Vehicle-to-everything (V2X)

An updated review of key research challenges, implementation barriers, and real-world innovation projects

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VEHICLE-TO-EVERYTHING (V2X): AN UPDATED REVIEW OF KEY RESEARCH CHALLENGES, IMPLEMENTATION BARRIERS, AND REAL-WORLD INNOVATION PROJECTS

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Abstract

By 2050, there will be more than 1 billion electric vehicles (EVs) on the road. This presents an opportunity for Europe to rapidly expand its share of variable renewable energy (VRE) generation, which is in line with major climate policies at European Union (EU) level. Despite that promising outlook, the rapid growth of electric mobility will pose major technical challenges and infrastructural risks to Europe's power system. One way to address this is through widespread implementation of smart bidirectional EV charging, which can potentially provide the power system with the flexibility to accommodate higher shares of VREs. The implementation scenarios for this technology are collectively known as vehicle-to-everything, or V2X, including vehicle-to grid (V2G), vehicle-to-home (V2H), and vehicle-to-building (V2B). This paper summarizes recent developments in the V2X arena, doing it in three stages. Firstly, it focuses on taxonomy aspects, performing a bibliometric analysis and studying technical term conventions. Secondly, it compiles relevant barriers to implementation and maps key issues addressed in scientific literature. And thirdly, it surveys past and existing projects to retrieve updated insights on its technical and market orientations. This review is produced as part of the EU-funded DriVe2X project, which develops new expert knowledge and technical solutions to help cope with the forthcoming mass EV deployment in Europe.

1 Introduction

Global electric vehicle (EV) sales across all transport modes have grown steadily over the last decade, including during the COVID-19 pandemic, despite strong declining trends in overall car sales in that period [1]. Supply chain disruptions, macro-economic and geopolitical uncertainty, and high commodity and energy prices didn't seem to affect this trend, as 2022 was another record-breaking year. In that year, a total of 14% of new cars sold were electric, up from around 9% in 2021 and less than 5% in 2020 [2]. This brought the global number of electric cars on the road to some whopping 26 million, up 60% relative to 2021 and more than 5 times the stock in 2018 [2].

EV growth shows no signs of slowing down. Expert predictions place the worldwide EV stock somewhere between 250 million and 500 million units by 2035, and between 700 million and 1.1 billion units by 2050 [4,5]. According to recent projections, Europe accounts for approximately 30% of the global stock for electric cars [3]. There, the inexorable growth of electric mobility is seen both as an opportunity in view of the climate challenges the region faces, and an infrastructural threat to the energy system, which needs to be carefully managed.

1.1 Impacts of EV growth

On one hand, the mass deployment of EVs carries a hidden game-changing decarbonization potential. By 2050, around 14 TWh worth of EV batteries will be available, which could be used to support the flexible operation of the power system [6], thus facilitating the expansion of the shares of variable renewable energy (VRE) sources into the generation mix. There is great support to such technologies in Europe, in no small part due to the ambitious set of European Union (EU) policies aimed at reducing greenhouse gases (GHG) emissions in half by 2030, and at reaching climate neutrality by 2050 [7,8,9], but even more so now that the EU is taking swift action through REPowerEU to rapidly reduce dependence on fossil fuels and fast forward the green transition [10].

On the other hand, if scaled up to mass-market levels, the mainstream technical approaches to EV charging are likely to create dangerous upsurges in power system peak demand. This is due to EV charging being currently dominated by time-of-use (TOU) pricing-driven control or binary (on/off) control strategies [5,11,12]. Depending on context, this could either be deemed technically unfeasible, and result in system fault, or lead to potentially prohibitive grid infrastructure upgrade requirements [5].

1.3 Benefits of V2X

An effective shift to mass electromobility needs to be accompanied by robust technical advancements in digitally controlled smart charging techniques and by technological improvements in bidirectional EV charging solutions. This bidirectionality is the key technology feature that will lend the power system the ground-breaking levels of flexibility it needs to accommodate higher shares of VREs. There are various scenarios under which bidirectional EV smart charging can happen, which include "vehicle-to grid" (V2G), "vehicle-to-home" (V2H), and "vehicle-to-building" (V2B). The collective realization of these scenarios is known as "vehicle-to-everything", or "V2X".

The DriVe2X project [13] aims to tackle the multifaceted challenges laid out above. The project will develop new expert knowledge, software solutions, and hardware technologies to help cope with a mass V2X deployment future for Europe, while studying user behaviour and policy solutions to support V2X roll-out in smart cities.

1.2 Structure of the paper

This paper summarizes results of a scientific review and survey of V2X projects performed by the DriVe2X team. It does so in three stages. Firstly, it focuses on taxonomy aspects, performing a bibliometric analysis and studying naming conventions for smart charging. Secondly, it compiles the most key barriers to V2X implementation and maps key issues addressed in scientific literature. And thirdly, it surveys past and existing V2X projects with goal of retrieving insights on dominant technical and market features. A more detailed explanation of this work can be found in Deliverable D1.1 of the DriVe2X project [14].

2. Taxonomy of V2X

The topic of V2X faces lack of clarity regarding the meaning of various related technical concepts, which poses communication challenges amidst practitioners and non-professionals, and delays scientific and industry progress. Therefore, the clarification of V2X nomenclature is an important step to take if future roll-out is to be ensured. To address this, the authors analyze the body of V2X literature with view to establishing a clear and unequivocal taxonomy for smart charging terms.

2.1 Bibliometric analysis

Bibliometrics is a method for exploring the statistics of large volumes of data pertaining to scientific publications, such as books, journal articles, or conference papers. Here, bibliometrics is used to understand the spread of V2X concepts. To perform this analysis, the authors tapped into the Elsevier Scopus database [15]. In the queries, the search fields were the article title, abstract content, and publication's keywords. Five specific queries were performed: "bidirectional charging", "vehicle-to-everything", "vehicle-to-grid", "vehicle-to-building", and "vehicle-to-home". The output bibliographical information was exported from the Scopus interface into CSV data files. The bibliometric analysis tool VOSviewer [16] was then used to explore this information. Selected output charts from the analysis are displayed in Figures 1-4.

For bidirectional charging terms (figures 1-2), VOSviewer's results seem to suggest:

- A cluster linked to building energy management applications (network view, right, red colour).
- A cluster related to smart grid/electricity market research topics (network view, left, blue colour).
- A cluster related to vehicle-to-grid applications and respective services at DSO level, such as peak shaving (network view, top center, green).
- A cluster linking battery degradation with the provision of ancillary services (network view, center, yellow).
- A branch of research linking bidirectional charging to building energy management appear as the most nascent, with V2X concepts such as vehicle-to-grid, bidirectional charging, and smart charging coming after. Smart distribution grids and electricity markets are more mature topics (overlay view).

For V2X terms (figures 3-4), VOSviewer's results indicate the following:

- A cluster for V2X communications, including terms "connectivity" and "dsrc" ("referring to dedicated short-range communications") (top right, blue).
- The term "v2g" also prominently featured in a cluster linking bidirectional charging, energy management, and optimization (center-right, red).
- A small cluster of research on optimization supported by machine learning (network view, lower right, purple).
- Most of the communications-based terms as more mature, and some of the machine learning and optimization terms as more recent (overlay view).

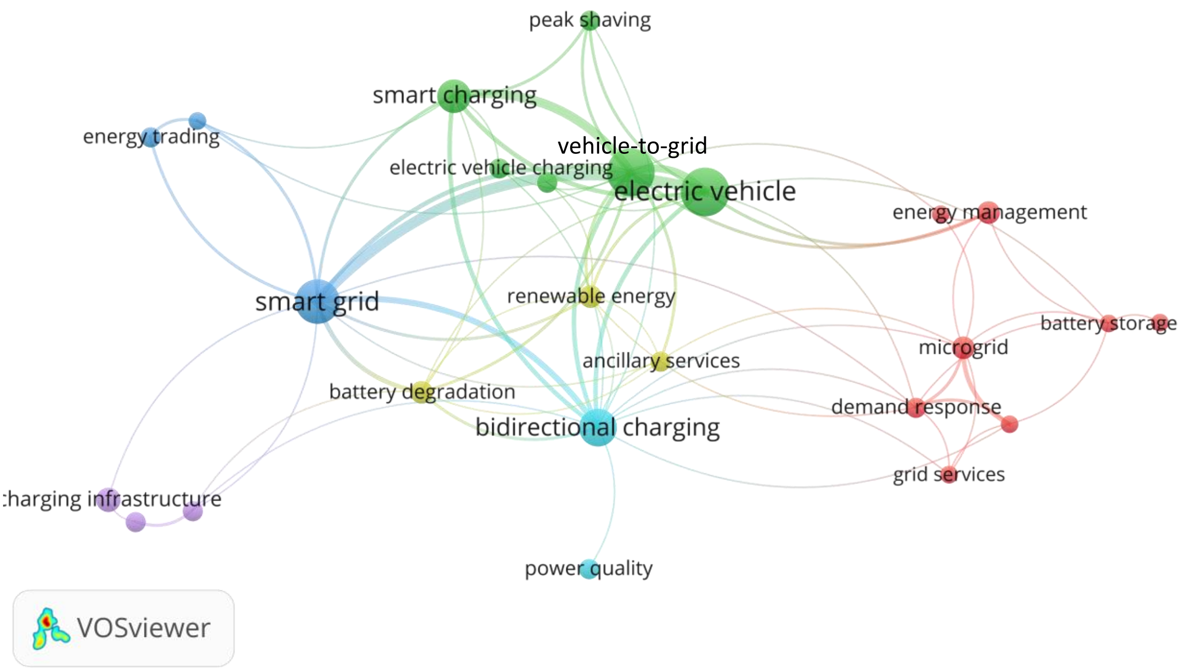

Figure 1 - VOSviewer bibliometric results for BIDIRECTIONAL CHARGING terms.
(NETWORK VIEW – COLOUR INDICATES KEYWORD CLUSTERS)

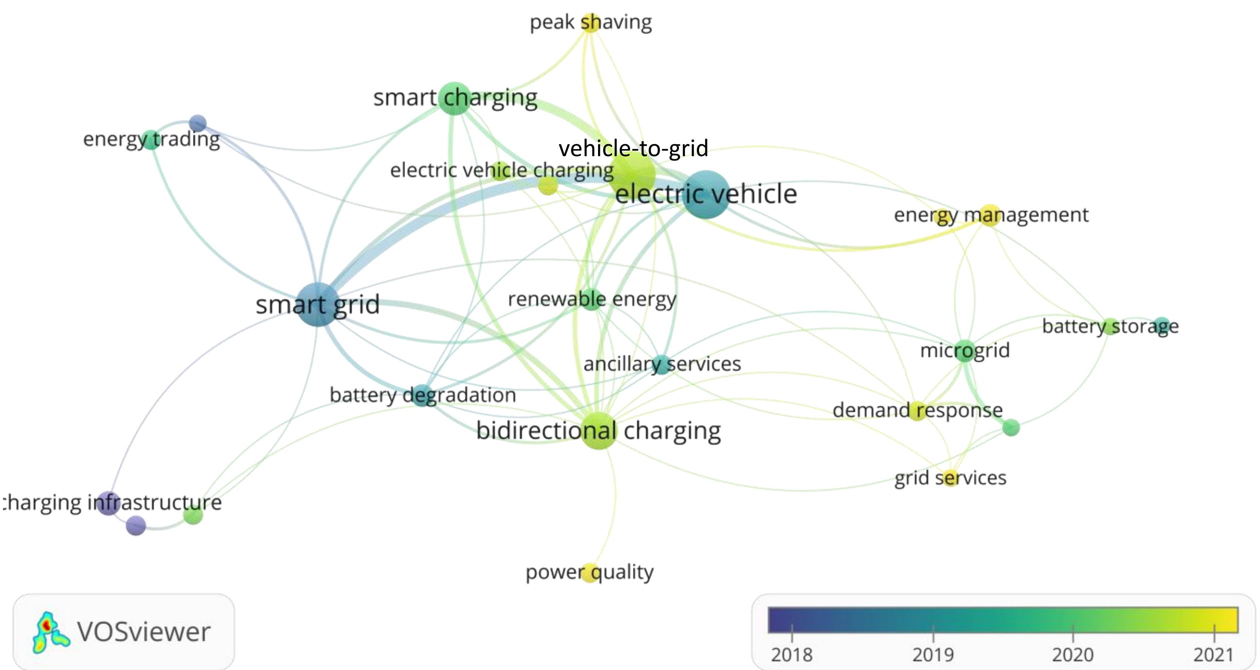

Figure 2 - VOSviewer bibliometric results for BIDIRECTIONAL CHARGING terms.
(OVERLAY VIEW – COLOUR INDICATES AVERAGE PUBLICATION YEAR)

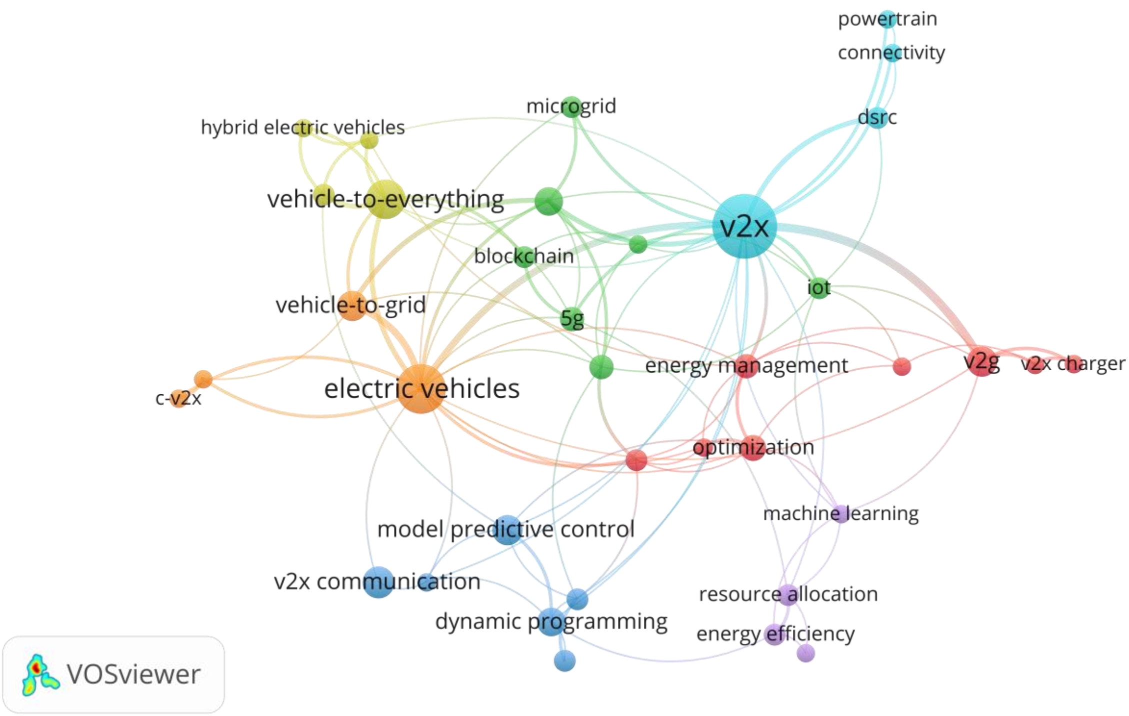

Figure 3 - VOSviewer bibliometric results for V2X terms.
(NETWORK VIEW – COLOUR INDICATES KEYWORD CLUSTERS)

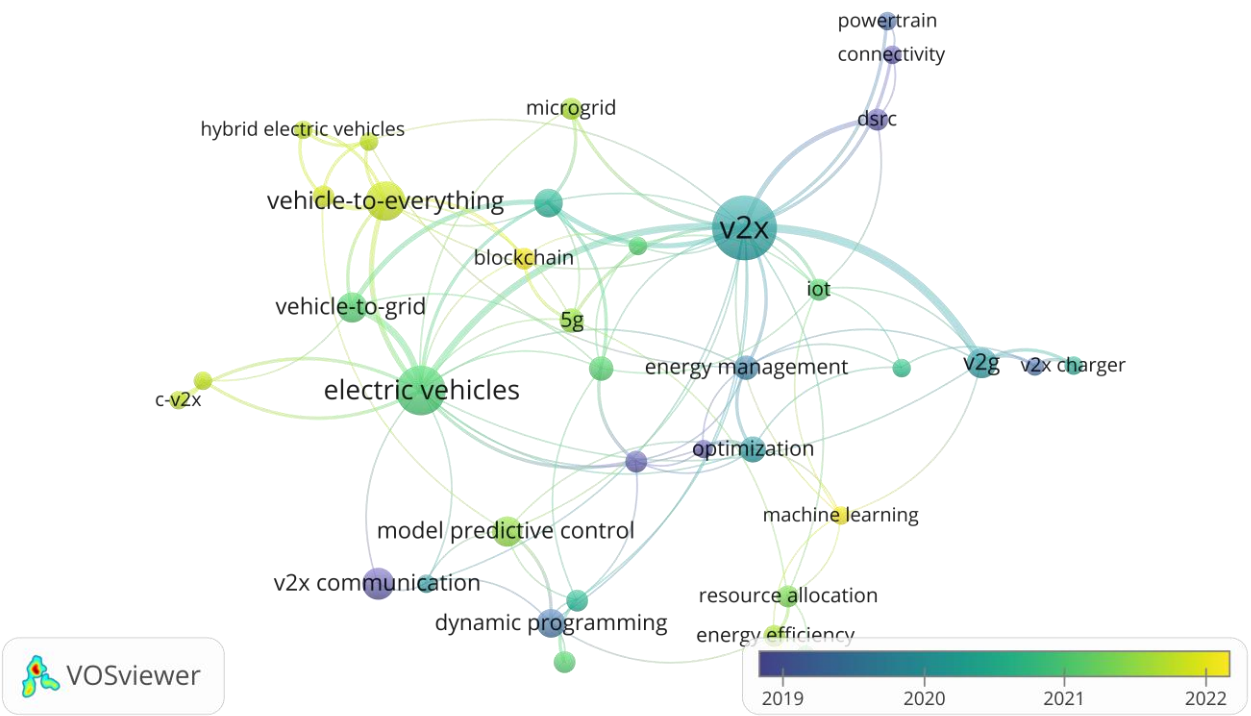

Figure 4 - VOSviewer bibliometric results for V2X terms.
(OVERLAY VIEW – COLOUR INDICATES AVERAGE PUBLICATION YEAR)

To support the bibliometric analysis, the authors have extracted from the broader database a small set of publications (twenty, in total) related to bidirectional EV charging, with the goal of capturing content use patterns related to V2X terms (figures 5-6).

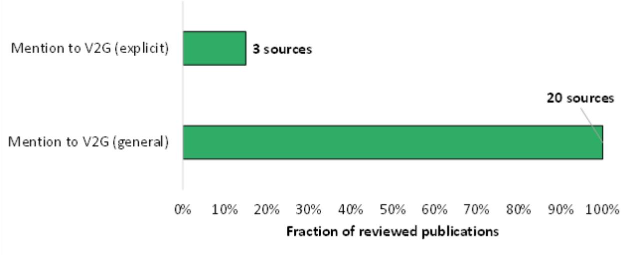

Figure 5 - Content research results: V2G.

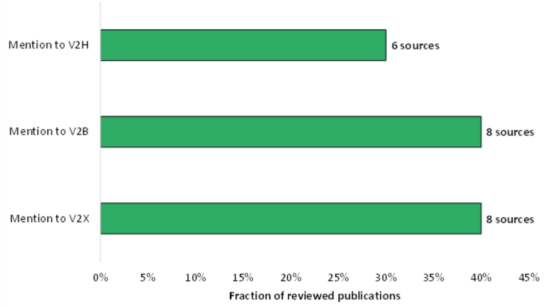

Figure 6 – Content research results: V2X, V2B, and V2H.

The combined analyses afford the following remarks:

- Bidirectional EV charging is perceived as a technology traditionally linked to V2G strategies, with building energy management as the only linked V2X-related emerging topic identified in the VOSviewer mapping outputs, despite no clear association to V2B found.
- The technical concept of V2X is filled with complexities. Its consideration as an agglomerate term to reflect multiple bidirectional EV charging strategies has only moderate scientific maturity, the VOSviewer maps show. In addition, only 40% of surveyed publications for content use that convention. The connection to V2G is well established, but bibliometric evidence of links to V2B and/or V2H is limited.
- The term V2X is used extensively in vehicular communications, a well-established field of work.
- The term V2G is widespread and universally used in the literature, but not always to express the same concepts. Most scholars consider it an umbrella term incorporating the various bidirectional EV charging strategies, i.e., V2G as a general substitute for V2X. The “explicit” consideration of V2G, i.e., to express “vehicle-to-grid” strategies alone, is less prevalent in the literature. Only 15% of the surveyed publications for content considered V2G explicitly (Figure 5).
- The terms V2B or V2H do not enjoy the scientific acceptance the term V2G does. Only 40% of the surveyed sources for content have considered the former, whereas only 30% have considered the latter. This can be tentatively justified with the lesser maturity of both concepts, when compared to the V2G concept, as the VOSviewer mapping results also show.

2.2 Clarification of smart charging terms

Based on the bibliometric analysis and content research of selected publications, the authors propose a taxonomy for V2X terms for use as a best practice. First, it is important to clarify what is and what is not smart charging, and in addition, what are considered “advanced” forms of smart charging (this is found, for example in [5]), and where does bidirectional charging fits in this scheme of things. These two terms are often used interchangeably, leading to technical ambiguities and communication issues.

It is understood that certain types of EV charging leave the burden of control to the discretion of EV users/electricity customers, by means of implementation of static TOU tariffs (indirect control) approaches. To the authors’ view, this approach does not fall under the category of smart charging, because there is no explicit/direct control mechanism in place.

Basic binary charging control approaches or more advanced charging rate adjustments all consist in direct control mechanisms. This is the case of V1G, V2G, V2B, and V2H. There are numerous technology advancements and research efforts underway focused on these types of EV charging, and its current market implementation maturity is medium-to-low. However, this is inconsequential to the definition of smart or advanced smart charging. Regardless of level of technical sophistication and the nuances of the implemented control, all these approaches are considered a form of advanced smart charging.

Lastly, bidirectional charging approaches are often considered the only type of advanced smart charging, but this is not the case, since V1G also belongs to this group.

Thus, the authors establish the following:

- SMART CHARGING corresponds to those EV charging approaches where mechanisms for direct control of the charging cycle of EVs are implemented.
- ADVANCED SMART CHARGING corresponds to those smart charging approaches where mechanisms allowing for EV charging rate adjustments are implemented.
- BIDIRECTIONAL (EV) CHARGING is an advanced smart charging approach that is specifically characterized by a two-way flow of electricity. It can take different configurations, depending on the type of system the EV charger is connected to (i.e., bidirectional EV charging scenario), e.g., the electric grid (V2G), a building meter (V2B), or a home (V2H). In certain and less common circumstances, the connection could be also to an electric load sink (V2L) or another vehicle (V2V).

3 Review of V2X literature

This section summarizes outcomes of a scientific literature review on bidirectional EV charging, by identifying main barriers to V2X innovation and pinpointing key scientific issues that currently draw most attention from researchers.

3.1 Hierarchy of V2X barriers

An extensive consultation of V2X literature retrieved a statistic of barriers to innovation in bidirectional EV charging. Here, the authors summarize the five most important barriers pinpointed in the study. The total of 15 barriers is mapped in Figure 7. Further details and a full register of references to this work are provided in [14].

3.1.1 Battery degradation: Allowing for an external entity to control and increase the charging and discharging cycles of an EV battery may result in proportional reduction of that battery's lifespan. However, this is not equally true for all V2X applications nor all battery chemistries, and for most batteries, the amount of potential degradation is linked to charging power and depth of discharge. Thus, battery degradation in V2X is a complex phenomenon, whose extent is dependent on the technical circumstances of a specific application. A more significant issue slowing down V2X advancements is the lack of scientific consensus around the level of degradation afforded by V2X applications, especially pertaining to V2G. A branch of the research suggests that significant disruption of the battery life cycle may occur, with severe economic impacts for EV owners. Another branch finds that additional degradation from V2G is limited, when compared to that from driving an EV. In addition, industry advancements and modern battery management systems seem to have significantly minimized such impacts. Clearly, the battery degradation body of research has not matured to a convergence point when the knowledge on dependence from multiple battery chemistries, V2X charging services and scenarios, as well as corresponding management strategies is well established. One point of consensus among researchers and industry alike is that more research and experimental testing is required to better understand the impacts of V2X operations on battery health, performance, and life span, as well as on the financial flows of EV techno-economics.

3.1.2 User adoption-related barriers: Behavioural barriers prevent the uptake of V2X technologies and services. These are generally a function of technology maturity levels, being invariably linked to the user's knowledge or concerns about that technology. Most EV users still know very little about how V2X works, or what it could do for them. A smaller fraction of users – those that are aware – takes due consideration of the development stage of the industry, holding legitimate concerns about its limited performance or benefits. In addition, third-party access and control of the vehicle constitutes an inconvenience for most users, leading to uncertainty about impact on driving range and fear of interference with their driving behaviors or lifestyle, or even with an unplanned use in case of an emergency. Another issue is user distrust in electricity market players running EV charging programs, due to potentially misaligned interests or invasion of privacy. Awareness campaigns on the potential benefits and risks of V2X, via social media campaigns, information events, and demonstration programmes can help manage and decrease user misconceptions and fears.

3.1.3 High upfront costs: V2X requires technically sophisticated power infrastructures and architectures with real-time integrated exchange of informational and transactional flows between multiple electricity market actors (EV users, grid operators, aggregator entities, etc.), all of which comes at a high cost. Given the value chain of electricity market services, it is expected that EV users will sustain the bulk of the added V2X costs, some of which also under the shape of new service subscriptions. On the other hand, many consumers are not drawn enough to financial savings in their consideration of costs linked to V2X and tend to undervalue aspects such as fuel savings (when switching from internal combustion vehicles) or other value streams that may emerge from the V2X upgrade. Thus, consumers need to become more informed to make educated decisions about their own mobility.

3.1.4 Lagging EV charging standardization: Slow standardization progress is a prominent barrier to V2X, related to the lack of standards and grid codes for integration of EV charging equipment in the power system, for the manufacturing of V2X-capable EVs, and their power electronics' components. This is partly a result from the still relatively low share of EVs in the global vehicles stock, especially bidirectional charging compatible EVs. Standardization is a crucial pillar of any industry as a technical means to ensure systems' compatibility/interoperability, due performance, and electrical safety. The growing EVs' penetration is expected to push industry and standardization organizations active in this domain, such as the International Electrotechnical Commission (IEC) and the International Organization for Standardization (ISO), to further develop and transpose common standards for charging infrastructure and interoperable solutions between bidirectional charging stations, distribution networks and the EVs themselves. It remains a key challenge for the whole industry that standards are generally country-specific and must be adapted each time.

3.1.5 Immature market and pricing mechanisms: The European electricity market regulatory context is not adjusted to V2G, considering that not even the provision of flexibility from stationary distributed resources is fully allowed in many European countries. This is partly the result of slow governance action on the integration of

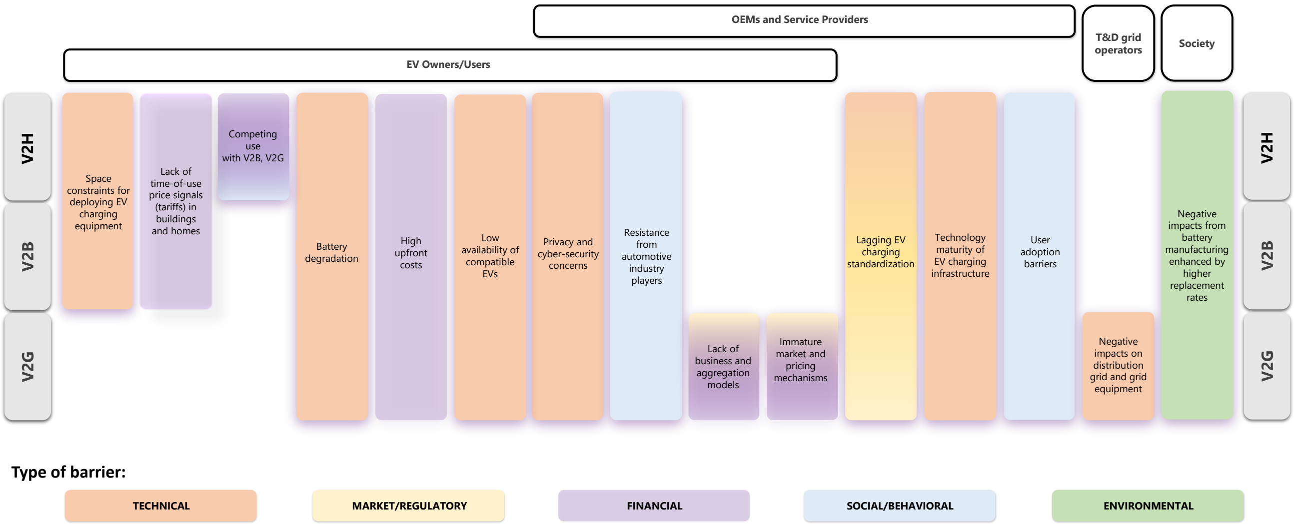

Figure 7 – Map of barriers to V2X implementation, categorized by typology, impacting actor, and application scenario.

charging infrastructure and of lack of clarity on the roles specific actors may come to play in the advent of mainstream V2G. DSOs need concrete input on the charging assets to be installed in their networks, and their potential ability to control them. More pilot projects are necessary studying the compatibility and ability of V2G to support the flexibility needs of grid operators, especially at the distribution grid level. The portfolio of services to be possibly provided and stacked by V2G are identified by IRENA [5] as being energy arbitrage, different types of frequency regulation, congestion management, and voltage regulation. However, V2G access to these markets is currently difficult or unclear. In other cases (e.g. solving DSO grid constraints), the markets may not exist yet. Here, government support in the form of regulatory sandboxes could play an important role in steering future legislation. If concrete benefits from V2G for DSOs remain unclear, then the required market mechanisms to accommodate it have no chance of emerging. Likewise, without a clear picture of service value, the enabling pricing mechanisms cannot be put together by DSOs and regulators. Without a consolidated V2G value proposition, V2X-compatible EV owners must resort to behind-the-meter energy optimization strategies for capturing energy savings, which is hardly motivation enough to invest.

3.2 Key issues in V2X literature

The symbiosis between the transport and power sectors brought by V2X creates major complexities. The authors propose the following group of six research topics that dominate the V2X research landscape. Further details, including extensive references to this are provided in [14].

3.2.1 Battery degradation minimization: Battery degradation research strives firstly to better understand battery wearing and loss of life under varied charging/discharging cycle combinations and scenarios. Secondly, it develops and implements methods to reduce it as much as possible. Working against this goal is the complex phenomena of battery cell degradation, which takes place in the electrochemical, thermal, and mechanical dimensions, being a function of a slew of parameters that include temperature, depth of discharge, rate of charging, duration of the connections, storage environment, cycling patterns, etc. Particularly important in maintaining battery health are thermal management strategies, which are themselves a sub-field of experimental research on degradation.

Other relevant battery degradation analyses include the study of the differential impact on the battery from providing different grid services and/or management strategies. Of particular importance is to clarify whether power-based services could be less impactful on the wearing than energy-based services and strategies; current literature seems to indicate so. Lastly, it must be noted that these studies must be run for different battery chemistries.

3.2.2 Bidirectional EV chargers' development and integration: Another branch of V2X research consists of technology advancement and integration of intelligent bidirectional EV chargers to enable mass deployment. These chargers are lagging in various features when compared to unidirectional chargers, including efficiency, costs, bulkiness, and weight. Another reported objective has been to minimize total harmonic distortion, with view to keep charger components within their operational limits. EV chargers also need to become better integrated with available EVs, resources, and systems. Lastly, user interface designs and charging sessions' management need to become more user-friendly to enable stress-free experiences. To reach the above goals, researchers focus on adjustments to the topological structure and control strategies of the chargers. There is also no definitive consensus on what the ideal electrical topology for a bidirectional charger should be, and debates on onboard vs. offboard charging or AC vs DC are still ongoing. As a result, only a handful of bidirectional chargers are commercially available, with low performance being reported by various projects. The development of a wider range of available charging infrastructure is critical for the further development of the V2X market.

3.2.3 Technical optimization and control: This type of studies focuses on control and optimization theory, applying innovative mathematical formulations (e.g., metaheuristics) to find optimal solutions for different technical problems related to V2X integration in smart grids, buildings, and homes, such as minimizing power losses, improving battery lifetime, increasing stability of power supply, scheduling EV charging, estimating driving patterns, etc. The work under this topic addresses some of the most demanding mathematical problems brought about by V2X, specifically treating stochastic variables related to EV charging and discharging behaviours, driving patterns, battery SOCs, but also related to the stochastic nature of electricity production from intermittent renewables, such as wind and solar power generation. It is also necessary to study imbalances and power quality impacts on the TSO and DSO-managed power grids, and to understand the implications on the operations of the electricity markets. A smaller branch of this research focuses on the role of flexibility aggregators in V2G service operations, by identifying the best control approaches and dispatch strategies, and on defining appropriate market models for those operations to take place safely and efficiently.

3.2.4 Techno-economic feasibility studies: In a mass deployment future, EV users will be confronted with multiple value stream possibilities from different possible V2X services and strategies (e.g., providing voltage support to a DSO, providing ancillary services to the TSO, providing energy management services in a parking lot, etc.) and choosing which ones to tackle, at what time and to what extent is a complex decision, for which techno-economic optimization is be required. This type of work is relevant for all the electricity market participants. Another important area is optimal energy resource allocation in building and homes, where EV batteries are considered an additional asset at the service of an energy management system or home energy management system, respectively. Business models' research is a recent sub-branch of this topic, in which potential revenue streams or savings from V2X can be analyzed in a systematic and quantitative manner. This kind of profitability analysis is pertinent in context of market uptake studies, representing a step further towards mainstream commercialization of V2X.

3.2.5 Policy and Regulation: The policy and regulation side of V2X research includes analyses of broader scope (typically market or sector-related) that often materialize with sets of policy implications and/or recommendations. The regulatory environment has a crucial effect in supporting and enabling V2X, and it has been observed that in absence of well-established market frameworks, together with already existing technical challenges and widespread lack of awareness, users tend not to engage and steer away. Some authors suggest that regulatory policy has the important role of diversifying the range of feasible use cases for V2X, under penalty of undue promotion of only the most simplistic use cases. Example recommendations that may arise from V2X policy research include the removal of administrative barriers and design of support policies to aggregators, and the design of fair compensation schemes for V2X service providers.

3.2.6 Social aspects: EV user awareness and engagement in V2X activities are markedly low. This is a product of technological, market, and behavioural determinants, requiring resolution trough concerted actions. Research addressing this topic of V2X attempts to turn that current situation, for example by producing sociotechnical models that analyze the interactions between market stakeholders under different sets of incentives to participation. More traditional social sciences research tries to uncover the complex behavioural phenomena preventing wider adoption of V2X, such as perceptions of inconvenience, distrust, confusion, and range anxiety suffered by users. Many seem to recognize the importance of such studies, but they constitute only a small fraction of the literature reviewed here. In practical terms, only a handful of studies investigate the role of consumer acceptance and driver behaviour in context of V2X systems, and even less address the need for institutional capacity building and cross-sectoral policy coordination.

4 Survey of V2X projects

This section provides a selection of existing and past V2X projects with the aim of providing limited insights on dominant market and technical orientations. In [5], the authors have identified a total of 159 projects and devised a systematic approach for comparing functional features between these projects, where further details and analysis on this topic can be found.

Generally, it is seen that most projects have a technical and market orientation, but that social issues are rarely addressed. In terms of charging solutions, most projects have adopted DC offboard solutions (in this survey, with only one exception). Lastly, there are very few projects where CCS port technology has been implemented and its interfaces fully tested.

4.1 The PARKER project

PARKER is Danish landmark V2G project known for being the first at demonstrating commercial-grade provision of frequency regulation by EV fleets to a TSO via market aggregation. The project has successfully validated the hypothesis that fleets of series-produced, un-modified EVs can support the power grid both locally and at a system-wide level, by becoming a vertically integrated resource. The project analyzed grid applications, grid readiness, as well as scalability and replicability of V2G schemes. Most of the pillar technologies adopted in PARKER, including the EV charging equipment, the EVs themselves, and aggregation software, had already been tested and validated, which reduced operational risks.

The project's multidisciplinary collaboration among academia, technology conglomerates, fleet owners, and customers included Nissan, Mitsubishi Corporation, Mitsubishi Motors Corporation, PSA ID, NUVVE, Frederiksberg Forsyning A/S, Insero A/S, Enel and DTU Electrical Engineering (PowerLabDK).

The main demonstration site for PARKER is the headquarters of utility company "Frederiksberg Forsyning", close to Copenhagen, where frequency regulation on market terms is provided by a fleet of 10 Nissan eNV200 electric vans used mostly for maintenance and service tasks (7AM – 4PM). The vehicles are connected to 10 units of 10 kW ENEL V2G DC bidirectional chargers. At Frederiksberg, the company NUVVE operates as an aggregator, whereas the utility SEAS acts as balance service provider to the market. CHAdeMO allows for the use of, vehicles supporting V2G. By controlling the vehicles bidirectional active power set-point, according to the system frequency, NUVVE and SEAS acts in the market as to receive a capacity payment.

The most relevant finding of the PARKER project is that EV models from PSA, Mitsubishi, and Nissan together with Enel X DC V2G chargers can support V2G and are market-ready to provide advanced frequency regulation services to a TSO. In Nordic market terms, this can be realized under the auspices of Frequency Containment Reserve (FCR) provision. However, replicability of this solution is only valid where similar support framework and service remuneration conditions are established.

4.2 The Nuvve-SDG&E V2G School Bus Pilot – Cajon Valley

Electric medium- and heavy-duty vehicles, such as electric school buses are a valuable resource for provision of V2G services due to holding larger batteries than light-duty vehicles and typically spending many peak solar hours parked. Yet, projects capitalizing on that looming opportunity are considerably rare across the globe. The V2G School Bus Pilot program in California is one such initiative, here fruit of a partnership between electric mobility company Nuvve and utility company San Diego Gas & Electric (SDG&E). The program involves three school districts, one of which being the Cajon Valley Union School District. This specific 5-year long V2G pilot was the first-ever to become operational in Southern California, helping to reach climate goals while also bolstering grid reliability. As part of the initiative, SDG&E helped fund and installed six 60kW bi-directional DC fast chargers at Cajon Valley's bus yard, in El Cajon. The electric school buses were provided by the Lion Electric Company.

The groundbreaking aspect of this project is the participation of the electric buses in a market mechanism encouraging business customers to voluntarily reduce energy usage or feed energy back to grid during emergency load reduction events – the summer Emergency Load Reduction Program (ELRP). The program put forth by SDG&E had been proposed earlier to the utilities by the California Independent System Operator (CAISO) as a strategy to manage increased demand for energy statewide and prevent blackouts, especially during the summer season. By leveraging V2G technology, Cajon Valley participates in the ELRP and receive $2 per kWh for each (verified) load export event, for a minimum of 30 hours and up to 60 hours for the season (which lasts from May to October). Customers are informed of eligible grid emergency periods via a grid alert emitted by CAISO.

4.3 The SEEV4-City project – Smart, clean Energy and Electric Vehicles for the City

The SEEV4-City project is a large-scale Northern European trial combining electric transport, renewable energy (generation, storage, and consumption), electricity grid and smart energy management. One of the core objectives was to introduce the concept of "Vehicle for Energy Services" (V4ES) into sustainable commercial/social business models. By optimizing the use of EVs, renewable energy sources and smart Information and Communication Technologies (ICT) in a series of novel and unique operational pilots, SEEV4-City demonstrates how electric vehicles can support the energy transition in cities.

SEEV4-City's operational pilots exhibit V2X potential at different scales, aiming for an increase in energy autonomy and in ultra-low emission kms, and for avoiding extra investments, in order to make existing electrical grids compatible with an increase in electromobility and local energy production. The project delivered 6 pilots in 4 countries, which are:

- Loughborough Living Lab - single residential household with solar also installed.
- Amsterdam ArenA - Up to 200 uni- and bidirectional connected EVs will be part of the smart energy system of the Amsterdam ArenA providing backup and peak shaving services as well as increased renewable energy integration and FCR.
- City depot of Kortrijk - single Nissan LEAF van providing V2B with onsite solar.
- Leicester City Hall - Vehicle to office with four vehicles at present.
- Vulkan Real Estate Building Oslo - innovative EV parking garage seeking to deploy V2G.

The pilots involve different operational environments and levels of smart charging or V2X integration, including charging scenarios V2H, V2B, and also concepts such as "Vehicle-2-Street/Neighbourhood" (V2N), and Vehicle-2-City (V2C). As result from the operational pilots, SEEV4-City also developed commercially and socially viable business models to integrate EVs and renewable energy.

4.4 The "LEAF-to-Home" project

The "LEAF-to-Home" project has been the first in the world to enable a commercially available V2H product. The project took shape in the immediate aftermath of the 2011 Tōhoku earthquake and tsunami, when large parts of the grid went offline. The business case for this application is to provide V2X technology as an emergency power supply, i.e., as an "insurance" that allows people to proactively prepare for future emergencies. This system helps balance the electrical supply system and can lower a consumer's electricity bill. The LEAF-to-Home system helped encourage Nissan LEAF owners to charge their cars with electricity generated during the night, when demand is low, or sourced from solar panels. This assists in balancing energy needs by supplying electricity to the grid during daytime, when demand is highest. It can also be used as back-up power source in case of power outages and/or shortages.

4.5 The SCALE project – Smart Charging Alignment for Europe

SCALE is a large-scale initiative with strong orientation towards commercialization and uptake of V2X technologies and services, contributing to reduce technical, organizational, economic, social, and policy-related uncertainties, and help shape an ecosystem where flexibility potential of EV batteries will be harnessed for the first time at "scale". The project tests and validates advanced smart EV charging solutions and services for different vehicle segments and across 13 high-value use cases in 7 real-life demonstration contexts: Oslo, Norway, Rotterdam/Utrecht and Eindhoven, Netherlands, Toulouse, France, Greater Munich Area, Germany, Budapest/Debrecen, Hungary, and Gothenburg, Sweden. The strategic charging technology choice for the demonstrators is AC onboard charging, given (according to project's team) the current stronger scale-up business case for that option. SCALE will create a system blueprint for user centric V2X for European cities and regions.

Going further, SCALE's project results, best practices, and lessons learned will be shared across EU cities, regions, and relevant e-mobility stakeholders.

5 Conclusions

This paper summarizes results of a scientific review and survey of V2X projects performed by the DriVe2X project team. It does so in three stages. Firstly, it focuses on taxonomy aspects, performing a bibliometric analysis and studying nomenclature conventions for smart charging. The analysis delivers targeted insights that help better understand misconceptions around the utilization of terms such as "Bidirectional EV charging", "V2X", and "V2G". Subsequently, a clarification of smart charging terms is proposed with goals of resolving technical ambiguities and communication issues among practitioners.

Secondly, it compiles the most important barriers to V2X implementation and research topics from the scientific literature. Among the barriers, battery degradation may be the biggest bottleneck. More research and experimental testing are required on this field to better understand the impacts of V2X operations on battery health, performance, and life span, as well as on the financial flows of EV techno-economics. Highlighted research topics dominating the current V2X landscape include user adoption aspects, control optimization approaches, bidirectional EV chargers' development and integration, techno-economic feasibility analyses, and once again battery degradation minimization studies.

Finally, it surveys a small selection of existing and past V2X projects, most of these having a technical and service provision orientation. DC offboard solutions are dominant, but some projects argue against its business case. Also, most project experiments took place under CHAdeMO connectivity, with still very few projects where CCS port technology has been implemented and its interfaces tested. Several new V2X projects are up and running and the next years will deliver exciting results.

A more detailed explanation of this work can be found in Deliverable D1.1 of the DriVe2X project [14].

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