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Electric Vehicles Management for carbon neutrality in Europe

Deliverable D10.8

Roadmap for the solutions enabling the mass deployment of EVs

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Disclaimer

This document has been produced in the context of the EV4EU[1] project. Views and opinions expressed in this document are however those of the authors only and do not necessarily reflect those of the European Union or the European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the grating authority can be held responsible for them.

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[1] https://ev4eu.eu/

Executive Summary

The EV4EU project has developed new methods for electric vehicle (EV) integration into energy systems through the successful testing of advanced smart charging and vehicle-to-everything (V2X) technologies across several European demonstration sites. Deliverable D10.8, *Roadmap for the Solutions Enabling the Mass Deployment of EVs*, consolidates the technical, regulatory, economic, and user-centric insights derived from these large-scale demonstrations, with the objective of informing future deployments and supporting the mass adoption of EVs as active participants in the energy ecosystem.

The findings presented in this document provide an extensive evaluation of real-world implementations, demonstrating both the factors that enabled success and the obstacles that remain. The project identifies two major challenges for V2X service scalability: fragmented national frameworks and the absence of common standards for V2X service delivery. This situation is further complicated by market design uncertainties and insufficient mechanisms to remunerate EVs for the flexibility services they provide. The demonstrations show that EVs can support grid stability, manage congestion, and help integrate renewable energy sources when appropriate regulatory conditions are in place. Through its business and market analysis, the project demonstrates that practical value propositions must be established for all stakeholders, including distribution system operators (DSOs), aggregators, service providers, and end-users. Multiple business cases show strong potential for smart charging and local flexibility services, but their financial viability depends on regulatory compliance, market development, and technological integration.

The implementation of user-centred design has become a key foundation of EV4EU, as user acceptance and consumer behaviour patterns are critical to project success. The study shows that users are more likely to engage with the system when it is simple, transparent, and clearly communicates its perceived economic and environmental value. The research also shows that user participation in flexibility programmes improves through well-designed user interfaces and reward systems that maintain user satisfaction.

The project delivers essential technical knowledge on the operation of flexibility services and the integration of EVs into power grids. The demonstrations validate a range of services, including peak shaving, load shifting, and bidirectional energy exchange, while also exposing operational constraints related to communication reliability, device heterogeneity, and limited protocol standardisation. The findings highlight the need for architectures that ensure strong interoperability while managing multiple assets in real time. The analysis further emphasises the transformative potential of smart charging and V2X in enabling a more flexible, efficient, and resilient energy system. The benefits include improved renewable energy utilisation, enhanced operational efficiency, and the development of additional revenue streams. At the same time, the project highlights several challenges, including the coordination of multiple agents, current restrictions in AC and DC charging systems, and the need for reliable large-scale solutions capable of operating during periods of high EV usage.

The project establishes interoperability as a central theme, bringing together knowledge from both device operators and system operators. The integration of different technologies and protocols remains a major challenge and requires further standardisation through common control systems. The deliverable establishes essential performance metrics to evaluate demonstrator effectiveness and presents an organised plan for deploying EV and V2X systems across Europe. The roadmap provides specific guidance for different stakeholder groups while identifying key areas requiring further research and policy development to achieve European standardisation. EV4EU demonstrates that EVs are essential components of the energy transition, functioning as flexible and distributed energy resources. Fully realising this potential requires international collaboration among standard-setters, technology developers, and market operators. The project outcomes provide a strong foundation for

organisations to overcome current barriers and advance towards a sustainable, user-centred energy system.

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Acronyms

AC	Alternating Current
AC/DC	Alternating Current/Direct Current
ADMS	Advanced Distribution Management Systems
BESS	Battery Energy Storage System
BM	Business Model
BMC	Business Model Canvas
BUC	Business Use Case
CIM	Common Information Model
CPMS	Central Point Management System
CPO	Charge Point Operator
CS	Charging Station
DC	Direct Current
DER	Distributed Energy Resources
DR	Demand Response
DSO	Distribution System Operator
EMPS	Electromobility Services Provider
eMIP	eMobility Interoperation Protocol
EU	European Union
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FCR	Frequency Containment Reserve
GDPR	General Data Protection Regulation
G2V	Grid-to-Vehicle
GHG	Greenhouse Gas
KPI	Key Performance Indicators
LFMS	Local Flexibility Market Services
LV	Low Voltage
MFE	Market-Flexible Entities
OCPP	Open Charge Point Protocol
OCPI	Open Charge Point Interface
OICP	Open InterCharge Protocol
Open ADR	Open Automated Demand Response
OSCP	Open Smart Charging Protocol
RES	Renewable Energy Sources
SC	Smart Charging
SoC	State of Charge
TSO	Transmission System Operator
V1G	Controlled Unidirectional Smart Charging
V2B	Vehicle-to-Building
V2G	Vehicle-to-Grid
V2H	Vehicle-to-Home
V2L	Vehicle-to-Load
V2X	Vehicle-to-Everything
VPP	Virtual Power Plant

1 Introduction

1.1 General Context

The transition towards carbon neutrality in Europe is strongly supported by the electrification of transport and the increasing integration of renewable energy sources (RES). In this context, electric vehicles (EVs) are expected to play a central role, not only as additional electrical loads, but as active elements within a broader, interconnected energy ecosystem.

However, the large-scale deployment of EVs introduces significant challenges for power systems, urban infrastructure, and energy markets. Uncoordinated charging may lead to peak demand amplification, network congestion, and inefficient use of existing assets. At the same time, the growing interaction between mobility, energy systems, and urban environments requires solutions that are not only technically efficient but also aligned with user behaviour and real-world constraints.

To address these challenges, the EV4EU project adopted a bottom-up and user-centric approach to the development and validation of Smart Charging (SC) and Vehicle-to-Everything (V2X) management strategies. These strategies support the transformation of EVs into flexible, bidirectional resources capable of supporting power system operation, facilitating renewable integration, and contributing to the evolution of energy services and urban systems.

Through multi-site demonstrations across different European contexts, EV4EU evaluated the performance, feasibility, and scalability of advanced control methodologies, digital platforms, and service-oriented approaches. This includes the interaction between EV users, system operators, technology providers, and market mechanisms, ensuring that the proposed solutions reflect the complexity of real-world deployment conditions.

This deliverable builds on these activities to consolidate the main lessons learned, with a focus on identifying the key factors that enable or constrain the large-scale adoption of Smart Charging and V2X solutions in Europe.

1.2 Document Structure

This document is structured to provide a comprehensive and integrated analysis of the lessons learned within the EV4EU project, bridging technical findings with strategic insights for large-scale deployment.

Section 2 presents the core lessons learned, organised across key dimensions including regulatory barriers, business models, consumer engagement, flexibility services, grid management, and advantages of Smart Charging and V2X. Complementary aspects such as charging infrastructure (AC vs DC), interoperability, and key performance indicators are also addressed.

Section 3 defines a roadmap for the mass deployment of EVs and V2X solutions, providing targeted recommendations for different stakeholder groups and outlining priorities for Europe-wide harmonisation and future research. Section 4 summarises the main conclusions, and finally, Section 5 presents the references supporting this work.

1.3 Relationship with Other Deliverables

The deliverable *Roadmap for the solutions enabling the mass deployment of EVs* coordinates the main project results from the EV4EU project to establish regulatory analysis connections with business modelling and technical validation and user engagement activities. The document combines *D1.3 –*

Regulatory opportunities and barriers for V2X deployment in Europe [1] findings about regulatory frameworks with *D1.4 – Business Models Centred in the V2X value chain* [2]*,* business case with the *D1.5 – V2X Use Cases Repository [3]* and *D5.1 – Information Exchange needs to enable different UCs [4]*, that includes information exchange requirements data to create a unified system that links market needs with technical requirements and operational needs.

The study also combines user-focused deliverables from WP3 [5], [6] which deliver analysis through user behaviour data and demonstrator-specific deliverables from WP6 [7], [8], WP7 [9], [10], WP8 [11], and WP9 [12] which tested Smart Charging and V2X solutions in real-world environments. The KPIs demonstrate technical performance and economic viability and user acceptance through their definition and assessment across demonstrators, which establishes a framework for performance assessment.

2 Lessons Learned

This section exhibits the main findings achieved through the design, implementation, and operation of the EV4EU project. The analysis demonstrates real-world validation results which show both enabling factors and ongoing difficulties that electric vehicle integration poses to energy systems. The discussion covers essential thematic areas which include regulatory barriers, business models, user engagement, flexibility services, markets, grid management, smart charging, V2X technologies, AC and DC charging infrastructure. The section establishes links between empirical research results and system impacts through integrative analysis which shows how technology and regulation and market design elements connect to each other. The study investigates interoperability and scalability and economic viability and user acceptance as essential success factors which determine deployment outcomes. The lessons presented are not only reflective of the EV4EU experience but are also intended to provide actionable insights to support future research, policy alignment, and the large-scale implementation of EV-based flexibility solutions across Europe. Figure 1 illustrates main areas of the lessons learned from EV4EU project.

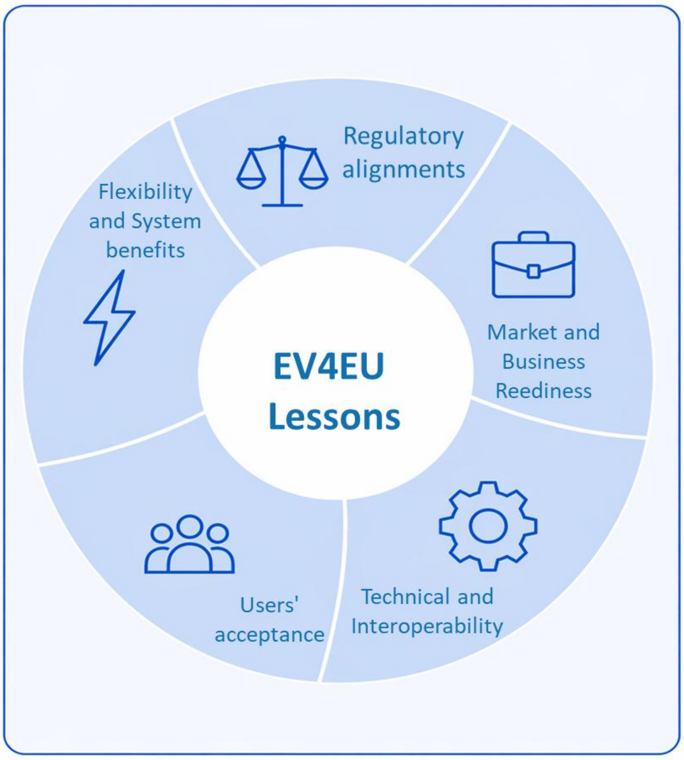

Figure 1: Main areas of the Lessons Learned from the EV4EU Project

2.1 Regulatory Barries and Guidelines

Deliverable 1.3 [1] presents a comprehensive analysis of the Regulatory opportunities and barriers for V2X deployment in Europe. It includes regulatory frameworks, barriers, and opportunities for V2X deployment and EV integration across Europe and within specific national contexts, based on the EV4EU pilot demonstrations.

The analysis included, first and foremost, the Energy Policy and the long-term targets that have been established by the European Union to tackle climate change and achieve energy independent community. The EU aims to reduce greenhouse gas emissions, increase renewable energy, and promote energy efficiency, with EVs playing a key role. Several regulations and directives have been established to promote these targets, providing energy efficient measures, climate actions, incentives on CO2 emission reductions, and more EU policies that emphasise the integration of EVs as energy storage and demand flexibility tools to support decarbonisation.

Additionally, EU legislation on EVs and charging infrastructure was introduced. That involved EU regulations govern vehicle type approval, safety standards, and the deployment of charging points, supporting the growth of EV adoption. EU directives set minimum requirements for EV safety, charging station deployment, and CO_2 emissions standards. Emphasis is placed on the Open Charge Point Protocol (OCPP) and interoperability standards that facilitate V2X communication and charging infrastructure integration. Legislation promotes the development of a pan-European charging network and standardisation of V2X technologies. Finally, national laws in Greece, Portugal, Slovenia, and Denmark, the piloting locations of EV4EU, align with EU directives, offering incentives and regulations to support EV deployment.

Legislation is considering also the energy market aspect, alongside emerging schemes and technologies such as distributed energy resources (DERs), demand response (DR), and market integration to enhance grid flexibility and support V2X functionalities. Legislation encourages the integration of renewable energy sources and energy storage solutions, including EV batteries. Additional policies aim to enable V2X to participate in energy and ancillary service markets, enhancing grid stability and efficiency.

One important emerging regulatory aspect is the data management and cybersecurity of the critical infrastructure, including the V2X deployment, with GDPR being a key regulation. Data privacy concerns and cybersecurity risks are major points that should be addressed during the E-mobility uptake, ensuring data protection, user privacy, and secure data exchange. Interoperability and secure communication between V2X systems and grid operators is also essential.

Each pilot country has tailored legislation to promote EV adoption and infrastructure development, aligned with the above-mentioned EU directives. While certain themes recur across national regulations, the structure of each section is not rigid in terms of the topics discussed. This is due to the differences in focus, prioritisation and maturity in each country that demands a freer format. In a nutshell, Greece has issued legislations since 2019 that offers incentives and rules to boost EV penetration, although regulations have been established already since 2014; Portugal has established a national electromobility plan since 2009, with recent laws on Zero Emission Vehicles in 2022, aiming for 18% EV fleet share by 2030 and 85% by 2040; Slovenia provided incentives for EVs, and mandates for charging points in new/renovated buildings, alongside integration with EU regulations; Denmark focuses on monetary incentives, charging stations, and smart meters, promoting the use of electric vehicles and encouraging the development of smart grid systems to integrate renewable energy sources into the existing grid.

The analysis also identifies legislative gaps and barriers, with opportunities to enhance V2X deployment. Based on each country's regulations several barriers are identified correspondingly. Greece currently lacks a framework for flexibility provision from DERs, including EVs and V2X, to transmission and distribution networks. Limited network observability further restricts DER capacity, creating an opportunity to expand demand-flexibility legislation towards local markets and V2X services. Portugal faces barriers related to charger deployment in old buildings, strict regulation, limited financial incentives, and the absence of specific rules for mobility and self-consumption in Energy Communities. Moreover, V2X is not yet legislatively covered, hindering EV adoption. Regulation should consider services to operators for grid management and incentives for EV adoption. Slovenia faces lack of encouragement for multi-apartment building chargers posing a barrier for widespread EV infrastructure, not sufficient incentives for the purchase of EVs, and regulations that make the charger installation process long-lasting and therefore not feasible in many cases; Denmark has a fragmented charging network that hampers accessibility, which is an opportunity to improve network integration and standardisation, additionally there is a lack of incentives for increasing the EV penetration rate and lack of unified regulations and standards of EV chargers.

2.2 Business Cases

The EV4EU project developed a structured set of business models (BMs) and business use cases (BUCs) to define the value that V2X solutions can provide across the entire value chain, from EV users to system operators. The work was conducted iteratively through dedicated workshops with all four demonstrator teams and built upon the Value Proposition Design methodology [13], using the Business Model Canvas (BMC) and Value Proposition Canvas (VPC) as primary tools.

Twelve BMs were developed in D1.4 [2], covering key actors in the V2X ecosystem: TSO and DSO services, Virtual Power Plant (VPP), V2X charging station manufacturers, Charging Point Operators (CPOs), fleet management service providers, cloud platform managers, and various categories of V2X managers such as companies, parking lot managers, building managers, and house managers. The proposed BMs span both product-oriented and service-oriented approaches, reflecting the diversity of deployment contexts across Portugal, Denmark, Slovenia, and Greece. It is important to note that while individual actor perspectives informed the development of these BMs, the BMs themselves are defined and operationalised at the level of each demonstrator, rather than at the level of individual actors. A key conclusion of D1.4 is that new V2X services create genuine business opportunities for all stakeholders involved, including the facilitation of distribution system operation, better coordination with RES, and the reduction of charging costs for end users [2].

Building on these BMs, D1.5 defined seven BUCs [3] following the IEC 62559-2 methodology, ensuring replicability and compatibility across different regulatory and technical environments. The BUCs cover market participation through a VPP (BUC1, WP7), system-level RES curtailment management (BUC2, WP6), explicit demand response for grid congestion management (BUC3, WP9), implicit demand response for RES and EV coordination (BUC4, WP6 and WP8), dynamic flexible capacity contracts (BUC5, WP8), DSO flexibility services (BUC6, WP7), and frequency regulation services (BUC7, WP9). These BUCs represent the operational translation of the proposed BMs into concrete, testable scenarios at the four demonstrator sites, each addressing a distinct set of grid management challenges and market participation mechanisms relevant to the mass deployment of EVs [3].

D5.1 extended this work by identifying the information exchange needs and barriers between actors for each BUC [4]. Four key technical and institutional requirements were identified across the BUCs: the existence of a flexibility market or equivalent contractual framework, V2X-capable charging infrastructure, a digital communication platform, and an Open V2X Management Platform. Where flexibility markets are not yet established, as is the case in Slovenia, simulation environments are foreseen to ensure that the results remain transferable and not limited to a specific regulatory context.

Taken together, the three deliverables D1.4, D1.5 and D5.1 establish a coherent and scalable foundation for the mass deployment of EVs and V2X services. The proposed BMs and BUCs are sufficiently general to be applicable beyond the specific demonstrator countries, while remaining grounded in the regulatory, technical, and market realities of each pilot region. The lessons derived from this work, summarised by demonstrator below, provide a basis for further development of exploitation strategies, innovation roadmaps, and replication frameworks in the subsequent project phases.

The Portuguese demonstrator, tested across households, a public office building, and a company campus on São Miguel Island, demonstrates that insular energy systems with high-RES penetration offer particularly favourable conditions for V2X business cases centred on renewables curtailment management and voltage regulation. However, the experience also reveals that the commercial viability of these BMs is contingent on regulatory adaptations that are not yet in place: the variable charging prices implied by BUC2 are not accommodated in current Portuguese legislation, and the role of the TSO in the invoicing process managed by the electric mobility roaming provider remains undefined. For replication in other islands or isolated energy systems, these regulatory gaps must be addressed before the proposed BMs can be fully operationalised, underscoring that technical readiness alone is insufficient without a parallel evolution of the regulatory and market framework [7].

The Slovenian demonstrator, with GEN-I simultaneously acting as aggregator and CPO, demonstrates the feasibility of V2X market participation (BUC1) and DSO flexibility procurement (BUC6) in a context where the local flexibility market in Slovenia is not yet fully established [2], [3], [14], [15]. A key lesson emerging from this demonstrator is that the technical capability to aggregate and dispatch V2X flexibility must be accompanied by a corresponding readiness on the DSO side. This encompasses two critical enabling conditions: first, the establishment of a local market platform through which flexibility can be procured and settled in a transparent and standardised manner; and second, the upgrade of ADMS to enable the DSO to send activation signals to aggregators and monitor network conditions in real time, so that V2X flexibility can be effectively coordinated within the broader distribution system operation. Furthermore, the need to simulate the flexibility market where it does not yet exist confirms that regulatory maturity is a prerequisite for commercial deployment, and that the transition from simulated to real market conditions represents one of the most critical steps on the path to mass deployment of V2X flexibility services. Building on knowledge acquired during testing and monitoring phases documented in D7.2 [9] and D7.3 [10], the BMs were further refined using the Service Business Model Canvas template, providing a more structured representation of the value delivered through V2X services in a real operational context. The resulting lessons learned, compiled in D7.4 [16], offer a concrete, evidence-based foundation for assessing service marketability and adapting the proposed BMs to broader deployment contexts.

The Greek demonstrator, involving HEDNO as DSO and PPC as CPO and platform manager, provides key lessons on the role of open platform interoperability as an enabler of scalable V2X business models. The demonstration of both dynamic network tariffs (BUC4) and flexible capacity limitation contracts (BUC5) shows that DSOs can access a spectrum of flexibility instruments without directly controlling distributed energy resources, ranging from price signals that motivate voluntary user response to structured procurement contracts that guarantee capacity availability. The primary lesson for mass deployment is that the success of these BMs depends critically on the smooth integration between the CPO's open V2X management platform and DSO support systems, and that achieving this interoperability requires both standardised communication protocols and a phased validation approach, as reflected in the four-phase deployment plan adopted in the Greek demonstrator [11].

The Danish demonstrator, operating across DTU Risø Campus and Campus Bornholm with parking lot managers as the central actor, demonstrates the conditions under which EV aggregations can participate credibly in both demand response and frequency regulation markets. The key lesson is that market access for new flexibility providers is governed by stringent prequalification requirements, including strict technical thresholds for frequency sensitivity, measurement resolution, and data retention, which represent a significant but manageable entry barrier. The Danish context also suggests that where a mature regulatory and market framework is in place, the business case for V2X participation in ancillary service markets is technically sound and can generate additional revenue streams for parking lot operators, making it a replicable model for other European countries.

Table 1: BUCs Demonstrator Lessons Learned - Limitations and Critical Insights

Demonstrator	Lesson Learned	Mitigation / Recommendation
Portugal	Regulatory gaps, undefined dynamic pricing rules and unclear TSO role in invoicing prevent full commercial operationalisation of RES curtailment BMs.	Update regulatory frameworks to accommodate dynamic charging prices and formally define TSO involvement in the invoicing chain prior to commercial rollout.
Slovenia	V2X aggregation readiness on the aggregator side must be matched by DSO-side readiness, namely a development of local market platform and upgrade of ADMS. The absence of an established flexibility market required simulation, limiting real-market validation of BMs.	Establish local market platforms for flexibility procurement and upgrade ADMS capabilities prior to commercial deployment. Accelerate flexibility market framework development to enable real-world validation.
Greece	Successful deployment of DSO flexibility instruments depends critically on interoperability between CPO platforms and DSO backend systems, requiring standardised communication protocols.	Adopt a phased validation approach and embed open standards (OCPP, OCPI) in national regulatory frameworks and infrastructure procurement specifications.
Denmark	Stringent frequency containment reserve (FCR) prequalification requirements represent a significant but manageable entry barrier; however, where a mature market framework exists, the V2X business case is technically and commercially sound.	Streamline prequalification procedures for aggregated flexibility providers and use the Danish market model as a reference benchmark for other European countries developing similar mechanisms.

2.3 Consumers and User Engagement

2.3.1 User-centric approach in EV4EU

The project strived to adopt a user-centric approach to the development and deployment of V2X strategies, recognising from the start that large-scale EV adoption not only depends on technological performance, but also on user needs, behaviours and expectations alignment, since they directly influence infrastructure usage, system efficiency, and ultimately V2X participation rates.

To capture this behavioural dimension, a comprehensive research framework was implemented, combining quantitative and qualitative methods across Denmark, Greece, Portugal and Slovenia. This included research prior to demonstrators' implementation, studies to understand experience during their usage, and a final assessment of user satisfaction with services deployed. Results from this research were reported during the project in the following deliverables: D3.1 - EV Users' Needs and Concerns - Preliminary Report [5]; D3.2 - Apps and Tools design principles promoting EVs and V2X adoption [17]; D3.6 - Decision support tool for high-level coordination of V2X management strategies [18]; D3.7 - EV Users' Needs and Concerns - Demonstrators' Experience Report [19]; D6.2 - Engagement Activities Report in Azores demo [8]. This section summarises the main results and conclusions drawn, highlighting lessons learned from this work.

From the research, it was possible to conclude that:

- EV adoption is driven by a mix of environmental motives, economic benefits (cost savings/incentives), and driving experience, and these drivers vary by country and user profile.
- Daily usability matters: reliability and accessibility of charging, simplicity and transparency of charging processes, home-charging access, and clear digital information/tools are central to satisfaction.

- Barriers to EV adoption can be both structural and behavioural:
    - Structural: high upfront costs, electricity price uncertainty, uneven/insufficient infrastructure, dependence on residential charging
    - Behavioural: range anxiety ("always charging"), battery degradation concerns, and confusion caused by fragmented charging networks and pricing schemes
- Trust and usage of new technologies increase when systems are predictable, transparent, stable, and easy to use, and drop quickly when reliability or connectivity issues appear.

2.3.2 Key insights on user needs and motivations

As presented in D3.7, there is an overall "*positive perception of electric mobility*" [19], but also an "agreement in persisting barriers related to costs, infrastructure availability and systems' reliability" [19]. Dividing by country profile, it is possible to add that in countries like Denmark and Slovenia, users appear to be more driven by environmental and technological innovation motivators, while in Greece and Portugal their concerns are more on the financial side, looking at both EV acquisition and charging costs.

Two key aspects to highlight are related to user expectations regarding costs versus benefits, and regarding control and transparency of the system.

As fossil fuel prices rise, the economic advantage of using an electricity-powered vehicle appear increasingly interesting to people, even though some barriers persist, like range anxiety, battery life and degradation, charging convenience. Specially for countries profiles like Portugal and Greece, financial incentives appear to be the way to increase adoption, because lowering the financial barrier of acquiring and maintaining the vehicle appears to ease concerns and make EVs more attractive.

More related to the systems surrounding electric mobility, like V2X technologies explored in the EV4EU project, besides the costs and financial benefits of possible energy savings and even earnings with energy sold back to the grid, a main concern that arises is control and transparency of the technology. People mention wanting to understand what is happening, wanting systems to be clear and provide information, and let users feel in control. "*Across all demonstrators, it was possible to note that participants' satisfaction increased when user-control and system predictability were ensured, by using methods like stable apps, reliable connections, clear SoC tracking, etc* [19]."

Table 2: Summary of User Needs and Motivations across EV4EU Countries regarding EV and V2X adoption

Category	Key Insights	Implications for EV adoption	Implications for V2X adoption
Environmental motivations	Low CO_2 footprint as key driver	Acceptance of EVs, even though concerns about battery recycling and electricity source are mentioned.	Acceptance of V2X for sustainability goals, mainly when highlighting energy savings and optimising renewable energy sources.
Economic motivations	Fuel savings, incentives	Electricity seen as cheaper than fossil fuels, and this perception is strengthened in people with PV systems at home.	Requires clear pricing and compensation mechanisms to be accepted.
Experiential benefits	Comfort, driving experience	Better driving experience overall, noise-pollution reduction, and convenient connection through car apps.	Clear system explanation needed, with transparency of each step of the process, to increase trust in users.
Infrastructure needs	Reliable charging availability	Critical for both EV adoption and V2X participation rates. Especially in areas with lower private parking options, charging infrastructure is crucial. Also, long-range mobility is a big concern, not only due to lack of charging options, but also related to charging times.	

Usability needs	Simple, transparent charging	Low impact on EV adoption. Important to reduce frustration in EV owners, so they become “ambassadors” to drive others to adopt.	Clear information reduces barriers to V2X adoption, as well as increases trust in the system after starting to use it.
Residential charging	Importance of home access	Not seen as an absolute requirement but still seen as a big facilitator. Increasing public charging infrastructure might reframe this concern.	From a private user perspective, V2H appears to be the most interesting scenario. Community-level V2X lacks clearer benefits for individuals. Public V2X adoption requires integration in urban planning.
Digital support	Need for apps/tools	Apps are already expected, even though there appears to be an “overload” of apps. Nevertheless, digital interfaces appear to ease EV adoption and facilitate charging efforts.	Appears to be critical to support V2X adoption, providing system clarity, user engagement and system optimisation.

2.3.3 Key insights on user engagement in demonstrators

Across the project, engagement relied on surveys, interviews, workshops, and demonstrator activities. Surveys enabled large-scale data collection, while qualitative methods, particularly interviews and workshops, were used to deepen understanding and validate results [5], [19]. Engagement was further strengthened through demonstrator-based interaction, where users engaged with real systems. This allowed the project to validate behavioural assumptions and assess user experience in practice. A key lesson is that real-world interaction is necessary to uncover gaps between expected and actual behaviour [8].

One of the most consistent findings is the importance of trust-building through direct interaction. Engagement activities involving close communication and in-person contact improved user participation and feedback quality. This indicates that engagement strategies must prioritise human interaction, particularly in early deployment phases [8].

Table 3: Engagement Methods and Outcomes in EV4EU

Engagement method	Purpose	Key Outcomes
Large-scale Surveys	Collect societal context user data	Identification of preferences and behaviours (150 responses for D3.1, 802 responses for D3.7)
Interviews	Deepen understanding	Insights on needs, barriers, usability preferences and expectations
Workshops	Co-create solutions	Validation of assumptions, user profiles and local requirements with partners
Demonstrator usage surveys	Real-world validation: Collect satisfaction levels with demonstrator usage	Reduced data collected, due to technical barriers described in D3.7
Demonstrator interviews	Real-world validation: Collect experience perceptions	Behavioural insights, user experience feedback
Direct engagement (in-person)	Build trust and participation	Improved engagement and feedback quality

2.3.4 Main takeaway

Overall, it is possible to suggest that V2X adoption can follow a behaviour-driven and iterative process, where user insights shape system design, engagement validates solutions, and feedback continuously refines both. The central implication is that aligning user behaviour, system usability, infrastructure deployment, and engagement strategies is essential to achieve scalable and sustainable V2X ecosystems. Figure 2 shows the proposed User-Centric V2X adoption framework mentioning deliverables where different types of phases were approached and developed.

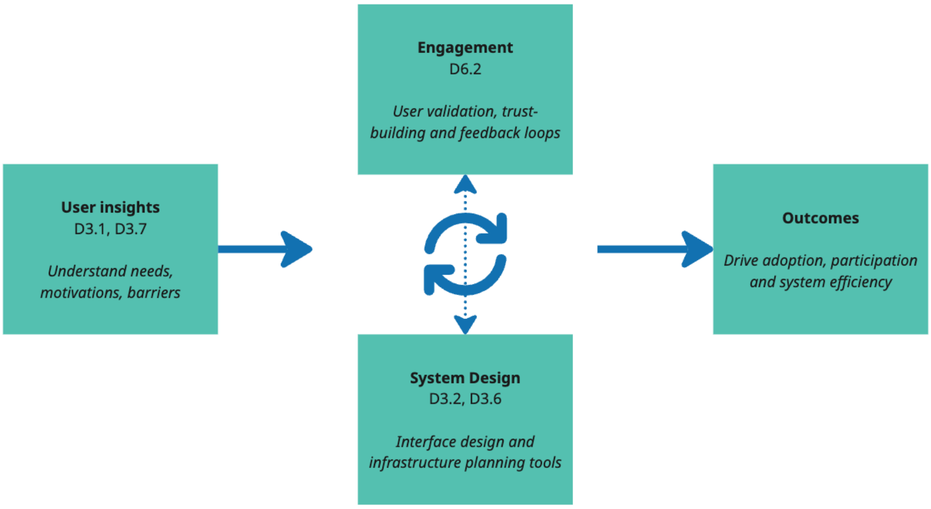

Figure 2: Proposed User-Centric V2X adoption framework

2.4 Flexibility Services and Markets

Flexibility services play a key role in enabling the large-scale integration of EVs while maintaining power system reliability. In EV4EU, EVs equipped with smart and bidirectional charging (V2X) are treated as flexible energy resources that can adapt their charging and discharging profiles in response to grid needs and market signals. Aggregated through Virtual Power Plants (VPPs), EV flexibility can be traded and activated across different market layers.

The project focuses on the participation of EVs in local flexibility markets and ancillary service markets, supporting both DSOs and TSOs. Flexibility services include congestion management, peak shaving, voltage control and frequency support, activated either manually or automatically through interoperable flexibility platforms integrated with DSO and VPP systems. By demonstrating real-life procurement, trading, and activation of EV-based flexibility, EV4EU contributes to the development of new market mechanisms, unlocks additional revenue streams for EV owners and aggregators, and supports a more resilient, renewable-based energy system.

2.4.1 Lessons Learned on Flexibility Services and Markets in EV4EU

In summary, the key lessons learned related to the flexibility services and markets are:

- **EVs can provide technically reliable flexibility – but aggregation is essential:** The Slovenian demonstrator confirmed that individual EVs are too small and uncertain to participate directly in flexibility markets, while aggregation via a VPP is a prerequisite for meaningful and reliable service provision. Aggregating EVs together with other energy resources (BESS, RES) increases predictability and enables participation in multiple services and markets [10].
- **System integration and interoperability are a major practical challenge:** A key lesson is that end-to-end integration between EVs, charging stations, aggregators, local market platforms, and DSO/TSO systems is complex and time-consuming.

Successful demonstrations required:

  - Tight integration with ADMS,
  - Harmonised flexibility product definitions,
  - Standardised data exchange (CIM, open interfaces),
  - Secure, role-based communication.

  Flexibility provision is therefore not only a market issue but a system engineering challenge [10].

- **Local flexibility markets (LFMs) are well suited for EV-based services:** The project showed that local congestion management and voltage control are particularly suitable use cases for EV flexibility. Activation thresholds are reached mainly at higher EV penetration levels, meaning that EV flexibility becomes increasingly valuable as electrification grows. This confirms the relevance of EVs in future DSO toolbox for avoiding or deferring grid reinforcements [10].
- **Automation is critical – manual operation does not scale:** Manual activation of flexibility services was tested, but the project clearly demonstrated that automatic activation via platforms is necessary for scalability. Automated activation reduces response times, avoids human error, and allows EV flexibility to be used under real operational constraints, especially when multiple activations occur per day [10].
- **User involvement must be minimal to ensure acceptance:** One of the strongest cross-cutting lessons is that EV users should not be actively involved in flexibility operations. Solutions that preserve driving needs, battery health, and comfort, while operating in the background, are essential for user acceptance and long-term scalability of EV participation in markets and services [10].
- **Flexibility potential depends strongly on local conditions:** Results from the Slovenian demo showed that the need for and effectiveness of flexibility services is highly location-specific. Network congestions are not driven solely by EV penetration, but also by the presence and operation of other flexible energy assets, such as market-flexible entities (MFEs). At low levels of overall flexible load penetration, congestion management services may not be required at all, while higher penetration of EVs and other flexible resources leads to more frequent activations and a measurable increase in delivered flexibility energy [10].
- **Regulatory readiness determines speed of deployment:** EV4EU highlighted that regulatory frameworks enabling VPPs, LFMs and aggregator-DSO cooperation are crucial. Where regulation is supportive (as in Slovenia with LFM development and VPP recognition), real-life demonstrations and market testing are feasible; where it is immature, scaling remains limited [10].
- **Market feasibility must be assessed alongside technical performance:** Beyond technical success, the project concluded that marketability, contractual arrangements, and incentive structures must be considered early. Flexibility services are viable only if procurement processes, remuneration mechanisms, and risk allocation are clearly defined for aggregators and asset owners [10].

2.4.2 Key insights on Flexibility Services and Markets in EV4EU

A key insight of the EV4EU project is that technological readiness at the level of aggregation platforms, VPPs and flexibility market interfaces is no longer the primary barrier to large-scale deployment of EV-based flexibility. Demonstration results show that core solutions for V1G/V2X management, automated service activation and market participation are already sufficiently mature.

In contrast, the main limiting factors are now located at the vehicle level and in the communication between EVs and charging infrastructure. Progress in these areas depends largely on the strategic choices of automotive OEMs and the pace of effective standardisation. Fragmented implementations, proprietary solutions, inconsistent support for flexibility functionalities, and uneven data availability across vehicle models continue to prevent scalable and reliable deployment.

Without stronger commitment from OEMs to provide native, standardised, and interoperable smart-charging and V2X capabilities, and without accelerated alignment on communication standards across vehicles, chargers, and backend systems, EV-based flexibility cannot move beyond pilot applications. Vehicle readiness and standard-compliant communication are therefore no longer secondary technical issues, but decisive enablers for market uptake.

Scaling EV-based flexibility beyond demonstrations will require coordinated action: OEMs must ensure consistent functionality and open interfaces across their fleets; standardisation bodies must deliver clear, implementable, and widely adopted standards. These efforts must progress in parallel with appropriate regulatory frameworks, scalable digital platforms, and viable economic incentives. If OEM engagement and standardisation do not advance at the required speed, EV-based flexibility will remain confined to demonstration projects, with limited impact on power system operation, system integration, and decarbonisation objectives.

Building on the results and lessons learned from the EV4EU demonstrators, particularly within WP7, the project has identified that scaling electric-vehicle-based flexibility from pilot implementations to system-level deployment requires more than technological maturity alone. While core V1G/V2X control, aggregation and market participation solutions have been successfully demonstrated, large-scale uptake depends on a coordinated set of regulatory, technical, organisational, and economic measures. Table 4 outlines the key actions that must be implemented in parallel to enable the transition towards mature flexibility services and markets, ensuring that EV-based flexibility can deliver a lasting impact on grid operation, market efficiency and decarbonisation objectives.

Table 4: Key actions to enable the transition towards mature flexibility services and markets

Area	Required Measure	Description of the Measure	Why It Is Critical for Large-Scale Deployment	Responsible Actors
Regulation & Market Design	Operational local flexibility markets (LFMs)	Establish LFMs with standardised products, procurement, activation, and settlement rules	Without functioning markets, EV flexibility cannot scale beyond pilots	Regulator, DSO
	Clear legal role of aggregators and VPPs	Explicit recognition of aggregators managing EV flexibility	Enables mass aggregation of small EV resources	Regulator
	Harmonisation of DSO–TSO flexibility products	Alignment of flexibility products across grid levels	Enables multi service participation of EVs	DSO, TSO

Technical Infrastructure	Rollout of smart and V2X-ready charging infrastructure	Large-scale deployment of V1G and V2X charging points	Flexibility volume depends directly on installed infrastructure	CPOs, Investors
	Use of open and standardised communication protocols	Adoption of standards such as ISO 15118, OCPP	Reduces integration and vendor lock-in issues	CPOs, Manufacturers
	Integration with ADMS systems	Direct link between LFM/VPP platforms and DSO ADMS	Essential for automated large-scale activation	DSO
Digital Platforms	Fully automated service activation	Shift from manual to algorithm-driven activation	Manual operation does not scale	DSO, VPP
	Scalability by design of platforms	ICT platforms designed for thousands of EVs	Pilot platforms are insufficient	Platform providers
	Reliable real time data management	Continuous, secure data flows (SoC, availability, power)	Trust and reliability of services depend on data quality	All actors
Aggregation & VPP Operation	Advanced forecasting algorithms	Accurate prediction of EV availability and flexibility	Reduces non-delivery risk at scale	Aggregators
	Hybrid portfolios (EVs + BESS + RES)	Combine EVs with other flexible assets	Stabilises flexibility offerings	VPP operators
	Battery health and degradation management	Integration of battery protection constraints in control logic	Essential for long-term user and OEM acceptance	Aggregators, OEMs
End Users & Acceptance	Minimal user involvement	Flexibility services operate fully in the background	Active user participation does not scale	VPPs, CPOs
	Transparent financial incentives	Clear and predictable benefits for EV users	Drives mass adoption	Market operators
Economics & Business Models	Stable and predictable revenue streams	Regular tenders and repeated activations	One-off pilot revenues are not sufficient	DSO, Market operators
	Quantified cost savings for DSOs	Demonstrated avoidance or deferral of grid investments	Critical for long-term DSO commitment	DSO
Operational Processes	Standardised operational procedures	Defined workflows for procurement, activation, validation	Reduces risk and operational complexity	All actors
	Capacity building and training	New skills for DSO and aggregator staff	Required for new operational paradigms	DSOs, Aggregators
Policy & Strategy	National strategies linking e-mobility and flexibility	Integration of transport and energy policy	Accelerates system-level scaling	Governments
	Phased scale-up approach	Gradual increase of volumes, complexity, and services	Enables controlled and secure scaling	Regulator, DSO

2.5 Grid Management with Electric Vehicles

Within EV4EU, several grid services were studied and, in some cases, tested across the four demonstrators, reflecting different levels of system integration and regulatory maturity.

2.5.1 Grid services proposed and validated in EV4EU

In the EV4EU project grid services were proposed and then validated in the demonstrators. For instance, in the Portuguese pilot, several grid services were tested at the *Laboratório Regional de Engenharia Civil* (LREC) building, where two services were implemented: wind curtailment mitigation and voltage control (under- and over-voltage) or congestion management (due to excess production or excess consumption). It is worth mentioning that congestion management in this context was not performed at the DSO level but aimed at decreasing or increasing the usage rate of the local secondary substation supplying the building. These services were supported by metering infrastructure and forecast inputs for wind generation, load, and voltage conditions, as described in [20]. While the technical provision of these services was successfully demonstrated, no explicit price incentives were provided to LREC, and no real-time coordination with the DSO was implemented during the pilot.

In the residential Portuguese pilot, smart charging was implemented with the objective of reducing users' electricity bills by shifting charging to more favourable tariff periods and of maximising self-consumption in the houses that had PV panels installed [21]. Although this behaviour contributes indirectly to grid operation, no explicit grid services were activated at household level, and no bidirectional charging was deployed. In the company context, coordinated charging strategies were implemented in a fleet scenario. By coordinating the charging of multiple vehicles, peak demand was reduced and load profiles were flattened, illustrating how fleet-based smart charging can mitigate local grid stress. While these actions primarily targeted internal optimisation rather than grid services, they demonstrate the strong potential of fleet scenarios to support peak shaving and congestion mitigation when appropriate coordination mechanisms are in place.

The Danish demonstrator focused on grid services delivered through unidirectional smart charging at campus parking facilities. Services tested included frequency regulation, renewable energy following, power sharing under constrained connection capacity, and phase balancing. Frequency regulation was activated based on system-level frequency deviations, following a TSO-driven logic, while the remaining services were implemented through local control strategies at the site level. These services were enabled by high-resolution metering and robust communication infrastructure, allowing charging power to be modulated dynamically in response to grid and system signals. Although bidirectional charging was not used, the demonstrator showed that V1G alone can provide technically reliable grid services, particularly when market frameworks and prequalification mechanisms are already established, as in the Danish context.

In Greece, the demonstrator adopted a DSO-driven approach, focusing on grid services enabled through indirect control mechanisms rather than direct real-time dispatch of EV charging infrastructure. In practice, grid services relied on contractual and price-based instruments, namely green charging schemes, where dynamic tariffs incentivised charging during grid-favourable periods, contributing to congestion mitigation without direct asset control, and flexible capacity limitation contracts, allowing the DSO to limit EV charging power at specific substations during periods of network stress, based on monitoring and short-term forecasts. These mechanisms were supported by extensive low-voltage monitoring and forecasting but did not involve real bidirectional operation, which was not possible due to regulatory and licensing constraints. As reported in [22], these mechanisms demonstrate that EVs can already support grid operation through contractual and price-based instruments, while also highlighting their limitations in terms of granularity, automation, and responsiveness when compared to direct control or aggregator-based solutions.

Finally, the Slovenian demonstrator explored grid services through aggregation and VPP operation, combining EVs with BESS and RES. Services such as congestion management and flexibility provision were tested through a mix of real operation and simulation, reflecting the absence of a fully operational local flexibility market. As described in [23], aggregation via a VPP was a prerequisite for enabling grid services, as individual EVs were not sufficient to provide reliable and predictable support to the grid. This demonstrator highlighted the technical feasibility of aggregated EV-based grid services, while also revealing the complexity of moving from controlled testing to real-market operation.

2.5.2 Barriers and limitations observed in real operation

Despite the successful technical demonstration of several grid services, their broader deployment was constrained by a combination of regulatory, technical, and organisational barriers. A key limitation across demonstrators was the lack of appropriate regulatory frameworks enabling EV-based grid services to be activated, remunerated, and scaled. In Portugal and Greece, dynamic pricing schemes and formal mechanisms for DSO procurement of flexibility from EVs were either absent or insufficiently defined, meaning that even when grid services were technically delivered, no economic value could be assigned to them. In Slovenia, the absence of a fully established local flexibility market required the use of simulation environments, limiting the validation of grid services under real commercial conditions.

From a technical perspective, the availability of suitable metering equipment and real-time data emerged as a critical necessity. Accurate measurement of power, energy, and local network conditions was essential for planning, activating, and validating grid services, yet this infrastructure was not uniformly available across all pilots. In addition, the limited availability of bidirectional chargers and the lack of interoperability between EV and EVSE capabilities constrained the services that could be tested in real operation. Even in contexts where V2G was technically possible, interoperability issues and heterogeneous device behaviour increased operational complexity.

System-level integration also proved to be challenging. Effective grid services require coordination between multiple actors, including DSOs, aggregators, CPOs, and platform providers, as well as integration with ADMS and other grid operation systems. In several demonstrators, this coordination was either not in place or limited to experimental setups, preventing automated and scalable activation of services. Finally, the absence of clear incentives for EV users meant that participation relied on experimental arrangements rather than stable, long-term engagement, reinforcing the need for background operation with minimal user involvement.

2.5.3 Lessons learned and implications for grid services with EVs

The EV4EU demonstrators confirm that EVs can technically provide a range of grid services, including congestion management, wind curtailment mitigation, frequency regulation, and peak shaving, even when relying solely on unidirectional smart charging. However, the pilots also show that the relevance and feasibility of these services depend on the usage context and driver profile. In practice, it can be concluded that different types of users are better suited to different categories of grid services:

- Fleet and company users are particularly well suited for grid services such as peak shaving and congestion mitigation, as coordinated charging can reduce peak consumption, smooth load profiles, and improve interaction with the grid without affecting mobility needs.
- Buildings and workplace environments offer favourable conditions for grid services due to predictable parking durations, shared infrastructure, and centralised control.
- Individual residential users primarily benefit from smart charging for cost reduction and self-consumption. However, they may also participate in grid services if clear incentives, strong automation, and guarantees regarding comfort and battery health are in place.

Across all contexts, robust metering infrastructure, grid observability and controllability, forecasting capabilities, and interoperable communication between EVs, charging stations, platforms, and grid operators are essential to move from pilot scale demonstrations to real-world deployment. Looking forward, enabling grid services with EVs will require regulatory frameworks that recognise aggregators, define clear rules for V2X operation, and allow DSOs to procure flexibility from EVs, alongside technical integration with grid operation systems. In parallel, the existence of clear incentives for EV users and fleet operators is critical to ensure sustained participation in grid services. Without appropriate regulatory provisions, incentives, and technical integration, EV based grid services are likely to remain confined to local or experimental applications, despite their proven technical potential.

2.6 Advantages of Smart Charging and V2X

2.6.1 System Transformation Under EV mass adoption

The analyses reported in Deliverable D1.2 - Impact of V2X in energy and power systems [24] clearly show that large-scale EV adoption significantly impacts power system across the four countries involved, with effects strongly dependent on penetration levels and local system characteristics. In high-adoption scenarios, EVs can contribute to peak demand increases of up to 49% [24], highlighting that unmanaged charging constitutes a critical stress factor for power systems.

Within this context, smart charging and V2X are not merely optimisation tools, but necessary mechanisms to maintain system operability under mass electrification. Their primary advantage lies in enabling the controlled integration of EV demand into the grid, avoiding uncontrolled peak amplification and inefficient infrastructure usage.

One of the most consistent findings across research activities is the role of smart charging in reshaping demand profiles to guarantee peak management and grid stability. Price-based strategies and coordinated charging approaches effectively reduce peak demand in the short term, particularly by shifting charging to off-peak periods [24]. However, the results also reveal an important nuance:

- Price-based strategies can be effective in early adoption stages, but they may introduce new synchronised peaks in high-penetration scenarios (e.g., concentrated charging at low-price periods).
- In contrast, strategies based on peak shaving and Coordination with RES prove to be more robust in long-term scenarios. These approaches allow EV demand to be distributed more evenly across time, maintaining system stability even under high penetration levels [24].
- V2X further enhances this capability by enabling active support to the grid. Rather than only shifting demand, EVs can inject energy during peak periods, reducing system stress and improving load balancing [24].

2.6.2 Integration of Renewable Energy

A key advantage identified across residential, fleet, and community-level studies is the strong coupling between smart charging and RES. Smart charging allows EV demand to align with periods of high renewable generation, particularly solar PV [20], [21], [23], [25]. This leads to:

- Increased local self-consumption
- Reduction of renewable curtailment
- Improved overall system efficiency

V2X amplifies this effect by enabling bidirectional energy flows, effectively transforming EVs into distributed storage units. This is particularly relevant in systems with high PV penetration, such as Portugal and Greece, where V2X contributes to:

- Supporting demand during periods of low renewable production
- Stabilizing net load profiles
- Increasing the effective utilisation of RES

Importantly, the results show that coordinated RES-based strategies can supply up to 100% of peak demand from renewables in specific scenarios, demonstrating the potential of integrated smart charging/V2X approaches [24].

2.6.3 Economic Benefits and Operational Efficiency

From an economic perspective, Smart Charging consistently reduces operational costs by leveraging temporal flexibility. In residential environments, optimised scheduling combined with forecasting enables reduction in total energy costs, improved use of locally generated energy, and increased economic value of PV integration [20], [21].

In fleet scenarios, coordinated charging strategies reduce grid dependency and can decrease energy consumption from the main grid by up to 22% when PV is available. Even when V2X is introduced, the findings of the researcher work during the project show that energy requirements from the grid remain significantly lower compared to non-coordinated scenarios.

Additionally, Smart Charging and V2X enable participation in grid services such as congestion management, wind curtailment compensation, and demand response programs. These services can reduce total energy costs for users by up to 7% annually, while also providing system-level benefits.

However, a critical insight from the results is that these economic advantages depend strongly on:

- The design of control strategies
- The availability of accurate forecasts
- The regulatory framework enabling flexibility markets

2.6.4 Flexibility Provision and System Services

One of the most significant advantages demonstrated in EV4EU is the ability of EVs to provide flexibility as a grid service or demand response. Across different use cases:

- In residential systems, EVs can participate in congestion and curtailment management [21].
- In fleet scenarios, coordinated charging reduces peak consumption and improves grid interaction [20].
- In energy communities, EVs and BESS jointly provide upward and downward reserves [23]. The stochastic modelling results further highlight that EVs can contribute to reserve provision and demand reduction, particularly under uncertainty. This confirms that EV flexibility is not only theoretical but can be reliably integrated into system operation.
- Additionally, the ability to provide services such as frequency control has been demonstrated at the infrastructure level, indicating that EV charging systems can support real-time grid stability.
- DR programs integrated with SC demonstrate strong potential for reducing charging costs and improving grid interaction. Main results from the project [23] indicate that:
  - Real-time pricing mechanisms can reduce charging costs by up to 38%,
  - Time-of-use strategies provide consistent savings and improve load distribution,
  - Incentive-based programs can reduce peak demand and mitigate grid constraints
- DR strategies tailored to EV behaviour can:
  - Avoid reverse power flows,
  - Reduce congestion,
  - Improve voltage stability
- User behaviour remains a key uncertainty. The effectiveness of DR programs depends on participation levels and charging preferences, which introduces variability in outcomes.

2.6.5 Coordination in Multi-Agent Systems

A critical advantage of Smart Charging emerges in multi-user environments, where multiple EVs compete for limited resources. The results founded in the project show that coordinated optimisation:

- Improves fairness in energy allocation
- Ensures higher SoC levels at departure
- Enables prioritisation without compromising system performance

When V2X is included, energy can be redistributed between EVs, allowing higher-priority users to meet their requirements without penalizing others. This highlights an important systemic advantage: ***EV fleets and shared infrastructures can operate as cooperative energy systems rather than independent loads [25].***

2.6.6 Limitations and Critical Insights

Despite the clear advantages, the EV4EU results highlight important limitations that must be considered:

- Price-based strategies alone are insufficient under high EV penetration and may create new demand peaks [24].
- Forecast uncertainty significantly impacts optimisation performance [20], [21], [25]
- V2X can introduce demand volatility if not properly coordinated
- Metaheuristic approaches underperform compared to deterministic and stochastic optimisation in energy management contexts [23].
- User behaviour and acceptance remain critical factors in real-world implementation

These findings emphasise that the benefits of Smart Charging and V2X are highly dependent on advanced coordination strategies, rather than simple rule-based approaches.

The EV4EU project demonstrates that Smart Charging and V2X provide substantial advantages across technical, economic, and operational dimensions. However, their true value lies in their system-wide impact. They enable controlled integration of large EV fleets, efficient use of RES, reduction of operational costs, provision of flexibility and grid services. At the same time, they reveal that the effectiveness of these technologies depends not on their existence, but on how they are implemented and coordinated. In high-penetration scenarios, only integrated strategies combining forecasting, optimisation, renewable coordination, and market mechanisms, can unlock their full potential.

Table 5: Advantages of Smart Charging and V2X - Limitations and Critical Insights

Environment	Most Suitable Approach	Key Strength	Critical Limitation	Observed Effect	Mitigation Direction
Households	HEMS-based SC + V2H/V2G	High PV self-consumption	Forecast uncertainty (load & PV)	Suboptimal scheduling, unmet targets	Forecast integration + adaptive control
Buildings	Coordinated SC (shared resources)	High PV self-consumption	Phase constraints & local congestion	Uneven load distribution	Phase-aware optimisation
Company Fleets	Priority-based SC + V2X	Operational predictability and Shared energy	Priority conflicts & limited availability	Some EVs fail SoC targets	Dynamic prioritisation + flexibility sharing
Energy Communities	SC + V2X + BESS coordination	Collective energy optimisation	Coordination complexity	Suboptimal dispatch under uncertainty	Stochastic optimisation frameworks
All Environments (early stage)	Price-based SC (ToU/RTP)	Cost reduction	Load synchronisation	Creation of new peaks	Combine with system-aware constraints
All Environments (high EV penetration)	Peak shaving + RES-based SC	Grid stability	Requires accurate coordination	Reduced performance if poorly forecasted	Integrated RES + demand control
All Environments (V2X)	Bidirectional flexibility services	Peak reduction & grid support	Demand volatility if uncoordinated	Secondary peaks, instability	Centralised and coordinated V2X control

2.7 AC vs DC Charging Stations

AC and DC charging stations serve different roles in EV infrastructure because they differ fundamentally in the delivered power level, charging duration, and typical usage context. This section provides the perspectives of the AC and DC charging technologies from power levels and utilisation.

2.7.1 Power and charging levels

An EV battery can only be charged with DC power. Therefore, the main technical distinction is where the AC power is converted to DC power. In AC charging, conversion occurs inside the vehicle through the onboard charger, which constrains practical charging power even when the external charger could theoretically supply more.

As a result, public AC charging is usually deployed at relatively modest power levels: around 3.7 to 22 kW depending on single-phase or three-phase configuration and local grid connection. DC charging, on the other hand, performs differently because the conversion from AC to DC is taking place externally in the electric vehicle supply equipment (EVSE) rather than inside the vehicle, hence allowing much higher charging power directly into the battery. Public DC fast charging commonly starts at 50 kW and extends to 150 kW, 250 kW, or 350 kW for high-power charging systems, although many currently deployed ports remain at or below 150 kW in real-world networks. This difference means DC infrastructure is designed for rapid turnaround and corridor charging, whereas AC infrastructure is better suited to destinations where vehicles remain parked for longer periods, such as workplaces, residential areas, and public parking lots.

According to the EV charging standard SAE J1772, charging can be categorised into three levels [26]:

- Level 1 Charging (AC): Delivers 1.4-1.9 kW via standard single-phase AC (120V/230V, 12-16A). This level is suitable for residential overnight charging of plug-in hybrids and low-range EVs. However, level 1 charging is not utilised in Europe as the EVSE units in Europe are primarily three-phase [27], [28].
- Level 2 Charging (AC): Provides 4-19.2 kW using 240-400V single/three-phase AC (32-80A). This level is mainly deployed at workplaces and public destinations, which requires dedicated charging infrastructure.
- Level 3 Charging (DC Fast): Supplies 50-350 kW of DC current (200-1000V, 200-400A) via off-board charging. This bypasses the limitations of the onboard charger. This technology enables 20-80% state –of charge in 15-60 minutes.

2.7.2 Utilisation

The difference in power level between AC and DC charging significantly affects the way these charging technologies are utilised in practice [29].

AC charging is typically associated with relatively long parking durations. Since AC chargers provide lower power, EVs generally remain connected for longer periods to obtain the required amount of energy. This is particularly the case in locations such as workplaces, residential areas, public car parks, and commercial destinations, where users tend to leave their EVs parked for several hours. As a result, AC charging infrastructure often supports fewer charging sessions per day per charging point, but each session is comparatively long in duration.

DC charging follows a different utilisation pattern. Thanks to its substantially higher power level, DC charging is primarily used where users require rapid energy replenishment within a short period of time. This is typically the case along motorway corridors, at fuel-station-type locations, and at high-turnover urban charging hubs. Consequently, DC chargers usually support shorter charging sessions and a larger number of users per day per charging point [30]. In this sense, DC infrastructure is characterised less by long occupancy and more by high throughput.

This distinction is important because similar occupancy rates do not necessarily indicate similar performance. An AC charger may be occupied for a long period while delivering a relatively limited amount of energy, whereas a DC charger may be occupied for a shorter period while delivering a substantially larger amount of energy. Therefore, the utilisation of AC and DC charging infrastructure should be assessed not only in terms of connection time, but also in relation to energy delivered, number of charging events, and the extent to which the installed power capacity is effectively used.

2.8 Interoperability and Integration

Interoperability and system integration constitute critical enablers for the large-scale deployment of Smart Charging and V2X solutions. The EV4EU project demonstrates that the effective operation of EV-based flexibility services depends not only on individual component performance but on seamless, end-to-end integration across a complex multi-actor ecosystem, including EVs, charging infrastructure, backend platforms, aggregators, and system operators.

2.8.1 Interoperability at the device level

A key requirement for interoperability is the adoption of open and standardised communication protocols across all system layers. At the device level, standards such as ISO 15118 and IEC 61851 enable communication between EVs and charging stations, supporting smart charging functionalities and, increasingly, bidirectional energy exchange. However, IEC 61851 is primarily suited for basic Smart Charging functionalities (V1G), as it relies on low-level signalling and does not support advanced V2X capabilities. In contrast, ISO 15118, particularly the latest ISO 15118-20 version, provides a significantly more advanced communication framework, enabling high-level data exchange, dynamic control, and full support for bidirectional power flow. Despite its technical advantages, ISO 15118-20 [31]is not yet widely adopted by EV and EVSE manufacturers. Current market implementations are largely based on ISO 15118-2, which supports certain smart charging features but does not fully enable V2X functionalities. As a result, the transition from ISO 15118-2 to ISO 15118-20 is essential to unlock the full potential of bidirectional charging and V2X services. This transition, however, requires further technological development, standardisation alignment, and time for widespread adoption across the ecosystem.

2.8.2 Interoperability at the system level

At the system level, protocols such as OCPP ensure interoperable communication between charging stations and backend systems, while OCPI facilitates data exchange between market actors, including charge point operators (CPOs) and e-mobility service providers (EMSPs) [1], [3], [4]. Currently, most commercially available EVSE products adopt OCPP 2.0.1 [32], which is broadly aligned with ISO 15118-2 [31] implementations at the EV–EVSE interface. While this setup enables basic and partially advanced smart charging functionalities, it only supports limited aspects of V2X and does not allow the full exploitation of bidirectional charging capabilities. The transition towards OCPP 2.1 [32] is therefore a key step for enabling full V2X deployment, as it introduces enhanced support for bidirectional energy flows, improved alignment with ISO 15118-20 [31], and more advanced functionalities for flexibility services, grid interaction, and market participation. However, like ISO 15118-20 [31], OCPP 2.1 [32]adoption is still at an early stage and will require time for widespread implementation across manufacturers and platforms. Regarding OCPI, the current widely adopted version in the market is OCPI 2.2.1, which provides mature and stable support for interoperability between CPOs and EMSPs, including roaming, session data exchange, and tariff communication. However, OCPI does not directly control charging processes or V2X functionalities; rather, it facilitates commercial and data exchange layers. The upcoming OCPI 3.0 aims to further enhance interoperability by supporting more advanced use cases, including improved flexibility services integration, energy management, and better alignment with smart charging and V2X ecosystems. Therefore, while OCPI 2.2.1 remains the *de facto* standard for current deployments, future-proof system design should consider alignment with OCPI 3.0 as it becomes more widely adopted.

Furthermore, interoperability plays a decisive role in enabling scalable business models and flexibility services. The Greek demonstrator showed that the successful deployment of V2X services depends on the smooth integration between CPO platforms and DSO backend systems. This integration requires not only technical compatibility but also the use of standardised communication protocols and a phased validation approach to ensure reliable operation under real-world conditions. From a technical perspective, CPO–DSO communication relies on well-established energy system and flexibility standards. Protocols such as IEC 61850 enable structured, real-time communication with grid management systems (e.g. ADMS), supporting monitoring, control, and grid-aware operation of distributed resources. In parallel, OpenADR (IEC 62746-10) [33] provides a widely recognised framework for demand response and flexibility signal exchange, allowing DSOs to send activation signals and constraints to external actors, including aggregators and CPO platforms. Additionally, open protocols such as OSCP (Open Smart Charging Protocol) [34] is specifically designed to facilitate capacity and flexibility exchange between grid operators and charging infrastructure, enabling grid-constrained charging and coordinated load management.

Another key challenge identified is the fragmentation at the vehicle level, where proprietary implementations and inconsistent support for Smart Charging and V2X functionalities limit interoperability. The lack of harmonised communication capabilities across different EV manufacturers remains a major barrier to scaling beyond pilot applications. Addressing this issue requires stronger alignment between automotive OEMs, standardisation bodies, and energy system stakeholders.

In addition, interoperability must be supported by secure and reliable communication frameworks, ensuring data integrity, cybersecurity, and user privacy. The increasing digitalisation of charging infrastructure introduces new risks that must be mitigated through encryption, authentication mechanisms, and compliance with cybersecurity standards such as IEC 62443.

Overall, the lessons learned indicate that achieving full interoperability requires coordinated progress across multiple dimensions:

- Adoption of open standards and protocols,
- Harmonisation of data models and interfaces,
- Alignment between vehicles, infrastructure, and backend systems,
- Integration with market and grid operation platforms.

Without these elements in place, smart charging and V2X solutions remain fragmented and difficult to scale. Conversely, a fully interoperable ecosystem enables cross-border compatibility, market participation, and efficient system integration, ultimately supporting the transition towards a flexible, decarbonised energy system.

2.9 Common Key Performance Indicators

The development of Key Performance Indicators (KPIs) within the EV4EU project was an interconnected process that built upon the progressive definition of BMs in D1.4 [2] and BUCs in D1.5 [3], extending through to the testing performed and the goals set for each demonstrator. In this context, KPIs served as important inputs to assess the progress of the project and the achievement of its objectives across the four heterogeneous demonstrators. The defined KPIs for each demonstrator are documented in the respective deliverables: D6.1 for the Portuguese demonstrator [7], D7.1 for the Slovenian demonstrator [14], D8.1 for the Greek demonstrator [11], and D9.1 for the Danish demonstrator [12].

The methodology adopted for the definition of KPIs was elaborated across the project, with the most detailed description provided in D7.1 for the Slovenian demonstrator [14]. The process drew on established literature on KPI definition, classification, and methodology, as well as on the review of related EU projects with similar scope, namely OneNet [35], X-Flex [36], [37], and ASSURED [37]. From these projects, the relevant KPIs and methodological approaches were extracted and adapted to the

EV4EU context. The adopted methodology combined a top-down perspective, where KPIs were derived from the EV4EU project objectives, such as demonstrating the impact of mass V2X deployment, evaluating different BMs, and developing planning and operational tools for DSOs. And a bottom-up perspective, where individual partners defined specific requirements and performance targets reflecting their roles and the local conditions of each demonstration site. Following the initial identification of KPIs at each demonstrator, a harmonisation phase was carried out across the project. This phase involved cross-project consultations aimed at facilitating the exchange of valuable lessons on methodologies. The harmonisation process included comparing the different KPI lists, merging identical indicators, and arranging the remaining KPIs according to their relevance, while excluding those considered unattainable or impossible to measure. This ensured that the project had a well-defined and focused set of KPIs at each demonstrator, while incorporating a collaborative and consultative approach among stakeholders to draw on different perspectives and expertise [7], [11], [12], [14].

2.9.1 KPIs across the four Demonstrators

At a high level, the KPIs across all four demonstrators were organised into groups, recognising the heterogenous nature of the project's impact. These groups include: technical KPIs, addressing aspects such as charger efficiency, setpoint compliance, voltage compliance, data acquisition accuracy, and scalability of the deployed solutions; economic and market-related KPIs, evaluating costs, profits for aggregators, cost reductions for DSOs, energy cost savings, and the financial viability of the proposed solutions for the involved stakeholders; environmental and social KPIs, measuring the reduction of CO_2 emissions and user satisfaction with the V2X services provided; and service-related KPIs, examining the utilisation and availability of flexibility, the uptime and connectivity of platforms and charging infrastructure, and the overall reliability of the service provision chain [7], [11], [12], [14].

- **Portuguese demonstrator KPIs:** The Portuguese demonstrator compiled a comprehensive array of technical, economic, environmental, social, and service-related KPIs, considering the three distinct pilots of the demonstrator, Azorean households, LREC's office building, and EDA's campus. These KPIs addressed, among others, energy self-consumption, energy cost savings, CO_2 emission reductions, customer satisfaction from different stakeholder perspectives, and service-related indicators such as wind curtailment mitigation and system uptime [7].
- **Slovenian demonstrator KPIs:** The Slovenian demonstrator defined KPIs divided into five groups: general descriptive, economic and market, environmental and social, technical and ICT, and service-related. These KPIs covered a broad scope, from demonstrator accuracy and V2G success level, through profit for aggregators and cost reduction for DSOs, to flexibility availability and forecast accuracy, data reliability, and the technical operation of charging stations [14].
- **Greek demonstrator KPIs:** The Greek demonstrator organised KPIs into technical, environmental and social, service-related, and economic and market-related categories, with a strong focus on RES curtailment reduction, peak load demand changes, data acquisition accuracy, flexibility utilisation, the scalability and availability of the Open V2X Management Platform, ICT costs, and the economic impact on EV users [11].
- **Danish demonstrator KPIs**: The KPIs defined for the Danish demonstrator focus on economic, technical, user, and environmental dimensions, with particular attention to the cost of flexibility, charger efficiency, uptime and resilience of chargers, scalability, and setpoint compliance [12], [38].

Due to the inherent differences between the demonstrators in terms of local regulatory frameworks, available infrastructure, tested BUCs, grid characteristics, and data availability, the KPIs are not fully common across demonstrators. Each set of KPIs was tailored to the specific objectives, conditions, and constraints of its respective demonstrator. However, through the cross-project consultations carried out during the working group meetings on KPIs, several thematic areas were identified as being addressed, in one form or another, across all or most demonstrators. The first common topic is flexibility-related aspects, where demonstrators defined indicators addressing the amount of flexibility requested, utilised, forecasted, or made available by EVs, although measured and quantified in different ways depending on the local context and the services being tested. The second common topic is charging infrastructure aspects, where the technical operation, uptime, efficiency, and occupancy of charging infrastructure were assessed across the demonstrators, reflecting the central role of charging stations in enabling V2X services. The third common topic is data-related aspects, where the reliability, accuracy, and availability of data collection and communication systems were evaluated, recognising that robust data infrastructure is a prerequisite for the successful operation of all proposed V2X solutions.

Relevant KPIs were addressed and assessed at each demonstrator. The results of the KPI evaluations are presented in the corresponding demonstration results deliverables: D6.4 for the Portuguese demonstrator [39], D7.4 [16] and D7.3 [10] for the Slovenian demonstrator, D8.6 for the Greek demonstrator [40], and D9.5 for the Danish demonstrator.

While each set of KPIs was tailored to the specific objectives, conditions, and constraints of its respective demonstrator, the cross-project consultations and working group meetings successfully identified common thematic areas that are shared across all demonstrators. These common topics, flexibility, CS, and data, together with the shared KPI groups adopted across the project, provided a solid basis for cross-demonstrator comparison and for drawing broader conclusions regarding the performance, scalability, and replicability of the proposed V2X solutions, addressed in other sections of this document. In this way, the EV4EU project was able to maintain a coherent evaluation framework at the project level, while at the same time respecting the diversity of the demonstrators and the wide range of V2X management possibilities.

Table 6: KPIs Lessons Learned and Recommendations

Lesson Learned	Mitigation / Recommendation
KPIs could not be fully unified across demonstrators due to differences in regulatory frameworks, infrastructure, grid characteristics, and data availability.	Common KPI groups (technical, economic, environmental, service-related) were defined at project level, while demo-specific KPIs were tailored within these groups to accommodate local conditions. Future projects should establish such common groups early in the project design phase.
Harmonisation of KPIs required significant cross-project effort, including merging duplicates and excluding unmeasurable indicators.	A structured harmonisation process with cross-project consultations proved essential. Predefined KPI templates and regular cross-demo alignment should be embedded in the project plan from the outset.
Common thematic areas (flexibility, CS, data) were identified through dedicated working group meetings, but the same topics were measured differently across demonstrators.	While the identified common topics provide a basis for cross-demo comparison, agreeing on shared measurement methods or normalisation rules for these topics early on would strengthen quantitative comparability.
Robust data infrastructure was identified as a prerequisite for the successful evaluation of all proposed V2X solutions.	Data collection, communication, and quality assurance infrastructure should be prioritised during the early deployment phases to ensure reliable KPI evaluation throughout the demonstration period.

3 Roadmap for Mass Deployment of EVs and V2X Solutions

This section provides a complete operational plan which helps move EVs and V2X technologies from their pilot testing phase to their full-scale implementation. The study integrates its main results through the EV4EU project by examining various elements including regulatory frameworks, BMs, BUCs, user engagement flexibility services and demonstrator validation. It includes: (i) targeted recommendations organised by stakeholder type, (ii) key priorities for European-wide harmonisation, and (iii) identified future research needs. The elements establish a unified framework which shows needed steps to solve existing obstacles that include regulatory fragmentation and limited interoperability and immature market structures, which must be resolved before the European deployment of EV-based flexibility systems can proceed.

3.1 Recommendations by stakeholder type

By combining results from the EV4EU demonstrators together with regulatory analysis results from D1.3, business modelling results from D1.4 and D1.5 and user engagement research from WP3 and flexibility services testing results from WP6 to WP9 and KPI testing results to create specific recommendations for the main stakeholder groups who work on Smart Charging and V2X system deployments. The recommendations show both the technical solutions that have been proved to work and the major obstacles which were found throughout the regulatory process and market operation and technical implementation and user interaction process.

3.1.1 Policy Makers and Regulators

The transition from pilot-scale demonstrations to large-scale deployment requires policy makers to take a central role in the implementation. The project shows that regulatory maturity serves as the main obstacle which blocks progress despite technical solutions being present. It is therefore recommended to:

- Establish clear regulatory frameworks which enable DERs to participate in flexibility and ancillary service markets through EV integration.
- Define the role of aggregators and enable their interaction with DSOs and TSOs within formal market structures.
- Introduce dynamic pricing mechanisms and contractual arrangements which facilitate both flexibility procurement and remuneration processes. However, appropriate limits should be defined to mitigate risks for the end users.
- The existing regulatory system needs to address V2X regulations which currently lack legal definition for bidirectional operation in specific countries.
- Being compliant with standards is not enough to ensure full interoperability due to the different interpretations adopted by each Original Equipment Manufacturer (OEM). Therefore, it is necessary to define technical application rules for the standards, as well as certification procedures, to ensure full interoperability between systems.
- National regulations should establish standardisation and interoperability through their alignment with European standards including ISO 15118 and OCPP.
- The data governance framework needs to achieve innovation goals while meeting cybersecurity and privacy needs which include GDPR compliance requirements.

The strategic implication states that regulatory evolution needs to progress alongside technological development; otherwise, existing solutions will remain restricted to experimental settings.

3.1.2 System Operators

System operators play a vital role in establishing the necessary conditions for flexible grid operations while ensuring grid systems remain dependable. The demonstrators highlight that operational readiness on the DSO/TSO side is as important as technological capability on the asset side. The recommendations can be listed as:

- Organisations should allocate funds to enhance their grid observability and controllability capabilities through advanced monitoring systems, which will work together with their existing ADMS setup.
- The LFMs should be established as an essential tool to provide flexible services through transparent procurement processes which establish equivalent mechanisms for their establishment.
- The system needs to allow real-time and near-real-time connections from aggregators and flexibility platforms through the implementation of standardised protocols which include IEC 61850, OpenADR, and OSCP.
- The organisation needs to establish specific technical standards which will guide the prequalification process of EV operators who want to participate in flexibility programs.
- The system should use forecasting tools that predict load, RES generation, and EV behaviour to aid operational decision-making processes.
- Grid codes should be updated to explicitly integrate flexibility services, EV charging infrastructure, and bidirectional energy flows while ensuring interoperability between market participants.
- Licensing frameworks should be simplified and harmonised to facilitate the participation of aggregators, charging point operators, and other new flexibility actors in energy markets.
- Hosting capacity information should be made publicly available through digital platforms to increase transparency and support efficient planning and connection processes for EV and RES integration.
- Contracts with flexible capacity should be defined using clear performance indicators, activation procedures and remuneration schemes.

The results show that digitalisation together with system integration creates the essential conditions for EV systems to achieve scalable operations which can access all available assets.

3.1.3 Aggregators and VPP Operators

The value of EV flexibility can only be unlocked through aggregators because single EVs lack sufficient capacity to deliver dependable services. The project results show that aggregators should focus on these five main objectives:

- Aggregation of heterogeneous resources (EVs, BESS, RES) should be their focus because it enables them to deliver more dependable services and different types of solutions.
- The development of forecasting and optimisation tools should focus on creating solutions that handle EV availability and user behaviour uncertainties.

- All charging systems must achieve compatibility through shared charging systems and communication standards.
- System operators need to establish partnerships with distribution system operators and market operators to develop services that meet grid requirements and market demands.
- Develop business models which achieve technological performance targets and sustainable financial results through effective risk management and revenue-sharing frameworks.

Aggregators need to implement complete business operations and revenue-generating processes which extend beyond their current technical aggregation capabilities to succeed in the market.

3.1.4 CPOs and Technology Providers

The CPOs together with technology providers handle the complete process of building and managing both physical assets and digital systems which create V2X functionality. The demonstrators reveal that interoperability and system integration remain major challenges. The main recommendations of the study include the following actions:

- Adopt and implement open, standardised communication protocols (e.g., OCPP 2.0.1/2.1, ISO 15118-20) to ensure compatibility and future-proof deployments.
- The charging infrastructure requires improvements to its reliability and uptime and connectivity because these aspects directly affect user satisfaction and the delivery of services.
- The system needs to provide support for bidirectional charging while ensuring that EVSE and vehicle functionalities remain in alignment.
- The charging infrastructure needs to connect with backend platforms and grid operational systems to enable automated delivery of flexibility services.
- Organisations need to invest resources into cybersecurity measures and development of safe data exchange systems.
- An optimal deployment strategy for AC and DC charging infrastructure should be established according to grid constraints, user charging behaviour, and the targeted flexibility services. The integration of solutions for private charging stations should be promoted to unlock additional flexibility potential from residential and commercial EV users.
- Scalable cloud-edge architectures should be adopted to support real-time monitoring, control, and management of distributed charging assets.
- Test and certification procedures should be implemented to validate interoperability between chargers, vehicles, aggregators, and flexibility platforms before large-scale deployment.

The primary insight shows that system growth faces major obstacles from existing fragmented proprietary systems which need to be replaced with standards-based solutions that comply with all requirements.

3.1.5 Automotive OEMs

The V2X system requires automotive manufacturers to serve as its essential stakeholder group for its large-scale implementation. The project shows that vehicle technological constraints now function as the main development obstacle. OEMs should execute the following actions:

- They need to provide ongoing Smart Charging (V1G) and V2X support for all their vehicle models.

- They should implement standardised communication protocols especially ISO 15118-20 which include public access interfaces.
- They must create secure systems that allow secure access to detailed data (including SoC and charging status) while maintaining user data safety.
- They should develop products through energy system requirements which perceive EVs as connected grid resources instead of standard electrical loads.
- Clear conditions and technical requirements should be defined for participation in V2X services while ensuring battery warranty protection.
- Monitoring services should be provided to continuously assess the state of health of batteries.
- A battery passport should be provided, including the description of the main battery characteristics and the registration of relevant lifecycle events.
- Tools should be provided to assess the state of health of batteries for the second-hand market.

OEM engagement needs to increase because current levels do not support EV-based flexibility beyond existing pilot programs.

3.1.6 End Users and Fleet Operators

The system needs end user participation to achieve better scalability although end users do not operate the system. The project demonstrates that user acceptance requires three essential factors which include usability and transparency together with minimal intrusion. The recommendations for this project include the following items:

- V2X services need to run continuously in background mode which should not disrupt user experience or their need for mobility or the preservation of battery life.
- Provide users with comprehensive information which consists of costs and benefits and system operation details to establish trust and encourage their active participation.
- To provide financial rewards together with uncomplicated ways to join the program especially in regions where people watch their spending closely.
- Promote charging systems which enable fleets to function together because this method produces major operational and financial gains while requiring minimal user involvement.

The study shows that organisations should reduce user interactions for daily operations, but they need to increase user trust and system transparency which creates perceived value.

3.2 Europe-wide harmonisation and future research needs

The EV4EU demonstration results show that Smart Charging and V2X systems need Europe-wide regulatory, technical, and market standardisation before they can move from pilot testing to full operational implementation. The project shows that essential technologies which include VPPs and aggregation platforms and flexibility service activation have reached their required maturity level, but international and stakeholder fragmentation continues to limit their deployment. This section outlines the key areas where harmonisation is required and identifies priority directions for future research.

3.2.1 Europe-wide Harmonisation

The primary discovery of EV4EU research shows that different regulatory systems used by Member States create major obstacles which prevent effective replication and expansion of V2X technologies. European directives establish a shared foundation yet their implementation through national laws shows different levels of development and execution speed across countries. The following harmonisation priorities were established to solve this issue.

- **Regulatory alignment for flexibility markets:** a European framework must be established to enable DERs which includes EVs to access LFMs and ancillary service markets. The system requires unified definitions of flexibility products together with common procurement processes and distinct responsibilities for aggregators DSOs and TSOs.
- **Standardisation of V2X operation and market participation**: The absence of unified rules for bidirectional charging and V2X services creates uncertainty for stakeholders. Harmonised guidelines should define how EV-based flexibility is activated, measured, and remunerated across markets.
- **Interoperability and communication standards:** The full implementation of V2X technology needs standardised systems which all operational components must follow. The system requires ISO 15118 standards to achieve this goal which includes ISO 15118-20 and OCPP version 2.1 and OCPI and IEC 61850 and OpenADR and OSCP. The EVSE needs to work together with vehicles and backend systems to support international operations.
- **Data governance and cybersecurity:** The growing digitalisation of electric vehicle charging systems requires standardised methods to manage data and protect user privacy and secure system networks. Organisations must follow both the General Data Protection Regulation (GDPR) framework and the specialised industry rules which define data access and ownership rights and safe data transmission methods.
- **Grid integration and operational coordination:** All flexibility platform systems need to reach operational unity with existing grid systems which include ADMS. Standardised interfaces and data models Common Information Model (CIM) are necessary to enable coordinated operation across DSOs and TSOs.
- **Cross-border market integration:** To achieve complete benefits from EV-based flexibility European energy markets need to establish systems that allow international market access. The process needs both market regulations and prequalification standards and settlement systems to be unified so that aggregators and VPP operators can function across different legal areas.

Europe-wide harmonisation requires multiple stakeholders, including regulatory bodies and standardisation organisations and industry stakeholders and research initiatives, to work together in a coordinated effort. The implementation of V2X solutions will suffer from restricted deployment that results in uncoordinated expansion until all parties achieve proper alignment.

3.2.2 Future Research Needs

The EV4EU project required additional research and development efforts to solve existing technical and operational problems which exist together with ongoing harmonisation activities.

- **Vehicle-level capabilities and standardisation:** a research gap exists at the EV level, the upcoming research should establish standardised Smart Charging (V1G) and V2X technology implementation practices which all OEMs must follow together with complete access to vehicle data (e.g., SoC) and standardised communication protocols.

- **Advanced forecasting and uncertainty management:** The success of optimisation and control methods hinges on accurate predictions of EV accessibility and user patterns and RES availability. Research needs to be conducted on both probabilistic and data-driven forecasting approaches and robust and stochastic optimisation methods which have the capacity to effectively manage uncertainty.
- **Scalable control and coordination architectures:** The growing adoption of EVs creates new challenges for controlling multiple remote energy resources. The upcoming research needs to develop scalable control systems which utilise hierarchical structures to manage EVs and BESS and other DER during live operations.
- **Integration of EV flexibility into grid operation tools:** The current grid management systems which include ADMS, and energy management platforms need additional development work to incorporate EV-based flexible resources. The system needs to establish standard interface specifications and develop real-time control systems and decision-support systems for DSOs and TSOs.
- **Market design and economic mechanisms:** Research is needed to design market structures and incentive schemes that ensure the economic viability of V2X services. This includes pricing mechanisms, risk allocation, and business models that balance stakeholder interests while enabling efficient market participation.
- **User behaviour and acceptance models:** Despite technological advances, user behaviour remains a key source of uncertainty. Future studies should further investigate behavioural patterns, acceptance drivers, and engagement strategies, particularly in relation to automated and background V2X operation.
- **Cybersecurity and resilience of digital infrastructure:** As system complexity increases, ensuring the resilience and security of communication and control systems becomes critical. Research should address advanced cybersecurity mechanisms, intrusion detection, and system robustness against failures and attacks.
- **Real-world validation at scale:** Finally, there is a need to move beyond controlled pilot environments and validate V2X solutions under real market conditions and higher penetration levels. Large-scale demonstrations and living labs will be essential to assess performance, scalability, and long-term impacts.

Figure 3 summarises how the EV4EU lessons, covering regulatory frameworks, business models, use cases, user engagement, and validation, are synthesised into integrated insights and translated into stakeholder-specific recommendations to support the large-scale deployment of EV and V2X solutions in Europe.

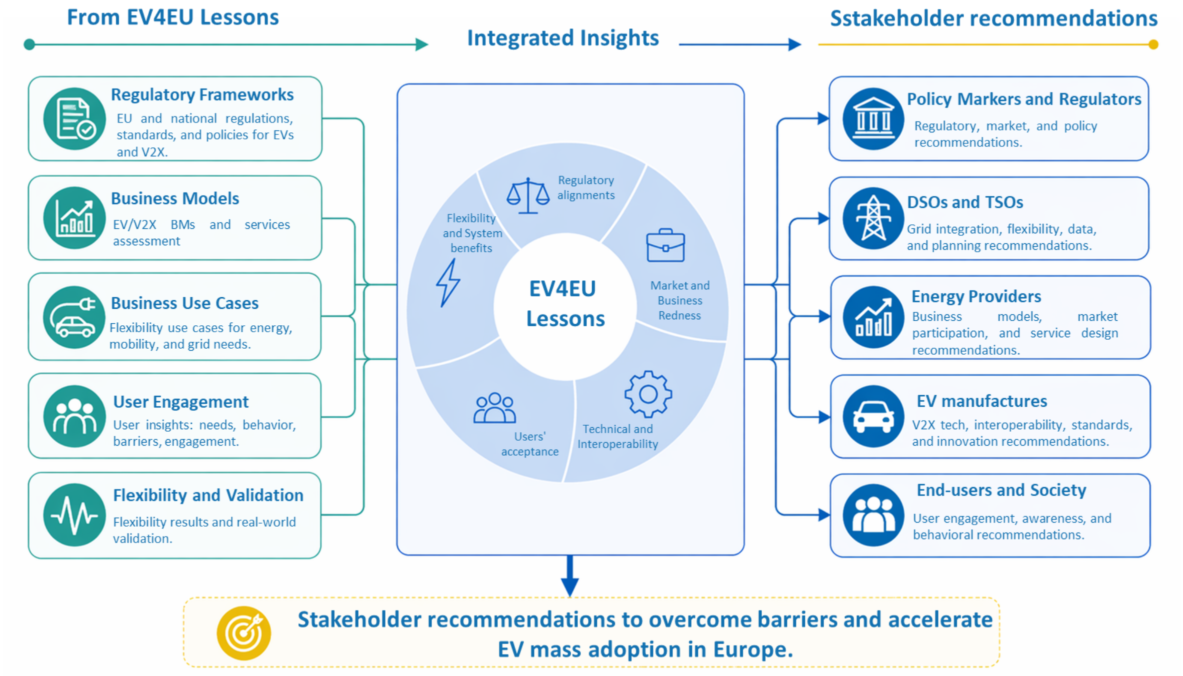

Figure 3: EV4EU Lessons to Integrated Insights and Stakeholder Recommendations for EV/V2X Deployment

4 Conclusions

The EV4EU project proposed and implemented bottom-up and user-centric Vehicle-to-Everything (V2X) management strategies to assist the development of electric vehicles (EVs) mass adoption. The project has tested multiple technical solutions together with business models (BMs), business use cases (BUCs) and flexibility services through four different demonstrators' sites which occurred in Portugal, Slovenia, Greece, and Denmark. The project shows through its technical evaluation that EV flexibility can be achieved through proper aggregation and coordination efforts. The system operated successfully through both unidirectional (V1G) and bidirectional (V2X) methods to deliver services which included congestion management, peak shaving, renewable energy integration and frequency support. The results demonstrate that Virtual Power Plant (VPP) aggregation requires forecasting and optimisation tools to maintain both predictability and scalability. The combination of EVs with other Distributed Energy Resources (DERs) such as photovoltaic (PV) systems and Battery Energy Storage Systems (BESS) creates greater system value while maintaining higher capacity for flexible energy distribution.

The project showed that technological readiness cannot drive extensive system deployment. The demonstrators faced their main obstacles because of regulatory and market-related restrictions. The system cannot move completely from pilot testing to commercial operation because mature flexibility markets do not exist and the responsibilities of aggregators remain ambiguous and the system lacks bidirectional operational support, and the available incentive systems do not provide sufficient motivation. The findings show that regulatory organisations need to develop together with technological progress. The electromobility ecosystem faced two main obstacles which included interoperability issues and system integration requirements. The standardised communication protocols ISO 15118 and OCPP exist but their implementation remains uneven because companies continue to use their proprietary systems which prevents different EVs from connecting to charging stations and backend systems. The automotive Original Equipment Manufacturers (OEMs) provide inconsistent support which creates vehicle-level fragmentation that stops V2X solutions from scaling beyond controlled environments.

The project demonstrated through user testing that acceptance and participation require usable systems which provide transparent information while causing minimal service interruptions. Users tend to maintain long-term usage of solutions which operate discreetly while delivering clear advantages to their functions. Economic incentives continue to function as a primary motivator because people tend to prioritise expenses above environmental concerns when they assess their decision-making process. The analysis of business models and use cases shows that V2X services create value throughout the entire value chain which includes EV users, aggregators, CPOs, and system operators. The commercial success of these BMs depends on having suitable market environments and suitable contractual agreements and suitable regulatory frameworks. Solutions that achieve technical success require these enabling conditions to become profitable and expand their operations.

The EV4EU project showed that implementing EV-based flexible systems at a large scale demands a complete system solution. European regulatory synchronisation needs to progress together with the complete adoption of standardised interoperability solutions and automotive manufacturers need to improve their participation, moreover energy systems need to achieve digital advancement and market system development needs to create effective functioning market systems. Research work needs to continue until the remaining problems related to forecasting control system scalability cybersecurity threats and user behaviour are solved.

Smart Charging together with V2X technology now functions as established solutions which can convert the way people travel while using energy resources. The process of successful implementation at large scale requires both technological progress and active coordination among regulatory bodies, technical systems, market forces, and social communities. The EV4EU program established a strong base for this transition by providing practical evidence and strategic guidance which will shape future developments across Europe and other regions.

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