D1.5
Analytical frameworks for V2X use cases testing and validation

Prepared by: NEW
Contributions from: LUT, TNTU, ENG, TNO, TEC, DUT, EMOT, SFC, ANA

Deliverable type	
Dissemination level	Public (PU)
Delivery date	2024-09-30
Version	V3.0
Total number of pages	30
Keywords	Vehicle-to-everything, Vehicle-to-home, Vehicle-to-building, Vehicle-to-grid, Testing, Validation, Use case, Demonstrator, Assessment, Methodology, Analytical framework, Analytical indicator
Cite as	Dias, L., Soares Branco, F., Matias, S., Mendes, G., Tikka, V., Vahidinasab, V., Ziu, D., Kaas, B., Alegría, J., Engström, C., Mancinelli, E., Székely, Z., Arnedo, A. (2024). Analytical frameworks for V2X use cases testing and validation. D1.5 of the Horizon Europe project DriVe2X, EC grant agreement no 101056934, Lappeenranta/Lahti, Finland
Contact person	Gonçalo Mendes (LUT). Email: drive2x@lut.fi

Co - Funded by
the European Union

UK Research and Innovation

Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them. This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056934.

UKRI reference number: 10055673

Disclaimer and acknowledgement

This project has received funding from the European Union’s Horizon Europe research and innovation programme under grant agreement No 101056934.

UK Research and Innovation UKRI reference number: 10055673

Executive summary

The DriVe2X project will assess the execution of five Vehicle-to-Everything (V2X) Use Cases (UCs) in eight demonstrators. Table 1 outlines the correspondence between the UCs and demonstrators.

Table 1. Summary of the DriVe2X project's UCs and demonstrators.

#	UC name	Charging scenario	Corresponding demonstrator
UC1	Medium-term Vehicle-to-Building (V2B) charging in commercial buildings for energy optimization operations and grid balancing benefits	Public-access charging station (building parking lot)	Demo 1 - Isle of Wight (V2B)
			Demo 6 - City of Amsterdam (V2B)
UC2	Long-term V2B charging with load aggregation in parking lots for dynamic load balancing and building energy management systems' integration		Demo 3 – Porto airport (V2B)
UC3	Vehicle-to-Home (V2H) integration with home energy management systems for renewables' integration and tariff optimization in prosumer and consumer homes	Private home charging	Demo 5 – City of Budapest (V2H)
UC4	Vehicle-to-Grid (V2G) integration in public charging stations for addressing technical grid constraints	Public-access charging station	Demo 2 – Isle of Wight (V2G)
			Demo 4 – Maia city centre (V2G)
			Demo 7 – Terni city centre (V2G)
UC5	V2G for network stabilization of locally-managed renewable energy source congested grids	Private-access charging station (facility parking lot)	Demo 8 - ASM Terni microgrid (V2G)

In order to ensure the demonstrators' success is accurately assessed, this deliverable contributes with a new methodology to test and validate the DriVe2X project's V2X UCs, which is inspired in state-of-the-art analytical frameworks for the testing and validation of electric mobility related UCs, in particular, the sociotechnical analytical framework (Sovacool et al., 2017). The sociotechnical analytical framework is an evaluation approach designed to assess the integration of EVs with the power grid in a manner that is complementary to traditional approaches. It focuses on the identification of potential technical, financial, social, behavioural, and environmental benefits, opportunities and barriers regarding the integration of electrified personal automotive transportation with the electricity network infrastructure.

The conceived methodology leads to a set of analytical indicators which will serve as the basis for the monitoring and evaluation efforts planned for the demonstration phase of the DriVe2X project, namely (as per Section 3.3): (i) flexibility availability; (ii) power demand; (iii) carbon intensity; (iv) grid independence; (v) financial savings; (vi) battery health; (vii) level of understanding; (viii) scheduling compliance; and (ix) ease of interaction.

Co - Funded by
the European Union

UK Research
and Innovation

Project information

Grant agreement No.	**101056934**
Acronym	DriVe2X
Full title	Delivering Renewal and Innovation to mass Vehicle Electrification enabled by V2X technologies
H2020 Topic	HORIZON-CL5-2021-D5-01
Project URL	www.drive2x.eu

Delivery date	**Contractual: M14, Actual: M21**
Type	☒Report ☐DEM ☐DMP ☐Other
Dissemination level	☒Public ☐Sensitive ☐EU classified
Authors (partners)	NEW, LUT, TNTU, ENG, TNO, TEC, DUT, EMOT, SFC, ANA
Reviewers (partners)	LUT, TNO
Summary (for dissemination)	Newly conceived analytical framework for the testing and validation of smart and bidirectional charging related use cases, according to a sociotechnical approach.
Keywords	Vehicle-to-everything, Vehicle-to-home, Vehicle-to-building, Vehicle-to-grid, Testing, Validation, Use case, Demonstrator, Assessment, Methodology, Analytical framework, Analytical indicator

Version	Date	Description
V0.1	2024-06-27	Table of contents
V0.2	2024-07-12	First draft for internal review (NEW)
V0.3	2024-08-09	Second draft for internal review (NEW)
V0.4	2024-09-06	Third draft for internal review (NEW)
V1.0	2024-09-18	First draft for consortium review (LUT, TNO)
V2.0	2024-09-26	Revised draft version by TNO
V2.1	2024-09-27	Revised draft version by LUT
V3.0	2024-09-30	Final version

Co - Funded by the European Union

UK Research and Innovation

Table of contents

Co - Funded by the European Union

UK Research and Innovation

List of figures

List of tables

Co - Funded by the European Union
UK Research and Innovation

Abbreviations and acronyms

Acronym	Description
CPO	Charging Point Operator
EV	Electric Vehicle
GHG	Greenhouse Gas
PV	Photovoltaic
SoC	State of Charge
SoH	State of Health
UC	Use Case
V2B	Vehicle-to-Building
V2G	Vehicle-to-Grid
V2H	Vehicle-to-Home
V2X	Vehicle-to-Everything
WP	Work Package

Co - Funded by
the European Union
UK Research
and Innovation

1. Introduction

1.1. Scope and objectives

The DriVe2X project's Work Package (WP) 1 – DriVe2X concept and visions, Use cases, and Validation framework – followed a funnel approach: it started with a worldwide review of V2X projects and literature review (T1.1), then consolidated a cross-sectoral vision for mass deployment of V2X in Europe up to 2050 (T1.2) and later laid the project's foundations regarding the flexibility marketplace concept, stakeholder mapping and UCs that will be tested and scrutinized in 2025 (T1.3 and T1.4[1]). Finally, T1.5, which is condensed in this deliverable, converts the preceding conceptual and modelling work into a set of analytical indicators that will help steer and validate field operations. The synthesis of these indicators closes the project's WP1 and directly supports WP9 – Testing, validation, and demonstration of V2X solutions in real contexts.

Another objective of T1.5 was to coordinate technical and demonstrator partner contributions under the guidance of NEW, WP9 leader. These coordination efforts indeed took place during T1.5, but started much earlier (Month 4), when NEW and demonstrator partners started the process of gathering practical and relevant information regarding the electric mobility ecosystems in each of the DriVe2X project's demonstrator geographies – United Kingdom, Portugal, Hungary, Netherlands, and Italy. The anticipation of these efforts revealed to be a judicious step: as presumed, there are currently no enforced regulatory frameworks or formal guidelines for V2X operation in any of the DriVe2X project's demonstrator geographies, so an early and comprehensive understanding of the status in each country enabled the demonstrator partners to identify and develop mitigation strategies for some of the implementation obstacles the project will face[2]. Additionally, the knowledge acquired at this stage allowed for a fine-tuning of the UCs to accommodate the idiosyncrasies of the testing locations, which is already partially reflected on T1.4.

These information gathering efforts also highlighted the fact that key factors governing electric mobility implementation can be clustered into categories such as technical, financial, regulatory, behavioural, *etc*. This influences the approach of T1.5, with the adoption of the sociotechnical framework for electric mobility, first introduced in the literature by (Sovacool et al., 2017).

[1] The corresponding deliverable was the first work of its kind to deploy the Electric Mobility Systems Architecture model, a framework derived from the well-established Smart Grid Architecture model – IEC SRD 63200. This framework enabled a clear representation of each UC within the DriVe2X project, per demonstrator geography, in terms of business, regulation, and functional relationships between actors, as well as in terms of the supporting technical protocols and infrastructure.

[2] This concern was particularly strong for the demonstrations open to the general public, such as the Isle of Wight (V2G), Porto airport (V2B), Maia city centre (V2G) and Terni city centre (V2G).

Co - Funded by
the European Union

UK Research
and Innovation

1.2. Structure

This document is structured as follows:

- Section 1 introduces the deliverable.
- Section 2 details preliminarily gathered information on the electric mobility profiles of the DriVe2X project's demonstrator geographies. Moreover, it carries out a review of analytical frameworks for the testing and validation of V2X UCs and thoroughly characterizes the sociotechnical analytical framework (Sovacool et al., 2017).
- Section 3 details the formulation of a novel methodology to test and validate the DriVe2X project's V2X UCs which is primarily based on the sociotechnical analytical framework, and subsequently lists analytical indicators with a view to guide and verify the success of field operations within the demonstration phase of the DriVe2X project.
- Section 4 substantiates the application of the newly created methodology for the testing and validation of the five DriVe2X project's V2X UCs, by matching the formulated analytical indicators with the project's eight demonstrators.
- Section 5 concludes the document.

1.3. Relationship with other deliverables

As mentioned in Section 1.1, this deliverable is a compound of the previous works performed in WP1, building upon the stakeholder needs, UC descriptions and technical bottlenecks identified in T1.1 to T1.4. Moreover, the efforts underlying the gathering of information with respect to the electric mobility ecosystems in each of the DriVe2X project's demonstrator geographies was carried out by making the most of the insights generated by the analysis of V2X upscaling's human dimension (T2.1), the analysis of gaps related to V2X grid services (T3.1), the identification of V2X flexibility products and services (T3.2), the characterization of the V2X system (T5.1), and the definition of project-level key performance indicators (T12.1).

The consolidation of the analytical indicators constructed in this task will influence the developments of:

- T3.4, which will adopt some of the established analytical indicators to test the ability of the DriVe2X project's business models to create value.
- T9.1, which will account for the time and effort to implement (or adapt) the means for collecting and monitoring these indicators.

- T9.2 to T9.6 and T9.7, where great part of the evaluation work will be based (directly or indirectly) on these indicators.

In addition to what is stated above, the insights derived from monitoring these indicators during the demonstration phase will likely provide inputs for the development of V2X-relevant standards and protocols (T7.6), the construction of stakeholder dialogue (T11.4), cluster-level collaboration (T11.5 and V2X Cluster [3]), civil society engagement (T11.6), and the consolidation of post-project exploitation (T11.7).

[3] The V2X Cluster is a collaborative group established between the partners of five electric mobility projects: EV4EU, SCALE, DriVe2X, FLOW and XL-CONNECT. It is targeted at enhancing research and development cooperation between relevant stakeholders with a view to tackle various topics related to bidirectional charging, namely: business modelling, consumer perspective, alternate current *vs*. direct current charging station technology, battery degradation, and policy and regulation.

Co - Funded by the European Union

UK Research and Innovation

2. A sociotechnical analysis of the electric mobility domain

2.1. Profiling electric mobility in the DriVe2X project's demonstrator geographies

In the early stages of WP5 – Predictive methods for V2G flexibility – and WP7 – Bidirectional charging technology for mass V2X deployment –, the corresponding leaders required concrete and reliable information on the deployment of V2X in each of the DriVe2X project's demonstrator geographies. The requested details spanned, *inter alia,* from charging station and electrical installation technical requirements, to charging station location and session log data, Electric Vehicle (EV) fleet characteristics, and national and regional policies.

NEW took the lead on gathering the abovementioned information, thus collecting an extensive body of electric mobility related knowledge under the form of laws, regulations and formal guidelines, national and municipal plans, statistics and news articles by reputable sources, and insights provided by local partners. These endeavours evolved in an unscripted fashion: research did not occasion the entirety of the requested information but led to relevant sources that provided other useful intelligence. Also, unsurprisingly, some demonstrator geographies had much more publicly available records than others, which reflects the varying maturity levels of the overall electric mobility ecosystem (Ayvens Societe Generale Group & Wheels, 2024).

In this regard, Table 2 displays a set of findings related to some of the challenges and characteristics associated with each of the DriVe2X project's demonstrator geographies.

Table 2. Preliminary findings collected during the gathering stage at each of the demonstrator geographies.

Geography	Findings
United Kingdom	Own vehicles are the main form of transport used on the Island (61.5%), and 31% of holidaymakers (203,002) stayed in a hotel, guest house or bed and breakfast lodging (Tourism South East Research, 2024). There is a remarkable body of knowledge accumulated from previous V2X projects in the United Kingdom, covering most of the related technical and regulatory challenges, whilst the behavioural dimension remains unexplored. The Isle of Wight's winter peak demand is 129 MW, being the total renewable capacity (excluding microgeneration below 50 kW) rated at 280 MW. The excess is exported to England mainland (Scottish and Southern Electricity Networks, 2024).
Portugal	The Porto airport terminal load profile is driven mostly by climatization, and it is insensitive to passenger volume variations throughout the year. In Maia, the average electric charging duration in a public charger is 57 min, consuming 17 kWh (Mobi.e, 2024); this typical usage can be related to the fact of public charger fees which discourage longer stays.

Geography	Findings
	The Portuguese distribution system operator recently ran tests with the Piclo platform in the form of a demand response trial, including EVs within the pool of flexible assets (E-Redes, 2022).
Hungary	A single home can have two simultaneous electricity tariffs according to season and assets connected (MEKH, 2024); the EV charger, for example, is connected to the same circuit where PV injects energy and most of the house loads are, but if the homeowners opt for an "H" type of tariff to their heating assets, these are separated from the first one. There is a price fixation on the kWh up to a pre-determined consumption per year, above which the cost is determined by the retailer (Szabó, 2022).
Netherlands	The Johan Cruyff ArenA hosts events (*e.g.*, concerts, football matches) with up to 80,000 people, and hence charging station usage is subject to a remarkably high degree of variability along the year. As of now, the Johan Cruyff ArenA encompasses: (i) 1 bidirectional charging station and 24 unidirectional charging stations, enabling vehicle-to-vehicle actions; (ii) a solar Photovoltaic (PV) system supplying electricity for up to 14 % of local consumption; and (iii) a battery energy storage system often participating in frequency regulation grid services.
Italy	EV flexibility marketplace participation is allowed by regulation, both for private and public charging station settings. As of now, the ASM Terni microgrid encompasses: (i) 2x 240 kWp solar PV plants; (ii) 1 bidirectional charging station and 2 unidirectional charging stations, enabling vehicle-to-vehicle actions; (iii) a building energy management system; (iv) a biodiesel generator; and (v) 10 staff EVs prepared to be installed with onboard diagnostics tracking devices for battery health related data retrieval.

Noticeably, the driving forces behind the implementation and operationalization of electric mobility demonstrators are groupable within a set of overarching evaluating dimensions. Thus, identifying a common evaluating framework is an essential step towards the creation of a structured and dependable set of analytical indicators meant to guide and verify the success of field operations within the demonstration phase of the DriVe2X project. The dimensions which govern the evaluation of the demonstration phase's success should be valid across every site and UC.

The all-encompassing nature of the evaluating dimensions is particularly important in the DriVe2X project, due to the multi-geography electric mobility demonstrations taking place therein. Effectively, it may be easier to uncover dimensional information for some of the geographies than for others, but having a clear understanding of the dimensions to be evaluated mitigates the risk of neglecting relevant insights (which could, in a worst-case scenario, act as blockers to the demonstrators' implementation and operationalization).

The identified overarching evaluating dimensions are listed in the table below, which furthermore poses guiding exemplificative questions to which these dimensions answer to.

Table 3. Electric mobility demonstrator evaluating dimensions arising out of initial information gathering and partner discussions.

Dimension	Description
Behavioural	What motivates an EV user to perform a smart and/or bidirectional charging session?
	How should the EV user journey be designed to ensure the smart and/or bidirectional charging session process is seamless and trustworthy?
Environmental	What are the environmental consequences arising out of smart and/or bidirectional charging?
	How can one validate the environmental impact generated by smart and/or bidirectional charging?
Financial	What is the direction and magnitude of the carried out financial flows?
	How much is smart and/or bidirectional charging worth for network operators, home/building managers and EV users?
Technical	What devices, interfaces and protocols are needed to perform and monitor smart and/or bidirectional charging sessions?
	What are the functional, technical or technological barriers preventing the execution of smart and/or bidirectional charging (*e.g.*, electrical installation characteristics)?
Regulatory	Is there any guideline or law which directly or indirectly prevents the execution of smart and/or bidirectional charging sessions?
	How can regulatory gaps be leveraged to enable smart and/or bidirectional charging?

The Electric Mobility Systems Architecture model, deployed in T1.4, resonates with the technical and financial dimensions, as it structures the electric mobility ecosystem of each one of the DriVe2X project's demonstrators into layers, namely, business, function, component, information, and communication. However, due to its origins in the Smart Grid Architecture model, it does not sufficiently reflect regulatory, behavioural or environmental aspects.

At this point, the list of evaluating dimensions listed above is still tentative, inherently emerging from the discussions held between partners. Its correctness and completeness will only be confirmed after proving it against the literature and experience in similar projects.

2.2. Literature review

Due to the niche nature of the subject at hand, it was decided to expand the scope of the state-of-the-art review beyond V2X UCs, rather reviewing analytical frameworks with a view to test and validate all manner of UC classes within the electric mobility domain. Examined analytical frameworks accounted for a vast array of evaluating dimensions, such as technical, technological, institutional, regulatory, market, economic, financial, social, behavioural and environmental.

First off, (Gonzalez Venegas et al., 2021) analyses and determines success factors regarding the interaction between an EV and the power grid. Apart from technical and economic aspects, the analytical framework developed herein also encompasses end-user and regulatory dimensions. The diagram in Figure 1 portrays this analytical framework.

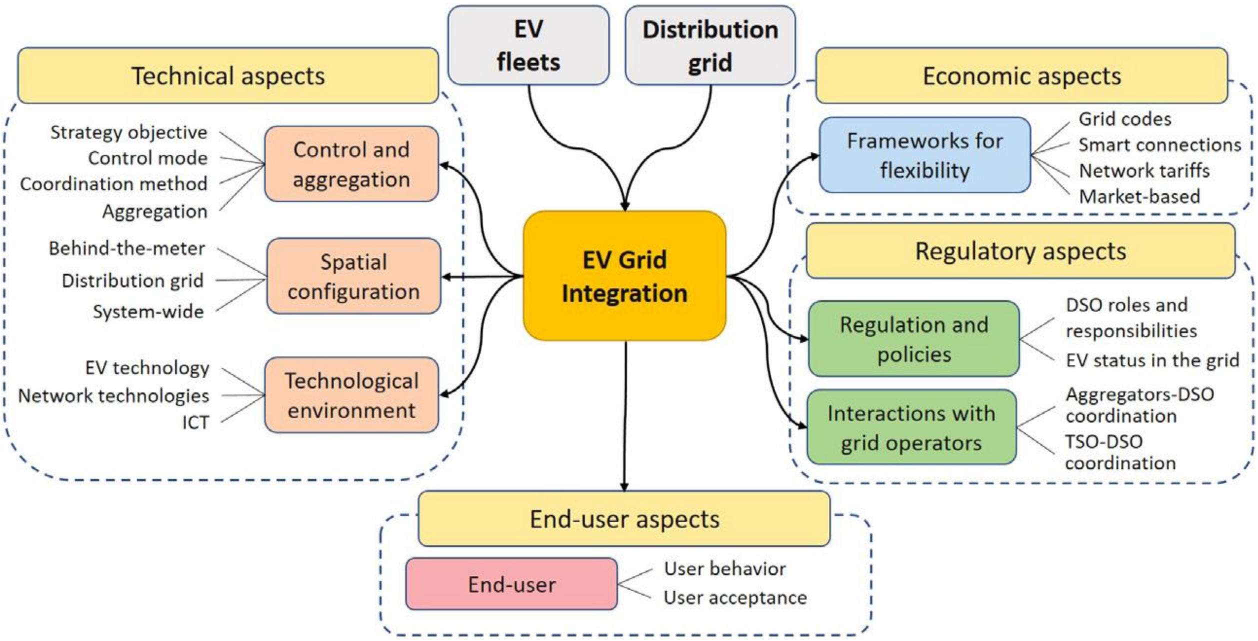

Figure 1. Analytical framework for the analysis of EV – power grid interaction (Gonzalez Venegas et al., 2021).

Next in order, (Thompson & Perez, 2020) designs an analytical framework for the analysis of economic potential of “in-front-of-the-meter” and “behind-the-meter” value streams arising out of V2X actions conducted by EVs participating in wholesale energy markets or interacting with electric utilities and network system operators. It furthermore delves into regulatory limitations related to the identified value streams. The study concludes on the superior economic potential of V2X value streams such as the usage of V2H or V2B to reduce energy and capacity charges, and the usage of V2H, V2B or V2G to delay electricity network upgrades in capacity constrained areas[4].

Moreover, (Saxena et al., 2023) conducts a survey with an extensive set of EV owners to capture the technical, economic, social, and environmental aspects they regard as the most relevant on the subject of V2X. Ultimately, evaluation metrics for V2X programs are created based on these aspects, to cater to user preferences. Amongst other results, the survey at hand ascertained that EV owners are more prone to participate in trial V2X programs with financial incentives (such as free EV charging and/or free energy billing), environmental benefits, no contractualization, as well as moderate driving ranges (1.5 times the EV owner’s daily commute) and plug-in times (eight hours a day).

[4] Whilst electricity network upgrade deferral is not directly covered by the analytical indicators evidenced further ahead in the document (see Section Analytical indicator list), some of these indicators might be leveraged to support such calculations.

Finally, (Sovacool et al., 2017) starts by identifying what it terms as the sociotechnical system for transportation, with a focus on personal automotive transportation (Figure 2).

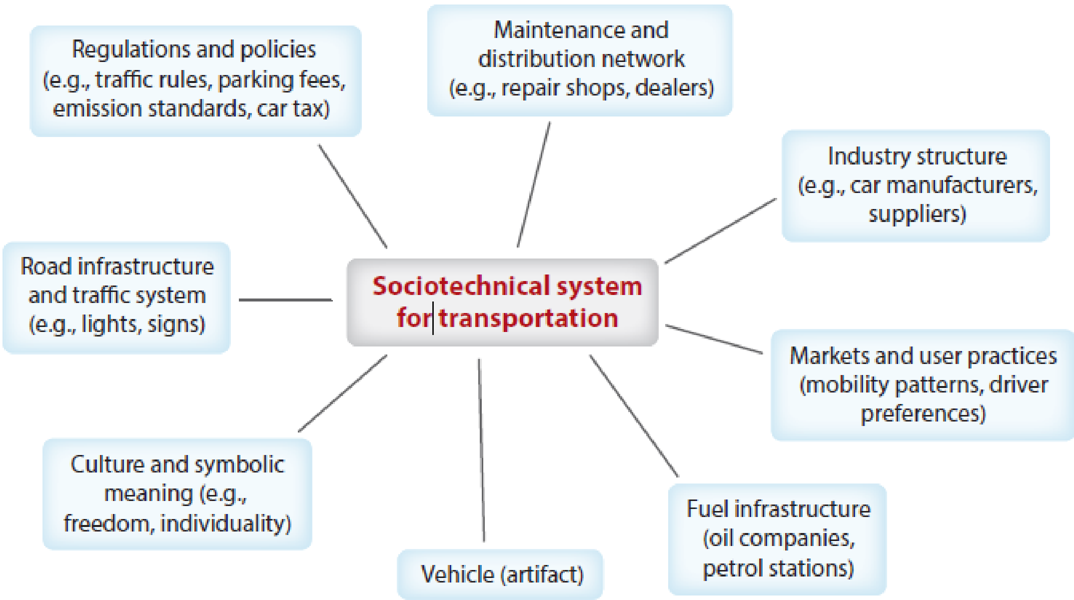

Figure 2. The sociotechnical analytical framework, considering personal automotive transportation (Sovacool et al., 2017).

(Sovacool et al., 2017) then details the so-called sociotechnical analytical framework, developed to identify the potential technical, financial, social, behavioural, and environmental benefits, opportunities and barriers regarding the integration between EVs and the power grid. Table 4 displays the key concepts and attributes subjacent to the integration between electric mobility transport and electricity network infrastructure as per this framework.

Table 4. Key concepts and attributes subjacent to the integration of EVs with the power grid, adapted from (Sovacool, Axsen & Kempton, 2017).

EV to power grid integration concept	Description	Attributes
Power flow direction	Direction of the energy transferred between the charging station and the EV.	Unidirectional: *e.g.,* "dumb" charging, smart charging[1].
		Bidirectional: *e.g.*, V2H, V2B, V2G.
Aggregation of resources	Pooling of EVs.	Individual: one resource or multiple resources in one location.
		Aggregated: multiple resources in multiple locations.
Actor objectives	The alignment of participating stakeholders' goals.	Unified: one actor or multiple actors with aligned objectives.

		Fragmented: multiple actors with varying or conflicting objectives.
Mechanism of actor engagement	Method of incentivization of EV users/owners, home/building managers or network operators.	Time-of-use pricing.
		Revenue sharing.
		Education or voluntarism.

[1] Smart charging refers to charging rate control or to the switching of charging on or off, requiring added control commands but little alteration to charging station hardware.

On another note, the foreseen mechanisms of actor engagement are threefold, in particular: (i) Time-of-use pricing refers to situations where the electricity price is linked with electricity availability – generally, incentives are provided to users so as to charge EVs at times when the price is lower and discharge them at times when the price is higher; (ii) revenue sharing concerns cases where an electric utility or aggregator shares revenues (*e.g.*, acquired via grid service participation) or savings (*e.g.*, acquired via smart charging actions) with the user; and (iii) education or voluntarism deals with informing the EV user/owner, home/building manager or network operators of benefits (such as social and/or environmental) reaped from integrating EVs with the power grid (Sovacool et al., 2017).

Following, the sociotechnical analytical framework is broken down into four distinct but interconnected evaluating dimensions which might be called upon to test and validate UCs related to the integration between EVs and the power grid. These dimensions are the following: (i) technical; (ii) financial; (iii) socio-environmental; and (iv) behavioural. An overview of the sociotechnical analytical framework's evaluating dimensions and underlying topics is replicated herein for future reference.

Table 5. Evaluating dimensions and topics concerning the integration of EVs with the power grid, adapted from (Sovacool et al., 2017).

Dimension	Topics	Examples
Technical	Technology, infrastructure, hardware.	EV performance, grid interconnection, communication, battery degradation.
Financial	Price signals, economics, regulatory tariffs.	Capital cost of charging stations, EVs, batteries and interconnectors, revenues, cost savings.
Socio-environmental	Broad social benefits and burdens.	Mitigated Greenhouse Gas (GHG) emissions, air pollution, integration with renewable energy sources, externalities.
Behavioural	Consumer and user perceptions, attitudes, and behaviour.	Consumer perceptions of all the above, including benefits, inconvenience, distrust, confusion, and range anxiety.

The sociotechnical analytical framework serves to evaluate the integration of EVs with the power grid in a manner which is complementary to conventionally studied arrangements. In fact, this analytical framework introduces novel perspectives concerning the testing and validation of electric mobility domain related UCs, by looking into benefits and drawbacks regarding non-conventionally researched EV categories (*e.g.*, medium- and heavy-duty EVs, plug-in hybrid EVs), resource aggregation and actor objective structures (*e.g.*, fleet operators), EV ownership structures (*e.g.*, shared EVs), power flow direction schemes (*e.g.*, V2X), and actor engagement mechanisms (*e.g.*, voluntary enrolment) (Sovacool et al., 2017).

The dimensions laid on the table above will act as one of the bases for designing the analytical framework of the DriVe2X project. Their comprehensiveness add a confidence layer that every key aspect of the project's goals will be covered. Moreover, these dimensions leverage the originality of the UCs, focusing not on their general setting (V2G, V2H, V2B), but on the context they are deployed.

3. Methodology

3.1. Introduction

Although primarily supported by the sociotechnical analytical framework in (Sovacool et al., 2017), the methodology herein conceived to test and validate the DriVe2X project's V2X UCs is not a direct transposition of the sociotechnical analytical framework, but rather an adaptation of it. The present section details the creation of this novel methodology.

3.2. Methodological development steps

First, to ensure the requirements of every demonstrator are accommodated by the newly created V2X UCs testing and validation methodology, all partners (in particular, demonstrator managers) were surveyed on the features they deemed relevant to assess within the demonstration phase.

After collecting the results of the aforementioned survey for each of the eight demonstrators – Isle of Wight (V2B), Isle of Wight (V2G), Porto airport (V2B), Maia city centre (V2G), city of Budapest (V2H), city of Amsterdam (V2G), Terni city centre (V2G), ASM Terni microgrid (V2G) –, envisioned features were post-processed in order to avoid duplication and ensure maximum transversality across the demonstrators, resulting in Table 6.

Table 6. Features to be assessed within the demonstrators, according to related stakeholders.

Feature	Description
Charging station performance	Charging station technical and functional operability.
EV performance	EV technical and functional operability (including regarding its battery).
Grid stability	Network balance between production and demand (including in terms of frequency and voltage), often achieved by distribution system operators or distribution network operators via grid service requests for the activation of external dispatchable assets (*i.e.*, flexibility delivery requests), such as EVs.
Self-consumption	Reliance of load fulfilment (including EV charging) on locally (onsite or nearby) generated energy, such as solar PV or wind energy.
Business	Revenues and cost savings associated with EV charging/discharging actions (*e.g.*, energy arbitrage, load balancing, flexibility delivery, solar PV and wind curtailment mitigation, grid investment deferral).
Engagement	User acquisition and inducement of EV charging/discharging actions.
User experience	User operational approach to EV charging/discharging actions and respective perspective in terms of related features, advantages, and disadvantages.

Co - Funded by the European Union

UK Research and Innovation

Parallel to the gathering of the partners' insights, the Excellence section of the DriVe2X project's Grant Agreement was conscientiously revised. In doing so, the project's goals which are suitably assessable during the demonstration phase were listed, namely:

- To increase the level of understanding of V2X concepts among demonstration phase stakeholders.
- To assess EV user charging behaviour, expectations, as well as determinant factors (drivers and barriers) regarding V2X adoption.
- To reduce battery degradation under different V2X approaches.
- To reduce the average cost for all actors involved under different V2X approaches.
- To demonstrate grid stabilization and increased renewable energy consumption.

Moreover, within the DriVe2X project, T12.1 will produce a set of key performance indicators relating project-level objective fulfilment with the following elements of green electrification in Europe:

- Awareness of V2X concepts on the part of demonstrator stakeholders.
- V2X flexibility business models testing.
- Deployment of V2X chargers for V2H, V2B, and V2G applications.
- Deployment of V2X energy management system integrations.
- Reduction in energy exchanges with the grid.

Given the abovementioned key performance indicators, collaborative efforts were conducted between WP1 and WP12 – Project Coordination –, given a two-folded aim: (i) avoid superpositions between the analytical indicators herein conceived and the key performance indicators under construction within T12.1; and (ii) create analytical indicators which complement these key performance indicators by reflecting localized evaluating metrics that focus on the steerage and validation of field operations within the demonstration phase.

Finally, the features collected from each local partner and the DriVe2X project's goals were harmonized into a set of analytical indicators spanning the sociotechnical dimensions. The harmonization process consisted in two major stages, namely: (i) filtering; and (ii) compatibilization. The filtering stage put aside features which, although relevant, were not suitable candidates for an actionable indicator (*e.g.*, "energy losses in the bidirectional charging cycle" is an important figure, but better suited for the laboratory testing instead of on-site operation to be carried out in T7.4).

The compatibilization stage elicited the indicators in a way that ensured their applicability and relevance to as many sites and UCs as possible.

3.3. Analytical indicator list

The contents presented in the tables within this section represent, at the date of the writing of this document, a minimum viable set for the analytical indicators aimed at the evaluation of the DriVe2X project's field operations during the demonstration phase. In fact, the detailing of the UCs and the integration of the field devices needed to ensure all required control and monitoring capabilities are still ongoing, which means the following analytical indicators may yet be expanded or implemented in a different way than what is proposed herein, following the contextual, technical, and operational evolution of the implemented setup: these additions or adjustments may inclusively occur after the demonstration phase begins.

Table 7. Analytical indicator list.

Analytical indicator	Sociotechnical dimension	Description and relevance
Flexibility availability	Technical	This indicator will track how flexible EVs can be as an energy asset while attending to the EV users' preferences and mobility needs, by comparing the amount of energy made available (for EV charging and discharging) within the idle timeframe against standard charging operation (*i.e.*, charging start immediately upon arrival, at maximum charging rate). The comparison at hand will preferably be carried out by means of parallel collection of real-world data from two physical charging stations under similar external conditions but can also be performed via simulation if the former approach is deemed operationally unfeasible. This indicator will be useful to determine sets of actions with a view to maximizing the EV flexibility potential during the demonstration period and later provide concrete evidence on the feasibility of flexible EVs for each site and UC.
Power demand	Technical	This indicator will track the actual load relief potential based on the feeder loading (primarily estimated, but accounting for real data whenever possible), comparing advanced charging and standard charging operation.
Carbon intensity	Socio-environmental	This indicator will track how much GHGs are emitted due to advanced charging, when compared to standard charging operation (including self-consumption). Its computation implies estimating regional or national carbon intensity for the electricity consumption realized during the charging/discharging session, based on external sources.
Grid independence	Technical	There will be no islanded operation during the demonstration phase. Still, it is relevant to assess how bidirectionality may improve an installation's resiliency. This indicator measures for how long an installation could rely on its local generation and storage assets (including backup systems) with the introduction of a bidirectionally-capable EV, comparing advanced charging and standard charging operation.
Financial savings	Financial	Savings resulting from the advanced charging deployment, when compared to standard charging operation. Contrarily to most other indicators, this is an absolute figure. Savings are to be presented from the perspective of the network operators, home/building managers and EV users (either individually or in an aggregated manner). Moreover, savings may account or not for the provision of grid services (the demonstrators carried out with home managers test the effect of V2H in the home energy bill savings, while the demonstrators

Analytical indicator	Sociotechnical dimension	Description and relevance
		conducted with car clubs test the impact of grid service provision by means of V2G in the car rental business and the demonstrators carried out with network operators test the effect of flexibility provision by means of V2X in the grid management business).
Battery health	Technical	Battery health preservation (or improvement) is one of the flagships of the DriVe2X project, which entirely dedicates WP6 – Operational and economic trade-offs on the EV user side under mass V2X deployment conditions – for this topic. The definition and detailing of this indicator shall be provided by this WP.
Level of understanding	Behavioural	User perceived level of understanding of V2X concepts.
Scheduling compliance	Behavioural	Level of agreement between EV charging/discharging planning and user response.
Ease of interaction	Behavioural	User perceived easiness of EV advanced charging, in comparison to standard charging operation.

Table 8 presents smart and/or bidirectional charging session parameters, alongside the origin of these data (measurements registered during the demonstrators' operation, either from field devices or trustworthy resources, such as official platforms and information aggregation services[5]), their level of aggregation, sampling rate (*i.e.*, frequency with which data are captured), refreshment rate (*i.e.*, frequency with which data needs to be interpreted for suitable operation) and measuring unit.

Table 8. Smart and/or bidirectional charging session extractable parameters.

#	Parameter	Origin	Aggregation level	Sampling rate (min)	Refreshment rate	Unit
1	Charging point identifier	Charging Point Operator (CPO) platform	Per charging point	N.A.	Per semester	-
2	User identifier	CPO platform	Per charging/discharging session	N.A.	Monthly	-
3	User target EV battery State of Charge (SoC)	CPO platform	Per charging/discharging session	N.A.	Weekly	%
4	User target departure time	CPO platform	Per charging/discharging session	N.A.	Weekly	hh-dd-mm-yyyy
5	User inputted EV battery SoC on arrival	CPO platform	Per charging/discharging session	N.A.	Weekly	%

[5] T5.2 has already identified several sources for various types of information related to electric mobility performance and user behaviour.

Co - Funded by the European Union

UK Research and Innovation

#	Parameter	Origin	Aggregation level	Sampling rate (min)	Refreshment rate	Unit
6	User inputted EV battery capacity	CPO platform	Per charging/discharging session	N.A.	Weekly	kWh
7	Charging/discharging session timestamp	CPO platform	Per charging/discharging session	15	Daily	-
8	Charging point charging/discharging rate	CPO platform	Per charging/discharging session	15	Daily	kW
9	Energy transfer at solar PV system meter	Home or building energy management system	Per charging/discharging session	15	Daily	kWh
10	EV battery State of Health (SoH)	Onboard diagnostics tracking device	Per EV	15	Monthly	%
11	Energy carbon intensity	Estimation from historical data and external databases	Per charging/discharging session	60	Monthly	gCO2eq/kWh
12	Electricity import price	Estimation from historical data and external databases	Per demonstration site	60	Daily	€/kWh
13	Electricity export price	Estimation from historical data	Per demonstration site	60	Per semester	€/kWh
14	Time-based price	Estimation from historical data	Per demonstration site	N.A.	Per semester	€/min

Table 9 presents the auxiliary variables needed to calculate the proposed analytical indicators, based on the aforementioned smart and/or bidirectional charging session parameters.

Table 9. Analytical indicators' calculation's auxiliary variables.

#	Auxiliary variable	Description	Related session parameters	Unit
1	Plug-in time	Time between EV plug-in and plug-off.	#7	h
2	Active energy transfer time	Amount of plug-in time when energy is being transferred to/from the EV.	#7 #8	h
3	Maximum rated power	Maximum charging/discharging rate at which the charging point can nominally operate.	#1	kW
4	Power on duty	Charging/discharging rate during active energy transfer.	#8	kW
5	Charging energy	Energy charged into the EV.	#7 #8	kWh

#	Auxiliary variable	Description	Related session parameters	Unit
6	Discharging energy	Energy discharged from the EV.	#7 #8	kWh
7	Total energy scheduling	Energy scheduled to respond to EV mobility needs, considering the charging/discharging actions to be conducted and the charging point's maximum rated power.	#1 #3 #5 #6	kWh
8	Energy self-consumption	Energy transferred into the EV arising out of local solar PV generation.	#7 #8 #9	kWh
9	Carbon intensity on duty	GHG emission factor during active energy transfer, including the effects of energy self-consumption.	#7 #8 #9 #11	gCO2eq/kWh
10	Charging session energy cost/revenue	Cost or revenue related to energy charged into the EV.	#7 #8 #12	€/kWh
11	Discharging session energy cost/revenue	Cost or revenue related to energy discharged from the EV.	#7 #8 #13	€/kWh
12	Charging/discharging session time-based cost/revenue	Cost or revenue related to time between EV plug-in and plug-off.	#7 #14	€/min
13	EV battery SoH	EV battery condition compared to its original condition (*i.e.*, SoH of 100%).	#10	%

Finally, Table 10 comprehensively details the means of calculation for the analytical indicators based on the aforementioned auxiliary variables (represented therein as AV), as well as the analytical indicators' measuring units.

Table 10. Analytical indicators' means of appraisal and measuring units.

Analytical indicator	Equation	Measuring unit	Notes
Flexibility availability	$\frac{\left(1-\frac{\text{AV \#2}}{\text{AV \#3 . AV \#1}}\right)_{\text{Smart/V2X}}-\left(1-\frac{\text{AV \#2}}{\text{AV \#3 . AV \#1}}\right)_{\text{Standard}}}{\left(1-\frac{\text{AV \#2}}{\text{AV \#3 . AV \#1}}\right)_{\text{Standard}}}$	%	It is important to assess the UCs and sites with less flexibility potential and trigger actions to improve it further (*e.g.*, targeting a lower EV battery SoC). In particular, it is worth examining the charging/discharging sessions with no flexibility (when the EV user sets a SoC that prevents anything other than

Analytical indicator	Equation	Measuring unit	Notes
			charging at full power immediately). It is also relevant to quantify the flexibility potential per UC and site.
Power demand	$$\frac{\left(\frac{\text{AV \#4}}{\text{AV \#3}}\right)_{\text{Smart/V2X}} - \left(\frac{\text{AV \#4}}{\text{AV \#3}}\right)_{\text{Standard}}}{\left(\frac{\text{AV \#4}}{\text{AV \#3}}\right)_{\text{Standard}}}$$	%	It is likely real-time grid status (*e.g.*, transformer loading) will not be available. However, it is useful to assess the ability of the charger, in a standalone fashion, to mitigate demand: the installation should have enough capacity to feed the charger, that is, it should be possible to perform standard charging. Note the presented indicator is only true for pure consumer installations, not prosumers'.
Carbon intensity	$$\left[\frac{\text{AV \#9}_{\text{Smart/V2X}} - \text{AV \#9}_{\text{Standard}}}{\text{AV \#9}_{\text{Standard}}}\right]_{\text{"simple"}} \text{ or } \left[\frac{\text{AV \#9}_{\text{Smart/V2X}} - \text{AV \#9}_{\text{Standard}}}{\text{AV \#9}_{\text{Standard}}}\right]_{\text{"actual"}}$$ (see notes)	%	This indicator can be calculated either not considering negative GHG when discharging ("simple" method) or considering negative GHG when discharging ("actual" method).
Grid independence	$$\frac{\left(\frac{\text{AV \#8}}{\text{AV \#5}}\right)_{\text{Smart/V2X}} - \left(\frac{\text{AV \#8}}{\text{AV \#5}}\right)_{\text{Standard}}}{\left(\frac{\text{AV \#8}}{\text{AV \#5}}\right)_{\text{Standard}}}$$	%	It is herein assumed the local energy generation source foreseen in the scope of the project's demonstrators is a solar PV system.
Financial savings	$$(\text{AV \#10} + \text{AV \#11} + \text{AV \#12})_{\text{Smart/V2X}} - (\text{AV \#10} + \text{AV \#11} + \text{AV \#12})_{\text{Standard}}$$	€	Note this indicator is the only one out of the quantitative analytical indicators to be presented as an absolute figure.
Battery health	$$\frac{f(x,y,z,\dots)_{\text{Smart/V2X}} - f(x,y,z,\dots)_{\text{Standard}}}{f(x,y,z,\dots)_{\text{Standard}}}$$ (see notes)	%	This function f which defines battery health is yet to be defined within the scope of WP6.
Level of understanding	Directly acquired	Qualitative	The qualitative means of appraisal at hand is yet to

Analytical indicator	Equation	Measuring unit	Notes
			be defined within the scope of WP9.
Scheduling compliance	$$\frac{\left(\frac{\text{AV \#5} + \text{AV \#6}}{\text{AV \#7}}\right)_{\text{Smart/V2X}} - \left(\frac{\text{AV \#5} + \text{AV \#6}}{\text{AV \#7}}\right)_{\text{Standard}}}{\left(\frac{\text{AV \#5} + \text{AV \#6}}{\text{AV \#7}}\right)_{\text{Standard}}}$$	%	In the case of bidirectional charging sessions, the standard charging portion of the indicator at issue naturally neglects the discharged energy from the EV, as standard charging is, inherently, unidirectional.
Ease of interaction	Directly acquired	Qualitative	The qualitative means of appraisal at hand is yet to be defined within the scope of WP9.

4. V2X UCs testing and validation

4.1. Analytical indicator application to the DriVe2X project's demonstrators

The present section lays out the application of the newly created testing and validation methodology to the DriVe2X project.

Given the heterogeneity of the anticipated sites and UCs – in particular, in terms of the involved actors and respective objectives, power flow direction, resource aggregation structure, EV ownership structure, and actor engagement mechanisms –, some analytical indicators are naturally not befitting to all demonstrators.

Table 11 charts the agreement between the list of analytical indicators in Section 3.3 and each of the DriVe2X project's eight demonstrators (in Isle of Wight, Amsterdam, Porto, Maia, Budapest, and Terni)[6].

Table 11. Analytical indicator to demonstrator matching matrix.

Analytical indicator	Demonstrator							
	1 – Isle of Wight (V2B)	2 – Isle of Wight (V2G)	3 – Porto airport (V2B)	4 – Maia city centre (V2G)	5 – City of Budapest (V2H)	6 – City of Amsterdam (V2B)	7 – Terni city centre (V2G)	8 – ASM Terni microgrid (V2G)
Flexibility availability	X	X	X	X	X	X	X	X
Power demand	X	X	X	X	X	X	X	X
Carbon intensity	X	X	X	X	X	X	X	X
Grid independence	X				X	X		X
Financial savings	X	X	X	X	X	X	X	X
Battery health					X			X
Level of understanding	X	X	X	X	X	X	X	X

[6] It should be noted that the analytical indicator to demonstrator matching matrix herein presented serves at this stage as tentative and preliminary. In fact, its validation will be conducted alongside demonstrator stakeholders (in particular, demonstrator managers) within the scope of T9.1, being contingent on the operational capability of each demonstrator when it comes to the retrieval of its analytical indicators' underlying data.

Co - Funded by the European Union

UK Research and Innovation

Analytical indicator	Demonstrator							
	1 – Isle of Wight (V2B)	2 – Isle of Wight (V2G)	3 – Porto airport (V2B)	4 – Maia city centre (V2G)	5 – City of Budapest (V2H)	6 – City of Amsterdam (V2B)	7 – Terni city centre (V2G)	8 – ASM Terni microgrid (V2G)
Scheduling compliance	X	X	X	X	X	X	X	X
Ease of interaction	X	X	X	X	X	X	X	X

Co - Funded by the European Union

UK Research and Innovation

5. Conclusions

This deliverable presents a novel methodology to test and validate the DriVe2X project's five V2X (V2H, V2B or V2G) UCs, which are to be accomplished in each of its eight foreseen demonstrators – Isle of Wight (V2B), Isle of Wight (V2G), Porto airport (V2B), Maia city centre (V2G), city of Budapest (V2H), city of Amsterdam (V2G), Terni city centre (V2G) and ASM Terni microgrid (V2G). This methodology is not only based on the analytical frameworks applicable to electric mobility related UCs testing and validation which arose out of literature review – with a particular focus on the sociotechnical analytical framework –, but also rooted in the assessment goals expressed by the demonstrator stakeholders and on a thorough review of the DriVe2X project's goals expressed in the Grant Agreement.

What is more, based on the abovementioned methodology's evaluating dimensions and topics – technical, financial, socio-environmental, and behavioural –, the newly created methodology supported the construction of an extensive list of analytical indicators to assess the success of the execution of the field operations within the DriVe2X project's demonstration phase. The description, measuring units and means of appraisal of such analytical indicators are also presented in this deliverable, which closes off by matching these analytical indicators with the eight DriVe2X project's demonstrators.

In conclusion, the present deliverable is of the utmost importance to the DriVe2X project, as it contributes with a novel V2X UCs testing and validation methodology which will be later on called upon to support the monitoring and evaluation works within each demonstrator.

References

Ayvens Societe Generale Group, & Wheels. (2024). *Ayvens Mobility Guide: Navigate the electric ecosystem in 47 markets*.

E-Redes. (2022, December 12). *Primeiros passos no mercado de flexibilidade em Portugal*. https://www.e-redes.pt/pt-pt/noticias/2022/12/12/primeiros-passos-no-mercado-de-flexibilidade-em-portugal

Gonzalez Venegas, F., Petit, M., & Perez, Y. (2021). Active integration of electric vehicles into distribution grids: Barriers and frameworks for flexibility services. *Renewable and Sustainable Energy Reviews*, *145*. https://doi.org/10.1016/j.rser.2021.111060

MEKH. (2024). *Lakossági Energiadíj-kalkulátor*. https://www.mekh.hu/lakossagi-energiadij-kalkulator

Mobi.e. (2024). *Mobi.Data*. https://www.mobie.pt/mobidata/data

Saxena, S., Farag, H. E. Z., Hilaire, L. S., & Brookson, A. (2023). A techno-social approach to unlocking Vehicle to Everything (V2X) integration: A real-world demonstration. *IEEE Access*, *11*, 17085–17095. https://doi.org/10.1109/ACCESS.2023.3244562

Scottish and Southern Electricity Networks. (2024). *Isle of Wight Active Network Management Live*. https://www.ssen.co.uk/our-services/active-network-management/iow-anm/

Sovacool, B. K., Axsen, J., & Kempton, W. (2017). The future promise of Vehicle-to-Grid (V2G) integration: A sociotechnical review and research agenda. *Annual Review of Environment and Resources*, *42*, 377–406. https://doi.org/10.1146/annurev-environ

Szabó, K. (2022, August 9). *Record high "market prices" introduced in the Hungarian residential electricity and gas markets*. https://english.atlatszo.hu/2022/08/09/record-high-market-prices-introduced-in-the-hungarian-residential-electricity-and-gas-markets/

Thompson, A. W., & Perez, Y. (2020). Vehicle-to-Everything (V2X) energy services, value streams, and regulatory policy implications. *Energy Policy*, *137*. https://doi.org/10.1016/j.enpol.2019.111136

Tourism South East Research. (2024). *Isle of Wight Passenger Data Quarter 2 - Key Findings*.

Co - Funded by the European Union

UK Research and Innovation