar Charging	2015- ongoing	22	Dist. Services, Time shifting	Service procured commercially	http://smartsolarcharging.eu/en/
Netherlands	Solar-powered bidirectional EV charging station	2015- 2017	1	Time shifting	Proof of concept trial	https://www.tudelft.nl/ewi/over-de-faculteit/afdelingen/electrical-sustainable-energy/dc-systems-energy-conversion-storage/research/electric-vehicle-supported-pv-smart-grid/
Netherlands	City-Zen Smart City	2014- 2019	4	Arbitrage, Dist. Services	Small-scale commercial trial	http://www.cityzen-smartcity.eu/ressources/smart-grids/vehicle2grid/
Netherlands	Hitachi, Mitsubishi and Engie	2018- unknown	1	Time shifting	Proof of concept trial	https://bizz-energy.com/hitachi_mitsubishi_und_engie_koppeln_e_auto_mit_gebaeude
Netherlands	AirQon	2019- ongoing	unknown		Proof of concept trial	https://www.uia-initiative.eu/en/uia-cities/breda
Netherlands	Utrecht V2G charge hubs (We Drive Solar)	2018- ongoing	80	Arbitrage	Proof of concept trial	https://cleantechnica.com/2019/09/02/netherlands-subsidy-for-472-vehicle-to-grid-smart-chargers/
Netherlands	Share the Sun / Deeldezon Project	2019- 2021	80	Freq. Response, Dist. Services, Time shifting	Proof of concept trial	https://www.deeldezon.eu/
Netherlands	Direct Solar DC V2G Hub @Lelystad	2020- 2023	14	Freq. Response, Dist. Services, Time shifting,	Small-scale commercial trial	https://www.mijndomein.nl/energie/

				Emergency back up		
Netherlands	FlexGrid	2018- 2022	1	Freq. Response, Time shifting, Emergency back up	Proof of concept trial	https://www.tudelft.nl/ewi/over-de-faculteit/afdelingen/electrical-sustainable-energy/dc-systems-energy-conversion-storage/research/flexgrid
Netherlands	V2G @ home	2021- 2022	1	Time shifting, Emergency back up	Proof of concept trial	https://positive-design.nl/v2g-home/
Netherlands	Powerparking	2017- 2022	1	Time shifting	Proof of concept trial	https://www.flevoland.nl/dossiers/lelystad-airport/duurzame-luchthaven/powerparking
Netherlands	V2G/V2B at the Johan Cruijff ArenA in Amsterdam	2019- ongoing	1	Dist. Services, Emergency back up	Service procured commercially	https://www.mobilityhouse.com/int_en/magazine/press-releases/the-mobility-house-amsterdam-arena-v2g-project.html/
Netherlands	V2G Liberty	2020- 2030	10	Arbitrage, Time shifting	Other	https://v2g-liberty.eu/
Netherlands	Invade	2017- 2019	1		NA	https://h2020invade.eu/
Netherlands	Interflex	2017- 2019	unknown		NA	https://interflex-h2020.com/
Australia	Realising Electric Vehicle to Grid Services	2020- 2022	51	Freq. Response, Reserve	Small-scale commercial trial	https://secs.accenture.com/accenturems/revs/
Australia	Flinders University V2G Trial	2023- ongoing	10	Arbitrage, Time shifting	Service procured commercially	https://www.energymining.sa.gov.au/home/news/latest/all-systems-go-for-landmark-flinders-university-energy-project
France	Grid Motion	2017- 2019	15	Freq. Response, Arbitrage, Time shifting	Small-scale commercial trial	https://media.groupe-psa.com/en/gridmotion-project-reducing-electric-vehicle-usage-cost-thanks-smart-charging-process http://chairgovreg.fondation-dauphine.fr/sites/chairgovreg.fondation-dauphine.fr/files/attachments/20171214_ChaireAP_conference_GridMotion.pdf
France	SOLARCAMP	2018- 2020	1	Freq. Response, Arbitrage, Dist. Services, Time shifting,	Proof of concept trial	https://thecamp.fr/en/projects/solarcamp

				Emergency back up		
France	GROUPEE 4.0 : "Gestion Renouvelable Optimisée d'Unité de Production de biens et services Energetiquement Efficaces"	2020- 2023	2	Freq. Response, Dist. Services, Time shifting	Small-scale commercial trial	https://www.youtube.com/watch?v=omnsXd6xc8M
France	V1G / V2G solutions	2019- unknown	5000	Freq. Response, Reserve, Arbitrage, Time shifting	Service procured commercially	https://www.dreev.com/en/
Switzerland	EVFlex- Electric vehicle flexibility aggregation for grid services	2021- 2023	unknown	Freq. Response, Reserve, Time shifting	Proof of concept trial	https://www.hslu.ch/en/lucerne-university-of-applied-sciences-and-arts/research/projects/detail/?pid=5883
Switzerland	SunnYparc	2022- 2025	250	Reserve, Dist. Services, Time shifting	Service procured commercially	https://sunnyparc.ch
Switzerland	V2X Suisse	2021- 2023	40	Freq. Response, Reserve, Arbitrage, Dist. Services	Service procured commercially	https://www.mobility.ch/en/media/media-releases/2022
Switzerland	Smart Mobility V2X	2019- 2022	2	Freq. Response, Dist. Services, Time shifting	Proof of concept trial	https://novatlantis.ch/en/projects/smart-mobility-v2x/
Canada	IREQ	2012- 2014	1	Dist. Services, Time shifting, Emergency back up	Proof of concept trial	http://electriccarsreport.com/2012/07/hydro-quebec-launches-v2g-v2h-project/
Canada	Powerstream pilot	2013- 2015	unknown		Proof of concept trial	https://www.powerstream.ca/attachments/SmartGrid-OT-MicroGridTechnology.pdf
Canada	Peak Drive	2019- 2025	21	Dist. Services, Time shifting	Small-scale commercial trial	https://www.peakdriveenergy.com/
Italy	Genoa pilot	2017- unknown	2		Other	https://www.enel.com/media/press/d/2017/05/enel-energia-nissan-italia-and-iit-join-

						forces-for-the-development-of-electric-mobility
Italy	Fiat-Chrysler V2G (Italy)	2019- 2021	600			https://www.electrive.com/2019/09/22/it-fiat-chrysler-to-test-v2g-with-700-electric-car-fleet/
Italy	BloRin	2019- 2022	1	Freq. Response, Time shifting	Proof of concept trial	https://www.blorin.energy/en/
Italy	E-mobility Lab	2021-ongoing	13	Freq. Response, Reserve, Time shifting	Other	https://www.terna.it/en/electric-system/system-innovation/spotlight-emobility-lab
Italy	DROSSONE V2G PROJECT	2023-ongoing	280	Freq. Response	Service procured commercially	https://www.esolutions.free2move.com/na/en_us/vehicle-to-grid-drosso-one-project/
Korea	KEPCO, Hyundai	2012-ongoing	unknown		NA	https://www.koreatimes.co.kr/www/tech/2018/03/419_246417.html http://iobe.gr/docs/pub/PRE_Mr%20WON%20Taiseung_01062017_PUB_GR.pdf (slide 42) https://www.iere.jp/events/workshop/2016-hongkong/Presen/K-3_KESRI_Seung%20Il_MOON_1122_secured.pdf
Korea	SK Rent-a-car V2G Demonstration project Jeju	2024-ongoing	10		Small-scale commercial trial	https://www.sknetworks.co.kr/en/promotion/pressView.do?PRE_IDX=15561&curPage=2&keyword=&search=

Appendix C: Expanded Recommendations Roadmap

Barrier Type	Potential Reforms for BC	Responsible Actors
Policy & Regulatory	• Revise BC Building Code to mandate V2X-ready wiring in new developments and retrofits. • Expand CleanBC rebates to bidirectional chargers, with higher incentives for affordable housing. • Clarify aggregator/customer participation in demand response via BCUC. • Enable dynamic pricing/time-of-use tariffs for V2X. • Recognize emergency energy-sharing in provincial resilience planning. • Align standards & pilots with CleanBC, TSBC, CSA, NRCan, NRC.	BC Ministry of Housing; CleanBC; BCUC; BC Hydro; FortisBC; Municipalities
Technical	• Mandate/incentivize ISO 15118, OCPP 2.0.1, CSA/IEEE standards. • Require adoption of standards in BC Hydro/FortisBC interconnections. • Promote market-ready V2X-compatible EVs & chargers (Leaf, Outlander PHEV, F-150 Lightning w/ Wallbox or Fermata). • Establish certification/testing programs for bidirectional chargers (via TSBC, NRC). • Invest in cybersecurity standards tailored to V2X. • Clarify panel capacity, sub-metering, and inverter specs for BC Housing buildings.	BC Hydro; FortisBC; TSBC; NRC; Automakers; Charging Providers
Economic	• Expand CleanBC & utility rebate programs for bidirectional chargers, with added support for MURBs/social housing. • Pilot resilience credits & equity-focused tariffs. • Develop pilots across building types with success metrics. • Test new business models (utility aggregation, third-party services, co-ops).	CleanBC; BC Hydro; FortisBC; Municipalities; Housing Providers; Aggregators; Fleet Operators

	• Pilot governance models (utility-led, cooperative, joint ownership). • Encourage value stacking (ancillary + peak shaving + resilience). • Provide public funding/tax incentives for adoption. • Support public-private partnerships for scaling.	
Environmental	• Fund BC demonstration projects to track battery degradation & lifecycle emissions. • Integrate second-life & recycling into CleanBC's circular economy strategy. • Prioritize renewable + V2X pilots to maximize carbon reduction. • Require transparent reporting of environmental impacts.	CleanBC; Ministry of Environment & Climate Change Strategy; Utilities; Researchers (UBC, NRC)
Social	• Update BC Building Code for shared charging in new multi-unit residential buildings. • Subsidize V2X infrastructure for affordable housing. • Design equity-focused tariffs and targeted subsidies. • Reserve V2X capacity for backup power in vulnerable communities. • Launch tenant engagement & awareness programs. • Involve municipalities, Indigenous communities, and nonprofits in pilot design. • Showcase V2X at visible public facilities (schools, fire halls, community centers).	BC Housing; BC Ministry of Housing; Utilities; Municipalities; Indigenous Communities; Nonprofits
Research & Learning	• Expand applied research on degradation, optimization, and algorithms in the BC climate. • Model integrated PV + storage + V2X systems. • Translate global lessons (Japan, California, Netherlands) into the BC context. • Fill data gaps (cost-effectiveness, ratepayer impacts). • Apply behavioral science to improve participation. • Establish cross-sector knowledge-sharing networks. • Clarify governance on ownership and revenue-sharing in pilots.	UBC; NRC; CleanBC; BC Hydro; Automakers; Municipalities; Industry Associations