AI-informed Holistic Electric Vehicles Integration Approaches for Distribution Grids

D3.1

V2X flexibility services development

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EXECUTIVE SUMMARY

Deliverable D3.1 presents the outcome of Task 3.1, which focus on the development and validation of flexibility services for electric mobility within the AHEAD project. The task investigates how electric vehicles (EVs) can be integrated into distribution grids not just as passive loads, but as active providers of grid support. It aims to identify, classify, and demonstrate flexibility services enabled by various actors in the e-mobility ecosystem, considering both technical feasibility and regulatory context.

The methodology followed a four-step approach: (i) literature review of flexibility frameworks and standards, (ii) filtering of stakeholder positions from regulators, operators, and academia, (iii) classification of flexibility services across transmission, distribution, and charging site levels, and (iv) analysis and recommendations for service deployment. The review spans regulatory frameworks, technical standards, and operational roles, highlighting the evolving responsibilities of TSOs, DSOs, aggregators, and other actors in enabling EV-based flexibility.

Flexibility services are categorized by activation mechanisms—explicit, implicit, and autonomous—and by procurement models, including market-based and non-market-based approaches. The deliverable introduces a comprehensive trigger framework, mapping flexibility activation to grid needs such as congestion management, voltage regulation, and frequency control. The AHEAD demonstrators sites across Northern, Southern, and Western Europe validate these services under real-world conditions.

In the Northern Region demo fast and slow charging stations are used to test multi-level flexibility coordination, including direct control, dynamic capacity contracts, and AI-informed scheduling. The Southern demonstrator showcases real-time DSO-triggered flexibility, alongside smart charging solutions for heavy duty vehicles. Meanwhile, the Western region demonstrator explores renewable prioritization, peer-to-peer energy trading and site-level control across diverse urban and residential environments. These demonstrations confirm the technical viability of EVs as distributed energy resources (DERs) and their potential to support grid stability, resilience, and the energy transition.

This deliverable lays the groundwork for integrating EV flexibility into future grid architectures, emphasizing the need for interoperable standards, adaptive control systems, and collaborative market frameworks. The insights gained contribute to the AHEAD project's broader goal of enabling intelligent, resilient, and sustainable distribution networks through holistic EV integration.

List of Abbreviations and Acronyms

AC	Alternating Current
ACER	Agency for the Cooperation of Energy Regulators
AHEAD	AI informed Holistic Electric Vehicles Integration Approaches for Distribution Grids
AI	Artificial Intelligence
BESS	Battery Energy Storage System
BRP	Balancing Responsible Party
BSP	Balancing Service Provider
CapEx	Capital Expenditure
CCA	Conditional Connection Agreement
CEER	Council of European Energy Regulators
CINEA	European Climate, Infrastructure and Environment Executive Agency
COW	Coalition of the Willing
CPO	Charging Point Operator
DC	Direct Current
DER	Distributed Energy Resource
DSO	Distribution System Operator
ENTSO	European Network of Transmission System Operators
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FCR	Frequency Containment Reserve
FRR	Frequency Restoration Service
FSB	Flexibility Service Buyer
FSP	Flexibility Service Provider
IBR	Inverter-based Resource

IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
LV	Low Voltage
MSP	Mobility Service Provider
MV	Medium Voltage
MW	Megawatt
NEMA	National Electrical Manufacturers Association
OBC	Onboard Charger
OCPP	Open Charge Point Protocol
OEM	Original Equipment Manufacturer
OpEx	Operating Expenditure
PEV	Plug-in Electric Vehicle
PWM	Pulse Width Modulation
RES	Renewable Energy Source
RFID	Radio Frequency Identification
SCALE	Smart Charging Alignment for Low Emissions (EU project)
TSO	Transmission System Operator
V2G	Vehicle to Grid
V2X	Vehicle to Everything
VPP	Virtual Power Plant
WP	Work Package
RR	Replacement Reserve

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1. INTRODUCTION

In this section, we outline the objectives, methodology, and structure of this deliverable.

1.1. Background and objectives

AHEAD project is structured into 11 work packages (WPs) with the final goal of developing an AI tool for the deployment of charging infrastructure in Europe. Charging infrastructure serves as the interface between the power system and the transport sector. While WP 2 focus on charging technology and WP 4 centres on power grid and spatial models, WP 3 investigates the synergy of the power and transport sector, more specifically grid services. Therefore, e-mobility with the batteries sitting on wheels can contribute to enhance the integration of renewable energy and electrification of the demand. However, to develop such synergy a comprehensive planning of the charging and grid infrastructure should take place.

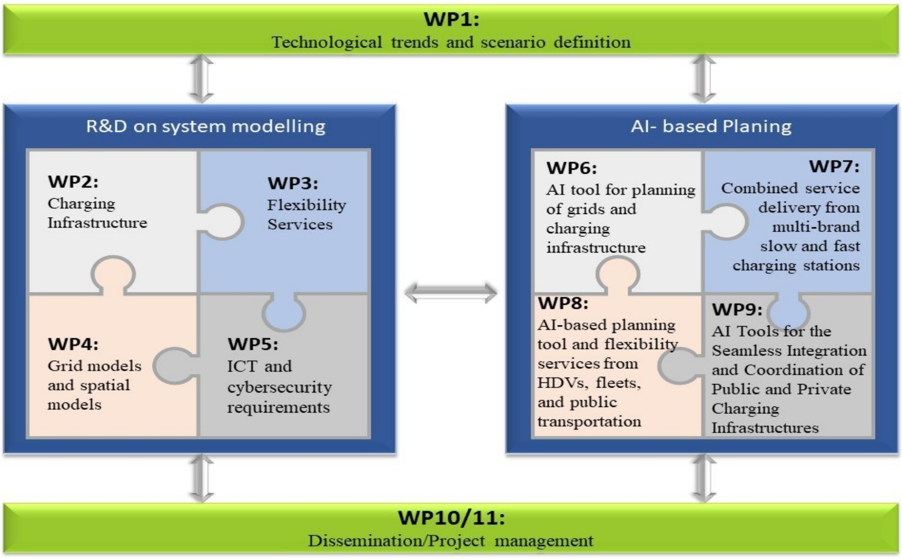


Figure 1 – Work Packages layout of the project.

AHEAD project proposal solution clearly focuses on the development of AI tool to facilitate the deployment of charging infrastructure while considering the need for creating a synergy between e-mobility and renewable energy. This synergy is envisioned at local level (neighbourhoods, feeder level or low-voltage transformer), city level (primary substation) and national level (system stability). To achieve this, as a first step, we are looking at what synergy can be achieved via grid service delivery from electric vehicles (EVs). The following text reflects the task description and the goals:

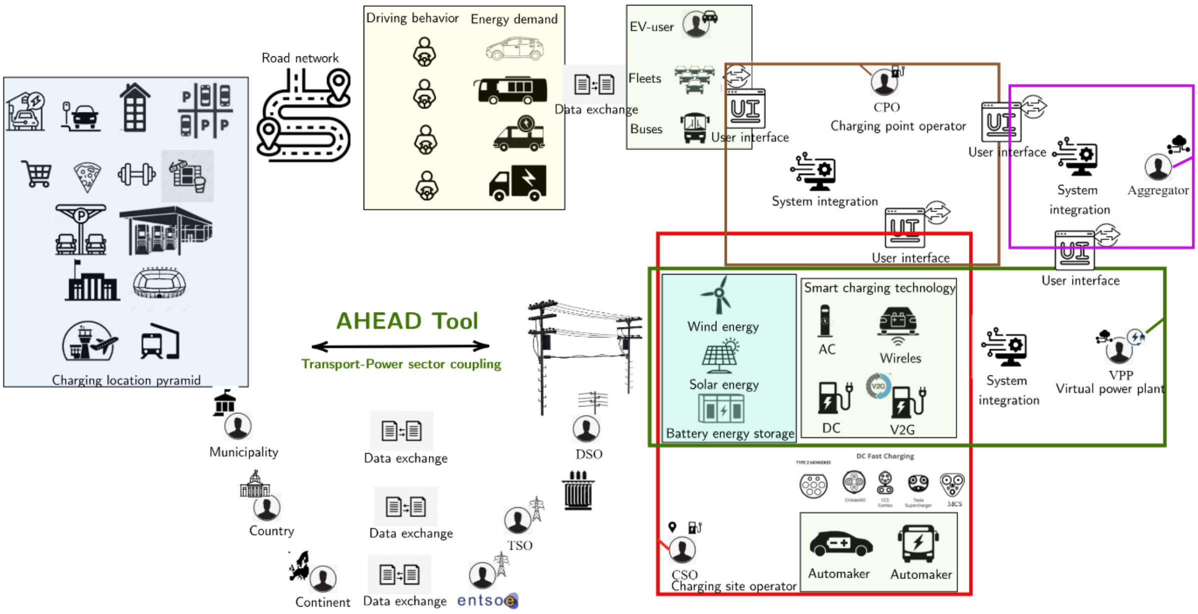


Figure 2 – AHEAD project proposed solution (boxes refer to the different entities behind that role).

T3.1: Development of flexibility services for electric mobility [M4-M18] (Leader DTU; Participants: E-Mobility Europe, EDP, INESC ID, EG, SPIRII, ELBIL, EEM)

The primary objective of this task is to review the flexibility services employed by different stakeholders, and to conceive novel approaches to integrate e-mobility into the power system. Flexibility services can be categorised based on their procurement and activation methods, with different options due to market negotiations at regional or local scales, implicit and explicit demand response initiatives, dynamic capacity contracts, direct control mechanisms, and autonomous control based on operational rules. However, it is important to note that these services have traditionally been tailored to accommodate the relatively limited flexibility of conventional loads, not accounting for the substantial proliferation of EVs with significantly higher flexibility. Within this task, innovative flexibility services, tailored to the capabilities of electric mobility and considering the overall vehicle-to-everything (V2X) potential, will be proposed.

1.2. Methodology and structure

To achieve the task objective, the workflow followed four steps, i) literature review, ii) filtering criteria, iii) classification and iv) analysis and recommendations. Literature review span across research articles, technical reports and legislation papers from European regulators such as Agency for the Cooperation for Energy Regulators (ACER), Council of European Energy Regulators (CEER), European Commission Task Force and system operators position papers. Filtering criteria focused to determine the position of regulators, operators and academia on flexibility services from EVs. Consequently, the delivery provides a definition of entity roles in the ecosystem and the grid services. However, it is necessary to understand data and standards for a full picture and activation mechanism. Therefore, the last step analysis and recommend feasible flexibility solutions for the EV ecosystem. This flow is followed for the chapters of this deliverable.

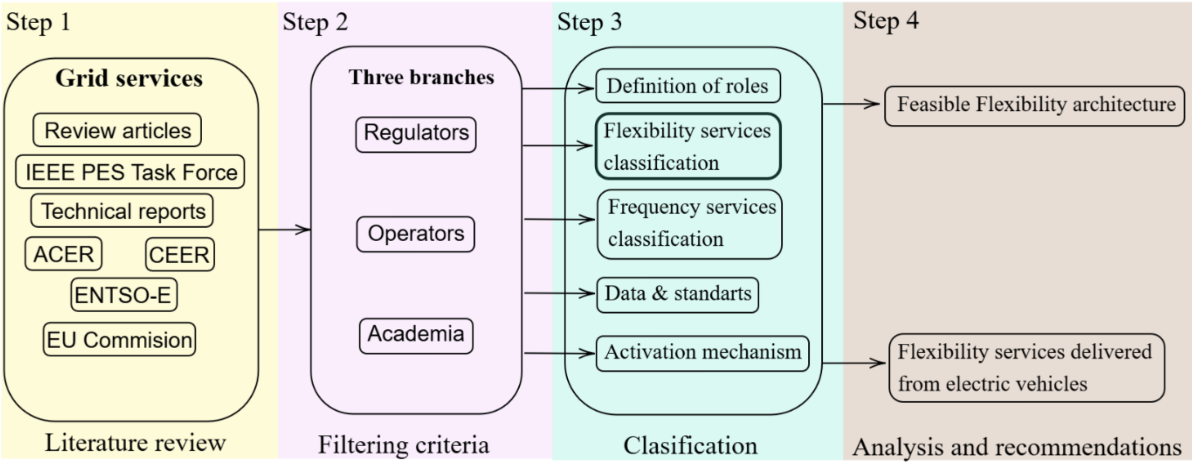


Figure 3 – Methodology employed for Task 3.1.

2. DEFINITIONS

In this section, we outline the actors and their roles for e-mobility ecosystem with a strong focus on grid service delivery.

2.1. Actors and Roles

There is a common understanding that to achieve an operational flexibility provision from e-mobility, we require a definition of roles and responsibilities for the ecosystem. In this regard, there has been research projects such EV4EU, FLOW, SCALE etc., task force groups at national and European levels such as Sustainable Transport Forum, ENTSO-E, E-DSO, ACER, CEER, etc. and worldwide working groups within IEEE and IEA. The goal of this delivery is to achieve a comprehensive overview and merge the learnings from different working groups and research projects. As outlined in the methodology, we divided the review work in three branches: i) regulators, ii) operators and iii) academia. Based on this approach the following Table 2.1 summarizes the key findings received from each branch. For example, ACER states that the rules in the Framework Guideline on Demand Response Article 59(1)(e) —covering demand response, aggregation, energy storage, and demand curtailment—should apply not only to Distribution System Operators (DSOs) but also to Transmission System Operators (TSOs). Similarly, ENTSO-E highlights the evolving role of TSOs as central actors in ensuring grid stability through enhanced data transparency, updated service market regulations, and coordination with DSOs to address the needs of their respective grids. In this context, TSOs are increasingly recognized as key enablers of flexibility, particularly for frequency control, by procuring services from distributed sources such as EVs. Meanwhile, DSOs leverage EV flexibility to address local grid challenges, including voltage control and congestion management. Bidirectional charging is highlighted as a promising solution to support both local and system-wide flexibility needs.

Table 2.1 – Entities and explanation of their roles.

Role	Branch	Stakeholder comments
	Description	TSOs are responsible for the reliable and secure operation of the high-voltage electricity transmission network. Their core functions include balancing electricity supply and demand in real time, managing grid congestion, and ensuring system stability across large geographical areas. TSOs coordinate with DSOs, market participants, and regulators to facilitate electricity flows, integrate renewable energy sources, and maintain grid resilience. They also play a key role in developing infrastructure, enabling cross-border electricity exchange, and supporting

Role	Branch	Stakeholder comments
TSO		the evolution of electricity markets through data transparency and technological innovation.
	Regulator	In the “Framework Guideline on Demand Response” [1] by ACER it is stated that the rules in Article 59(1)(e) on demand response, aggregation, energy storage, and demand curtailment should also apply to TSOs, and not only to DSOs. It is described that the rules should not apply only to TSO-TSO coordination as it is already covered by current legislation, but that DSO-TSO coordination should be involved. When it comes to flexibility provision, TSOs should be technology-neutral, and not exclude any type of provider. This means that both generators, as well as loads can supply this flexibility. There is a need for equal incentives for CapEx and OpEx solutions in the revenue regulation.
	Operators	As highlighted in [2] TSOs have historically been the experts balancing supply and congestion. They expect to continue serving as the future lynchpin in ensuring grid stability through data transparency, updating service market regulations and coordinating with DSOs on requirements of their respective grids. However, this may face pushback from DSOs willing to carve out a new role for themselves in this changing regulatory situation. In [3] the ongoing discussion on how to integrate TSO and DSO level perspectives to efficiently operate the entire electrical grid was highlighted.
	Academia	TSOs may procure flexibility services [4]—especially for frequency regulation—from various sources, including EVs [5]. In general, TSOs are responsible for system security and operate services like balancing and redispatch. Therefore, TSO-DSO coordination critical for leveraging distributed flexibility while avoiding congestion [6]. It is discussed in [7] that the TSO’s role in managing system’s needs is evolving due to increasing shares of inverter-based resources [5]. Although vehicle-to-grid (V2G) can technically support TSO-level services, access to these markets remains limited for EVs [8].
DSO	Description	DSOs are responsible for operating, maintaining, and developing the medium- and low-voltage electricity distribution networks. They ensure the safe and reliable delivery of electricity to end users, manage local grid constraints, and increasingly play a role in integrating distributed energy resources (DERs) such as solar panels, electric vehicles, and battery storage. DSOs are becoming more active in system planning and flexibility procurement, especially as electrification and decentralization

Role	Branch	Stakeholder comments
		increase. Their coordination with TSOs and market actors is essential for efficient grid operation and local system optimization.
	Regulator	CEER recommends, that the details of roles and responsibilities should be defined at the national level, as there is no one-fits-all solution. There is a need for equal incentives for CapEx and OpEx solutions in the revenue regulation. DSOs should choose the use of flexibility services, when it is the most economical option [9]
	Operators	Establishing the flow of information can enable DSOs to be an active participant in the balancing and congestion markets allowing them to proactively prevent issues instead of passively increasing the load limits. The interface between DSOs and TSOs is continuously being discussed and will likely settle in various implementation across nations depending on their characteristics and history.
	Academia	DSOs can use flexibility from EVs for local needs like voltage control, congestion management, and grid capacity issues [4], [5]. These roles are emphasized in discussions about future local system needs [6], [7]. Bidirectional charging is seen as a useful tool to meet these needs [8].
Energy Supplier	Description	Energy suppliers are market participants responsible for purchasing electricity from producers or wholesale markets and selling it to end consumers. They manage customer contracts, billing, and energy pricing, and are typically accountable for forecasting demand and ensuring supply adequacy. As the energy system evolves, suppliers face increasing complexity due to the integration of intermittent renewable generation, the rise of prosumers, and the growing influence of consumer behaviour on energy demand. Their role is central to enabling market-based energy delivery and supporting consumer participation in energy markets.
	Regulator	Today, energy suppliers are responsible for the imbalances they cause. CEER discusses whether this should be continued, or the cost should be passed onto consumers.[10]
	Operators	They are facing increasing complexity due to the forecasting needs of intermittent production, the price adaptive behaviour of smart users and the weather-based patterns of prosumers.
	Academia	It is discussed how energy retailers must adopt to distributed energy resources and prosumer behaviour in [11]. In [12], the relationship between energy retailers, aggregators and DSOs is discussed, in the context of local flexibility markets. [13]mentions that consumer behaviour,

Role	Branch	Stakeholder comments
		prosumer integration and policy can change the business models of retailers.
Energy Markets	Description	Wholesale energy markets are platforms where electricity is traded between generators, suppliers, and other market participants before reaching end consumers. In Europe these markets include day-ahead, intraday, and forward markets, which facilitate the matching of supply and demand based on price signals and forecasts. Their primary function is to ensure efficient resource allocation, minimise imbalances, and support system reliability. As renewable energy and flexible demand grow, wholesale markets are evolving to better accommodate variability and decentralization through shorter time intervals and improved market access.
	Regulator	Customers should have the right to be metered and settled at the same time scale, as the imbalance period.
	Operators	The markets should strive to reduce imbalances by ensuring proper price signals. Furthermore, the market time periods should be reduced to fluidly accommodate intermittent energy technologies.
	Academia	Traditionally, wholesale, retail, and ancillary service markets have ensured adequacy, stability, and resilience of electricity supply [4]. Balancing and flexibility markets—subsets of ancillary services—are especially relevant for integrating distributed resources like EVs but face limitations due to their centralized design. Market participation requires fulfilling strict conditions (e.g., becoming a Balancing Responsible Party (BRP)), yet new alliances among system operators, charge point operators (CPOs), and EV providers indicate a shift toward integrated, service-based models [4]. To support EV integration and prevent market power concentration, competitive and standardized market frameworks are needed [5]. Evolving designs, including time- and value-based market models, aim to enable local, flexible, and consumer-driven energy participation [6], [7], [8].
Balancing services market	Description	Balancing services markets are mechanisms that ensure real-time stability of the power system by correcting short-term imbalances between electricity supply and demand. These markets are typically operated by TSOs and include products such as frequency containment reserves (FCR), frequency restoration reserves (FRR), and replacement reserves (RR). Traditionally centralised and reliant on large generators, these markets are evolving to integrate distributed and inverter-based resources, such as electric vehicles and battery storage.
	Regulator	The markets for balancing services need to be technology neutral and include all types of providers. This means, that all kinds of generators or

Role	Branch	Stakeholder comments
		loads can act as balancing service providers. ACER suggests a minimum bid granularity that is not higher than 0.1MW and 0.1MWh for all balancing capacities and energy products, and to set a clear timeline for the implementation of this change.
	Operators	The balancing services markets must be designed in a way which allow the operators to accomplish their balancing goals. Furthermore, the markets should be designed in such a way as to ensure easy operation for the operator and low balancing costs. There is a divide between operators on how to best design markets and how fast changes are implemented to potentially accommodate new technologies.
	Academia	These markets have traditionally relied on centralised systems but are now increasingly challenged by the rise of distributed and inverter-based resources [4]. With the integration of EVs, new balancing resources such as bidirectional charging are emerging. Aggregated EV fleets can provide frequency and flexibility services through platforms like Virtual Power Plants (VPP), reducing system balancing costs [8]. As outlined in recent literature, TSOs require faster and more localized balancing services in high inverter-based resource (IBR) environments, which will need to be supported by redesigned market structures [7].
Flexibility services market	Description	Flexibility services markets are emerging platforms designed to procure services that help manage grid constraints, balance supply and demand, and enhance system efficiency—particularly at the distribution level. These markets enable distributed energy resources (DERs), such as electric vehicles, batteries, and smart appliances, to offer services like congestion management, voltage control, and peak shaving. Unlike traditional balancing markets, flexibility markets are often locally focused and coordinated by DSOs.
	Regulator	The markets for flexibility services need to be technology- neutral and include all types of providers. This means, that all kinds of generators or loads can act as flexibility service providers. CEER recognizes, that a lack of liquidity in flexibility service markets may lead to a situation, where long term contracts cannot be avoided and are still needed in some cases. CEER recommends four general principles for market-based flexibility procurement: balanced incentives, adequate neutrality, technical prerequisites, and an overall framework for procurement. The framework should at least consist of a description of the product design, the technical rules, a method to cope with imbalances that arise due to activations, tendering procedures, a market model design, and

Role	Branch	Stakeholder comments
		coordination schemes between system operators. The concrete implementation of the market should be based on the national level.
	Operators	The flexibility services markets must be designed in a way which allow the operators to accomplish their stability goals. Furthermore, their digital infrastructure must be designed to accommodate large and rapid data exchanges for the centrally activated flexibility services [14]. There is a trend that flexibility service markets should be updated to accommodate decentralised actors, which entails low minimum bid sizes to accommodate smooth capacity curves. Additionally, the regulation regarding balance responsibility and “energy heavy” services must be updated so that distributed assets can monitor their own services through means such as the Danish TSOs Energinet Independent aggregator. In addition, it should be possible for market participants to provide cross border services for the markets where this could be beneficial to maximize social welfare [14].
	Academia	As outlined in the Coalition of the Willing (CoW) report, the participation of EVs in such markets—particularly through bidirectional charging—can enhance local resilience and reduce redispatch costs[8]. Shell et al., also emphasizes the importance of market-based mechanisms and transparent regulation to unlock flexibility from EVs and storage, especially where national regulatory frameworks are still evolving [5].
Flexibility Service Provider	Description	Flexibility Service Providers (FSPs) are market participants that offer flexible energy resources, such as electric vehicles, batteries, heat pumps, and controllable loads, to system operators or other market actors. Their role is to aggregate, manage, and dispatch these resources in response to grid needs, such as balancing, congestion management, or voltage control. FSPs act as intermediaries between end users and grid operators, enabling participation in flexibility markets.
	Regulator	CEER supports DSOs accessing flexibility from flexibility service providers, which are acting on behalf of EVs, batteries etc [15].
	Operators	The role of FSP’s becomes increasingly complex, when they must handle distributed energy resources. As mentioned by [14] how FSPs manage the distributed assets will be a point of contention in the future. One can imagine centralised FSP’s where they directly control the distributed assets and customers have surrendered the control of their EV, heat pump and the like to the FSP.

Role	Branch	Stakeholder comments
		Alternatively, FSP markets might emerge, where customers actively sell their flexibility when available and continuously opt in and out of FSP control. This would allow customers to retain control but drastically increase the need for data exchange and control algorithms for the FSP. The regulation should allow FSPs to deliver services with a neutral outlook on which technologies they control, not discriminating between hardware options.
	Academia	As noted in [4], roles such as aggregators, CPOs, or energy suppliers may function as FSPs by submitting flexibility offers on behalf of EV users in platforms coordinated by DSOs or TSOs. It is highlighted that FSPs can operate through virtual power plants to enable EV participation in bidirectional services and help reduce balancing costs [8]. The effectiveness of FSPs depends on transparent market access, standardized protocols, and trust between users, aggregators, and system operators [5]
Balancing responsible party (BRP)	Description	A BRP is an entity that holds legal and operational responsibility for maintaining their schedule from the day ahead and intraday markets for a given portfolio or area. Contracting with BRPs has typically been a requirement for participating in the electricity markets, since the BRP is financially responsible for potential imbalances.
	Regulator	In the regulation of the EU on the internal market for electricity, it is defined that BRP should receive the delegation of responsibility contractually and that each BRP shall be financially responsible for the imbalances they cause [16]. A BRP shall strive to be balanced or help the system to be balanced.
	Operators	They are currently distinguished from other services providers by having balancing responsibility for their energy purchases allowing them access to markets with expected energy consumption or production. This distinguishing feature is expected to be diminished by the implementation of the independent aggregator.
	Academia	As frequency and flexibility services become increasingly tied to local grid contexts, BRPs play a key role in ensuring accurate forecasting and system-level alignment. While other reviewed sources do not directly define the BRP, they emphasize the importance of balancing forecasts and the growing complexity introduced by the integration of EVs.
	Description	A Balancing Service Provider (BSP) is a market participant that delivers balancing services, such as frequency regulation and reserve capacity to TSOs. Unlike BRPs, BSPs do not carry energy balancing responsibility

Role	Branch	Stakeholder comments
Balancing service provider (BSP)		and typically provide services without committing to energy production or consumption forecasts. Their market access is often more limited and regulated compared to BRPs, but they play a key role in supporting system stability, especially in high renewable and inverter-based environments.
	Regulator	*Not mentioned*
	Operators	*Not mentioned.*
	Academia	These actors deliver frequency and balancing services. It highlights how EV-based flexibility—aggregated by actors such as aggregators or virtual power plants—can contribute to balancing markets. BSPs are responsible for delivering services such as frequency regulation and reserve capacity to TSOs. In this context, aggregated EV fleets can participate in balancing markets through BSPs, helping reduce redispatch costs and enhancing system efficiency [8]
Independent aggregator	Description	An Independent Aggregator is a market actor that coordinates DERs—such as electric vehicles, batteries, and smart appliances—without being tied to a traditional supplier or BRP. These aggregators enable flexible assets to participate in energy and ancillary service markets by managing their operation and offering aggregated services like balancing, congestion management, and bidirectional charging. Variations of independent aggregator or similar contractual options are in varying stages of implementation across Europe.
	Regulator	ACER suggests a process including an analysis of ENTSO-e and EU DSO entity for further harmonising the main elements of different aggregation models.
	Operators	*Not mentioned.*
	Academia	They can group together EVs and other distributed energy resources to provide system-level services, such as balancing and congestion management [5], [6], [7], [17]. Aggregators are also essential for enabling participation in bidirectional charging services such as V2G, by interfacing between EV owners and system operators [8]. Their role becomes even more important as flexibility becomes decentralized and more reliant on consumer-owned assets. In this context, *energy communities* can also act as aggregators. These are legal entities that empower citizens, small businesses, and local authorities to produce, manage, and consume their own energy, often from renewable sources [8]. Energy communities can participate in flexibility markets by offering aggregated flexibility through platforms

Role	Branch	Stakeholder comments
		connected to DSOs or TSOs, helping to balance the grid. Moreover, when integrated with bidirectional charging, they can treat EVs as distributed energy resources—supporting local supply, grid resilience, and peer-to-peer energy trading [4], [8].
Charging point operator (CPO)	Description	A CPO is responsible for the operation, maintenance, and management of electric vehicle supply equipment (EVSE). CPOs ensure reliable access to charging infrastructure, handle payment processing, and provide customer support for EV users. In the context of smart and bidirectional charging, CPOs may also enable remote control functionalities and facilitate data exchange with aggregators or system operators.
	Regulator	CEER acknowledges the role of CPOs in several areas, e.g. the management and operation of charging points, system integration and smart charging, as well as consumer protection [18]
	Operators	According to AFIR Art 2. (39), the CPO refers to the entity responsible for the management and operation of a recharging point, which provides a recharging service to end users, including in the name and on behalf of a mobility service provider. Furthermore, the CPO must coordinate with FSBs/BRPs in order to participate in the markets and provide flexibility.
	Academia	CPOs operate EVSE infrastructure and play a critical role in enabling flexibility from EVs [5], [17]. They are responsible for services such as charging access, payment processing, and customer support for EV drivers [8] in the context of smart and bidirectional charging, CPOs may support remote control functionalities and help facilitate the aggregation of flexibility by providing site-level data and forecasts to independent aggregators or energy communities[4].
EVSE	Description	EVSE, commonly referred to as EV chargers, is the physical infrastructure that enables electric vehicles to recharge. While EVSEs are not considered market actors themselves, they play a foundational role in enabling smart and bidirectional charging, which is essential for delivering flexibility services such as V1G and V2G.
	Regulator	*Not mentioned.*
	Operators	*Not mentioned.*
	Academia	As highlighted in studies like [8] and [4], the controllability and interoperability and standardization of EVSEs are critical for unlocking

Role	Branch	Stakeholder comments
		flexibility potential, yet they function primarily as passive infrastructure within the broader flexibility ecosystem.
Mobility service provider (MSP)	Description	A Mobility Service Provider (MSP), often referred to as an e-MSP in the context of electric mobility, is a legal entity that offers services to EV users, typically including access to charging infrastructure, billing, and user interfaces such as apps or RFID cards. MSPs facilitate the commercial relationship between EV drivers and charging networks, often acting as intermediaries between users and CPOs. In advanced setups, MSPs may in the future also support bidirectional charging and help connect EVs to energy markets, enabling users to participate in flexibility services like V2G).
	Regulator	CEER acknowledges that one of the main instruments to build a trustful relationship for consumers and to improve transparency is by making MSP prices easily understandable, reasonable and available to customers before charging [18].
	Operators	According to AFIR Art. 2, point 36: 'mobility service provider' (e-MSP) means a legal person that provides services in return for remuneration to an end user, including the selling of recharging or refuelling service.
	Academia	According to the CoW report, e-MSPs primarily act as digital and contractual intermediaries for EV users, enabling access to charging infrastructure and billing services. While e-MSPs do not directly control grid interactions, they can facilitate user participation in bidirectional services such as V2G by collaborating with CPOs, V2G service providers and FSPs. This integration allows e-MSPs to support the aggregation of distributed energy resources and connect users to energy and flexibility markets. Through this indirect role, e-MSPs contribute to making V2G services more accessible, enabling users to benefit from financial incentives by feeding electricity bac into the grid [8].
Roaming service provider	Description	A Roaming Service Provider facilitates interoperability between different electric vehicle charging networks, allowing EV users to access and use charging stations operated by various CPOs without needing separate subscriptions. These providers enable seamless charging experiences across networks through contractual agreements, data exchange, and billing integration. Roaming services may be offered by independent entities or through behind-the-scenes arrangements between CPOs, supporting broader accessibility and convenience for EV drivers.
	Regulator	CEER states that EV owners should be able to charge in different charging networks without facing additional costs. Moreover, they

Role	Branch	Stakeholder comments
		propose additional requirements to CPOs to allow non-discriminatory access to third party MSPs offering roaming services [18].
	Operators	Currently found in different iterations, either as independent entities or hidden agreements between mobility service providers.
	Academia	*Not mentioned.*
EV- OEM	Description	EV Original Equipment Manufacturers (OEMs) are companies that design, produce, and sell electric vehicles. Their role in the flexibility ecosystem is primarily through the technical capabilities they embed in EVs, such as support for smart and bidirectional charging. OEMs influence the extent to which EVs can participate in energy and flexibility markets through decisions related to battery design, warranty policies, communication standards, and software integration. Their adoption of open standards like ISO 15118 is critical for enabling interoperability with charging infrastructure and market platforms
	Regulator	*Not mentioned.*
	Operators	They should have a focus on implementing bidirectional charging to fully unlock EV flexibility. Furthermore, there is a lack of implementation of the open standards on the EV side, which slows CPO implementation of standards like ISO 15118, due to immature EVs.
	Academia	OEMs influence how much EVs can participate in flexibility, through limits and designs on battery warranty, degradation, and certification [8]. However, they are barely mentioned in papers.
End-user	Description	An EV End User is an individual or organization that owns or operates an electric vehicle and interacts with the charging infrastructure and mobility services. While not traditionally considered a market actor, EV users play an increasingly active role in the energy system through smart charging, bidirectional services like V2G, and participation in flexibility markets.
	Regulator	CEER recommends, that whether to be actively a part of a flexibility market, should be the choice of the end user.
	Operators	They can either allow FSBs to control their car to unlock its flexibility, become prosumers with extensive smart charging integration at their home or simply not allow their EV to be used for “smart” charging.
	Academia	In current systems, end-users must give permission for their vehicles to be controlled or optimized for grid services, such as through a CPO or aggregator [4.] The EV Task Force[5] underscores the importance of empowering users through clear and transparent business models, as

Role	Branch	Stakeholder comments
		well as adequate compensation mechanisms, especially in early-stage V2G applications. Looking ahead, the CoW report envisions a future where end users can seamlessly integrate EVs with household energy systems, participating in flexibility through interoperable platforms [8]. Enabling this integration will require transparency, trust, and user-centric service design.

2.2. Standards and Protocols

The second step to achieving grid services, it is important to distinguish between standards and protocols. At this topic, there is plenty of work on the standardization and implementation side. Reliable, high-speed, large-scale control of AC charging for EVs is chiefly constrained by vendor-specific communication standards [19] and by the technical limits of onboard chargers (OBCs) [20]. As emphasised in [21], control reliability remains sub-optimal and EV models exhibit heterogeneous dynamic responses. Presently, the Open Charge Point Protocol (OCPP) is the dominant architecture for managing EVSE behaviour [4], whereas IEC 61851-1 specifies the EVSE–OBC interface. Investigations concerning OCPP have focused on expanding smart-charging functionality, enabling secure transactions, and realising plug-and-play interoperability [19]. Further complexity arises because the two most recent editions of IEC 61851-1 include partially conflicting control requirements [22] In particular, sequence 6 (current regulation) of a standard charging cycle differs between the editions (see Table 2.2). The latest version obliges the EVSE to adjust its pulse-width-modulated (PWM) signal within 10 s following an external command and introduces an additional constraint: a mandatory 5 second delay before any subsequent current change. These provisions limit the permissible frequency of current adjustments, thereby diminishing the potential of EVs to provide fast ancillary control.

Table 2.2 – Sequence 6 (current change) description in the IEC 61851-1 editions.

Edition	Standard explanation	Variable step	Timing	Explanation
IEC 61851-1:2010	$t_{external}$: Time of arrival of external control signal to EVSE.	$t_{external}$	10 s	Modification of pulse-width in response to an external command to EVSE.
		$t_{ichange}$	5 s max	Change of current following change in PWM duty cycle.

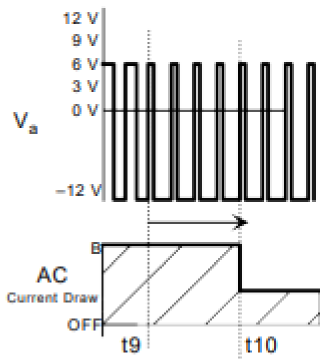
Edition	Standard explanation	Variable step	Timing	Explanation
	$t_{ichange}$: Time of change in current, given change in PWM duty cycle			
IEC 61851-1:2019	 AC supply remains available S2 remains closed Trigger: PWM duty cycle change	t_9	10 s max	The EVSE indicates an adjustment to the maximum AC line current. The EVSE may change the PWM duty cycle at any time to any valid PWM duty cycle. **In normal operation, during the 5 s allowed adjustment time $t_{10} - t_9$, the EVSE shall not initiate a new sequence 6 for changing the PWM.**
		$t_{10} - t_9$	5 s max	The EV shall adjust its maximum current drawn to be equal to or below the maximum current indicated by the PWM duty cycle.

Figure 4 schematically depicts the communication architecture and associated standards that facilitate the provision of ancillary grid services by EVs in AC-charging mode. More details can be found in Deliverable 5.1. The delivery of a given service—e.g., primary frequency regulation to a TSO—proceeds through a hierarchical chain of control transactions. The command originates at the aggregator, is conveyed to the CPO, and finally reaches both the EVSE and the EV itself. Two discrete communication domains are therefore involved:

1. Over-the-air domain: This path spans the aggregator, CPO, and EVSE, and is predominantly implemented using the OCPP.
2. Wired domain: This galvanically coupled interface links the EVSE to the vehicle and is governed by IEC 61851-1 and ISO15118, which specifies the signalling exchanged between the EVSE and the vehicle's onboard charger (OBC).

The coordinated operation of these two communication layers is essential to ensure reliable, standards-compliant provision of grid services by EVs.

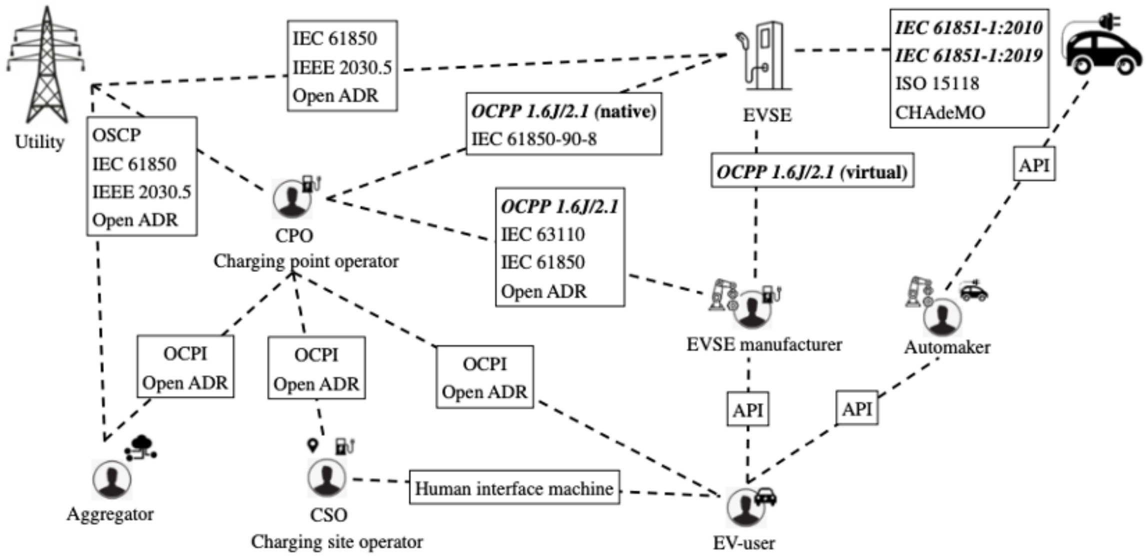


Figure 4 – Communication standards for delivering grid services [17].

3. GRID SERVICES

We cluster the potential grid services from EV into the following categories i) grid stability (TSO and DSO), ii) congestion management (TSO and DSO), iii) voltage regulation (TSO and DSO), iv) power quality (DSO) and v) resilience (TSO). We discuss each of these clusters of services and in the final subsection, a complete table highlights also the delivery feasibility for EVs per service.

3.1. Grid stability

Grid stability services play a crucial role in maintaining power system stability, adequacy, and security of supply beyond wholesale electricity and balancing markets. These services can be categorized into three key pillars:

- Inertia based services are employed to strengthen the frequency stability and thus reduce frequency deviations.
- Frequency arresting services react when frequency deviations occur, attempting to arrest them and stabilising the frequency.
- Frequency recovery services are used to alleviate the frequency arresting services and restoring the frequency.

In high-renewable energy sources (RESs) integration scenarios, additional services may be required to ensure safe system operation and maintain frequency reserves. These include

RESs power smoothing [23]. energy arbitrage, and seasonal balancing to address RESs unpredictability [24], [25].

3.2. Congestion management

Congestion management may include the actions taken by the system operator (DSO or TSO) to operate the network under normal loading conditions which is necessary for the safety of the power system components i.e., within the maximum loading ratings (usually in terms of the Amperes) and current flowing through this equipment should not exceed the ratings. The congestion services are usually enforced by different price-based mechanisms: dynamic tariff, dynamic incentives pricing, variable peak pricing, as mentioned in [26], [27], [28], [29], [30], [31]. These services are listed in Table 3.1 – Overview of grid services along with their definitions. To enable congestion management EV aggregators are often required to ensure behind the meter load management, entailing that for a fleet some cars are in a standby state waiting for their turn to charge to keep the load on the common point of coupling below a threshold [32].

A survey of different real-time pricing for the congestion management can be found in[33], [34]. The time-resolution of these services may vary from near real-time (15 minutes) to monthly as mentioned in the Table 3. In practice, congestion management product may be offered as two kinds (e.g. GOPACS1 platform): (i) Capacity limitation: it is usually done at the day-ahead state and different types are fixed capacity limitation contracts, on-demand limitation contracts, and non-firm connection agreement and (ii) Re-dispatching: adjustment after closing of the day-ahead market (intra-day bids).

3.3. Voltage regulation

Voltage regulation ensures that distribution network voltages remain within the ±10% range prescribed by IEC standards [35], safeguarding consumer devices against damage from overvoltage or undervoltage. The network operators also must ensure the compliance on voltage unbalances limits as per the standards set by organizations such as IEEE [36] IEC [37] and NEMA [38]. Traditionally, DSOs have employed passive elements like shunt capacitors and tap-changing transformers. The control of active and reactive power injections from the EVs presents new opportunities for the voltage regulation and phase balancing has been investigated in several literature. These services are listed in the Table 3.1Table 3.1 – Overview of grid services

3.4. Power quality

Power quality refers to the measures taken from DSO to improve supply quality and reduce grid operational losses. Here, the voltage regulation service is distinguished from the power quality service because it belongs to both DSO and TSO. In contrast, the power quality service belongs to the DSO. Besides, voltage regulation itself has become quite important; hence, it deserves to be mentioned separately. Power quality is focused on the fast dynamics of switching of electronic devices [37] the mitigation of DERs power flickers [39], [40], and the control of the end-user power factor [38].

3.5. Resilience

Being mostly reliant on user behaviour, the forthcoming high EV penetration will significantly impact grid resilience and mobility [41]. Leveraging the distributed nature of EVs offers a promising strategy for improving grid resiliency. Utilities and grid operators can mitigate the impact of outages, reduce load-shedding, and balance supply and demand by smart charging management of EVs [42], [43]. V2G services with a limited number of light-duty plug-in electric vehicles (PEVs) can also supply power for an adequate duration during blackouts [44]. Autonomous load restoration can also be achieved through EV [45]. In the event of natural disasters or other emergencies, maintaining a reliable power supply is crucial for public safety and quick recovery. EVs can provide a valuable source of backup power during such events [46]. EVs have the capability to relocate from areas experiencing power outages to unaffected regions for adequate charging, subsequently returning to their initial locations to offer V2G services. The consequences of the inability to charge EVs during outages can be severe as it also facilitates transportation out of hazardous areas for individuals to procure essential supplies. They can be deployed to power critical infrastructure, such as hospitals, emergency response centres, and communication networks, ensuring that essential services remain operational [47]. This capability is of utmost importance in areas prone to natural disasters like hurricanes, earthquakes, and wildfires [48]. By providing localized backup power through acting as grid forming inverters, EVs can help to maintain critical functions and support disaster response and recovery. Some services are dependent on the EVSE being capable of acting as a grid forming inverter, setting and regulating voltage and frequency, in contrast to grid following inverters, which can only accept the grid frequency.

3.6. Grid service overview

Table 3.1 – Overview of grid services provides an overview of the grid services EVs can deliver via smart charging or bidirectional charging.

Table 3.1 – Overview of grid services

Grid stability			**Explanation**	**Proven EV Feasibility in source**
Type	**Name**	**Duration**		
Frequency services	Group I: Arrest period. RoCoF based activation		Goal: Should reduce the rate of change of frequency (RoCoF) (prevent triggering RoCoF relays) and delay the frequency nadir.	
	1.Inertia [49]	0-5 sec	1. Inherent characteristic of rotating generators that contributes to frequency stability.	No
	2.Synthetic Inertia*[50], [51]	0-5 sec	2.Ability of converters to help reduce RoCoF by injecting power into the system. It is also associated with grid-following converters.	In paper
	3.Virtual Inertia[52], [53]*	continues	3. Ability of converters to mitigate or enhance RoCoF by injecting power into the system. It is also associated with grid-forming converters.	No
	4.Inertia floor[50], [54], [55]	continues	4. Refers to the requirement for rotating inertia to sustain or enhance the system's optimal inertia, helping to mitigate frequency excursions.	No
	Group II: Arrest-rebound-recovery period. Frequency-based activation		Goal: To halt frequency excursions and prevent a critical frequency nadir that could activate defense mechanisms.	
	5.Fast frequency reserve[56], [57], [58]*	0-10 sec	5. Refers to the requirement for rapid power injection, typically within less than 2 seconds, to be sustained for a predefined duration as specified by the grid code.	No
	6. Frequency containment reserve*[59], [60]	0-30 sec	6. Refers to the requirement for rapid power injection, typically within 15 seconds, to be sustained for a predefined duration in accordance with the grid code.	Yes
	Group III: Recovery period. Frequency-based activation		Goal: Should replace the generation loss and restore normal operation.	

	7. Frequency restoration reserve*[61], [62], [63]	0.5-30 min	7. Requesting a power delivery to restore the frequency deviation to the nominal operating point.	Yes
	8. Replacement reserve*[64], [65]	1-4 hours	8. Requesting a power delivery (generator rescheduling) to fully clear the frequency deviation.	No
Grid code	**9. Frequency ride through***	mili sec - sec	9. Demanding to be capable of operating (staying connected) across specified frequency ranges in the grid code (RfG and DC).	No
Wholesale markets	10. *Energy storage*[66], [67]*		10. Utilising battery capacity to provide renewable back up electricity	Yes
Congestion management			**Explanation**	**Proven EV Feasibility**
Type	**Name**	**Duration**		
Implicit demand response	11. Real-time pricing (or Dynamic pricing)[68], [69], [70], [71]	15 min – 1 h	11. Dynamic prices reflecting locational marginal prices (LMPs).	Yes
	12. Variable peak pricing	1 day -1 week	12. Flat prices for fixed periods and extra variable charge based on peak demand.	Yes
	13. Time of Use (ToU)[72], [73], [74]	hourly	13. Flat prices for fixed periods (independent of peak demand magnitude).	Yes
	14. Critical peak rebate (or Peak-time rebate)[75], [76]	Hour - day	14. During critical events, the consumer is paid for reducing every kWh reduced below a baseline quantity.	Yes
	15. Extreme day pricing	hour	15. Extra fee on high demand day imposed by the DSO.	No
	16. Inclining block rate[77]	Billing cycle	16. DSO charges a higher rate for each incremental unit of electricity consumption.	Yes

	17. Valley filling[78]	hour	17. EV scheduling strategy to uniformise consumption over time, to reduce load variations for the grid.	Yes
	18. Behind the meter load management [32]	Variable	18. Varying charging and standby for EVs charging at sites connected with limited capacity.	Yes
	19. Behind the meter Fair & Smart EVSE Scheduling	15min – 1 hour	19. With fewer EVSEs than households, an EMS/app allocates charging slots by need and availability to ensure fairness and avoid peaks.	Yes
	20. Behind the meter Dynamic Tariff & Flex Management	15min – 1 hour	20. Coordinate BESS/EV charging and discharging with tariff signals to minimize bills and reduce dependence on the main grid.	Yes
	21. Behind the meter self-consumption in house or building	15min – 1 hour	21. Using locally produced solar energy, stored in the BESS or EV, to supply the house/building's own loads and reduce grid dependence.	Yes
Voltage regulation			**Explanation**	**Proven EV Feasibility**
Type	**Name**	**Duration**		
	22. Dynamic voltage regulation[79], [80], [81]	Temporary or continues	19. Active power or reactive power control for tackling over/under voltages.	No
	23. Voltage balancing[82], [83], [84], [85]	Temporary or continues	20. Per-phase active power or reactive power control for balancing overall three-phase demand.	No
Power quality			**Explanation**	**Proven EV Feasibility**
Type	**Name**	**Duration**		
	24. Power factor control[86]	Temporary or continues	21. Reactive power support for improving overall power factor.	No

Grid code	25. Harmonics mitigation[86], [87], [88]	Temporary or continues	22. Damping harmonics using the inverter capabilities.	No
	26. Low voltage ride through [89], [90]	0-1 sec	23. Supporting to withstand a low-voltage or fault event for a defined time period.	No
Resilience			**Explanation**	**Proven EV Feasibility**
Type	**Name**	**Duration**		
Contractual	27. Anti-islanding	0 – 1 sec	24. Requesting from grid connected inverters to be able to recognize islanding events and prevent it.	No
	28. Black-start capability	0-1 h	25. Service to re-energizing the parts of the network to recover from a blackout.	No
	29. Localized power during emergencies	0- days	26. Service to provide recovery efforts during emergency scenarios.	No
Community	. Peer to Peer trading [32]	Variable	27. Service to allow V2G EVs to sell electricity to local peers behind the meter or at the low voltage level.	Yes

4. FLEXIBILITY INCENTIVES AND TRIGGERS

4.1. Transmission level

4.1.1. Continuous Markets

To ensure frequency stability and handle congestion TSOs can employ continuous market-based solutions, wherein flexibility providers provide their cost and flexibility capacity, allowing the TSO to activate them if needed. The flexibility is usually segmented into the services mentioned in section 3.1, of which the flexibility providers choose which to participate in based on their preferences [91]. These preferences vary from services requirements and price signals.

4.1.2. Grid Code requirements

Flexibility on the transmission level is also formulated in obligations, which are dependent on the national grid code. Specific grid code requirements for the connection of assets are described in section 3.6. They include, among others, anti-islanding detection of inverters, black-start capability and localized power support during specific events. Grid code requirements for flexibility services are described by the TSO, e.g. from Energinet.

4.1.2.1. Market participation validation

To validate market participants activations in flexibility and balancing markets TSOs set different monitoring standards to track asset activation. This task is straightforward with assets that follow a strict schedule, but it becomes more complex for distributed assets due to the variance of the individual. Thus, EV aggregators must constantly monitor their EVs so that they can provide TSOs with their expected and actual behaviour to prove their activation. The resolution needed depends on the TSO and service in question, which in turn sets contractual needs between the FSP and to what degree the CPO can monitor charging sessions on their EV chargers. Prequalification requirements for participation in frequency services are e.g. described for the Danish TSO Energinet in their tender requirements.

4.2. Distribution level

Flexibility on the distribution level is mainly required to manage congestion, and to keep voltage levels in acceptable ranges. The following subchapters describe common mechanisms to promote flexibility on the distribution grid level:

4.2.1. Variable network tariffs

As regulated monopolies, DSOs impose distribution grid tariffs to customers to recover their costs. In this regard, the DSO is providing the service of electricity transportation, while customers “buy” the delivery. Still, in the viewpoint of flexibility, the DSO is “purchasing” flexibility from the customers e.g. CPOs. Variable distribution network, or more formally use-of-system tariffs are another means to motivate demand flexibility. Variable network tariffs are a non-market-based mechanism to incentivise implicit flexibility. Their attributes are influenced by the limitations set upon such tariffs by the regulator, and the defined role of DSOs (which is also a regulatory aspect). Despite any limitations, recent literature [92][93] has proposed the utilization of network tariffs for flexibility mobilization for the following reasons:

- They are a price signal which a DSO (co)designs along with the regulator.
- They are the natural price for the use of the network which is the fundamental commodity associated with congestion.

There are different methods of how the DSO can determine the network tariff levels for different times, promoting flexibility:

4.2.1.1. Static variable network tariffs

Based on historical grid loading data, static variable network tariffs disincentivise consumption in typical peak-loading hours, while they incentivise consumption in typical low-loading hours. The patterns of the variable network tariffs repeat in a predefined periodicity, from which the prefix static originates. Traditionally, the main objective of network tariffs is to recover operating costs and to secure investments. In most countries, this translates to distributing the yearly operator costs among consumers, according to their volumetric consumption (€/MWh) and their installed capacity (€/MW) using flat rates. Variable network tariffs on the other hand are not flat. Instead, they might have temporal (and potentially spatial) granularity to mobilize flexibility and, ideally, reduce network costs. Thus, overall tariff burden on consumers might be reduced. A foreseen challenge is customer behaviour synchronisation when customers have high price elasticity. While at e.g. low EV penetration rates, the charging processes are shifted to nighttime to avoid evening peak consumption, at high EV penetration rates this can cause the formation of a new peak load at night. low EV penetration rates, the charging Click or tap here to enter text.processes are shifted to nighttime to avoid evening peak consumption, at high EV penetration rates this can cause the formation of a new peak load at night. In Denmark, this is already the case for some areas [95].

4.2.1.2. Dynamic variable network tariffs

Similar to variable network tariffs, dynamic network tariffs are a non-market-based tool to incentivise implicit flexibility. By applying dynamically adjustable tariff rates to customers, price signals incentivise flexible consumption. The key difference between dynamic and variable network tariffs, is that dynamic tariff rates are not determined based on historical grid loading but instead are adjusted dynamically based on grid loading forecasts. Foreseen challenges for dynamic network tariffs include transparency issues, as they are not easily communicated to customers [96], [97] which do not have access to forecasting methods. Again, the issue of synchronisation might occur, and lead to new grid loading peaks.

4.2.1.3. Real-time variable network tariffs

Real-time network tariffs are a non-market-based mechanism to incentivise implicit flexibility of customers by adjusting network tariffs in real time based on power grid loading [94]. For this, transformers and or power lines are equipped with measurement technology that transmit data in real-time. The grid tariffs are then directly based on the loading of assets. In contrast to variable and dynamic network tariffs, it is expected that this does not lead to synchronisation effects, avoiding the formation of new load peaks. Foreseen challenges include transparency issues, as customers are not informed in advance about the costs. Moreover, the measurement devices are cost intensive, and large amounts of data need to be processed.

4.2.1.4. Individual peak power component in network tariff

An individual peak power component in the network tariff is a non-market-based mechanism to incentivise implicit flexibility [98] [99]. As the highest loading of a power grid is the design criteria, avoidance of high-power consumption can be incentivised by applying a peak power consumption component in the network tariffs. This peak power is based on the individual user’s consumption. The mainly anticipated challenge for peak-power consumption-based tariffs is the calculation method. Since electricity meters mainly do not measure actual power (e.g. in Watt), the power consumption is instead calculated as an energy consumption in a time window (e.g. Watthour per hour).

4.2.1.5. Grid peak power component in network tariff

Peak power component can also be expressed as the consumption of a user in the moment of the grid peak loading, showing the contribution of a user to the high loading of the grid [98] [99]. An advantage of this is, that the actual grid peak is the reference for the tariff. However, a challenge is at which point in time the grid peak is communicated to the end-user. If the peak loading hour is communicated to the end user beforehand, strong demand response might lead to the peak not actually being the peak loading of the grid. On the other hand, if the timepoint is communicated to the end-users retrospectively, the flexibility is limited. Additionally, the same measurement challenges as in described in section 4.2.1.4 apply.

4.2.2. Conditional Connection Agreements

Conditional Connection Agreements (CCAs) are a non-market-based mechanism for the provision of explicit flexibility. CCAs are agreed upon between the DSO and the customers, typically starting on a medium voltage in the distribution network. However, there are R&D pilot projects that investigate the potential for EV charging stations [100]. In the view of flexibility, the DSO is buying flexibility from the flexibility provider, the CPO or a third-party aggregator. CCA mean that the grid connection capacity for a customer is non-firm. In certain situations, the grid connection capacity can thus be reduced, lowering the power grid loading. There are different methods of how the grid connection capacity is determined, as described in the three following subchapters of static conditional connection agreement, dynamic conditional connection agreement, and real-time conditional connection agreement.

4.2.2.1. Static Conditional Connection Agreement

A static CCA is a non-market-based mechanism for explicit flexibility. A user that is connected to the power distribution network with a static CCA has a non-firm grid connection capacity. This means, that the DSO can explicitly reduce the connection capacity temporarily in predefined time windows. The predefined time windows are based on historical grid loading data and repeat in a predefined periodicity. The predefined time windows can represent seasons, months, days or hours in different granularity. In return to the reduction of connection capacity, the user is forced to reduce its power consumption.

4.2.2.2. Dynamic Conditional Connection Agreement

Dynamic CCAs can be viewed as an extended version of Static Conditional Connection Agreements. As a non-market-based mechanism, dynamic CCAs can adjust the grid connection capacity of a user explicitly. The key difference between the two, is that while Static CCAs are based on predefined time windows, dynamic CCAs are based dynamically on power distribution network condition forecasts. Foreseen challenges for dynamic CCAs include transparency to the user. In contrast to predefined agreed time windows, the reduction takes place on a less transparent way, as grid users do not have insights into power grid loading forecast methods.

4.2.2.3. Real-time Conditional Connection Agreement

Real-time Conditional Connection Agreements are non-market-based mechanisms for explicit flexibility provision. As more complex compared to forecast based dynamic CCAs, real-time CCAs do not require forecasting methods, but are instead based on actual real-time power grid measurements. Known challenges include transparency and data availability. The real-time measurement devices are costly to install, and the measured data needs correct handling. Additionally, as users do not have access to power grid loading measurements, the issue of transparency persists.

4.2.3. Autonomous voltage support (LV)

Autonomous voltage support at the low voltage level is a mechanism to provide explicit flexibility. The procurement method might be either based on regulation, or on a monopsony market, where the single buyer of flexibility is the DSO. Providers of flexibility can be e.g. CPOs. To regulate voltage in low voltage grids, consumers can adjust their respective active and reactive power setpoints P and Q. The adjustment can be based on a droop control. Foreseen challenges include the tuning of the individual responses, thus avoiding instability and oscillations.

4.2.4. Autonomous voltage support (MV)

Autonomous voltage support on the medium voltage level is a mechanism to provide explicit flexibility. Again, the procurement method can be via regulation or based on a monopsony market. The flexibility providers on MV level can e.g. be aggregators or CPOs that are directly connected to medium voltage level. On medium voltage level, the voltage has a stronger dependency on the reactive power Q. Thus, consumers can regulate the reactive power setpoint to provide voltage support, e.g. via droop control. Correct tuning, and the avoidance of instability and oscillations is a foreseen challenge.

4.3. Charging site level

4.3.1. To manage congestion at the charging site level, a CPO can also apply some of the strategies previously explained for the network. Variable charging rates

The CPO can introduce variable rates/prices for charging. These rates are not flat, but instead change over time, thus financially incentivizing customers to adopt flexibility in charging time and location. Variable charging rates are a non-market-based mechanism to incentivise implicit flexibility. In this regard, the flexibility providers are EV users, while the flexibility buyer is the CPO. There are multiple ways, how the variable charging rates can be determined, as shown in the following sub-chapters. Generally, the charging rates can be based on electricity spot market, grid tariffs, carbon intensity, charging site occupancy and other factors.

4.3.1.1. Static variable charging rates

Static variable charging rates are typically based on historic charging data, as well as historical electricity prices. The patterns of the variable charging rates repeat in a predefined periodicity. The charging rates are published meaningfully in advance and cover a predefined time window. Potential challenges include over popularity of chargers in certain hours, given high price-elasticity of EV users. Additionally, encompassing other variable incentives from transmission and distribution system operators might cause contradicting price signals.

4.3.1.2. Dynamic variable charging rates

Dynamic variable charging rates are based on dynamic forecasts, that are communicated to customers e.g. a day in advance. Potential challenges include transparency issues, as the forecasting methods might not be clear to customers. Moreover, over population of chargers might occur given high price elasticity of customers. The issue of combining DSO and TSO incentives with variable charging rates persists.

4.3.1.3. Real-time variable charging rates

Real-time variable charging rates are based on the actual conditions of a charging site, such as occupation of chargers. Transparency is a challenge, as the information about the adjusted charging rates needs to be communicated clearly to customers. Moreover, the challenge of combining DSO and TSO incentives with real-time variable charging rates persists.

5. PROPOSED FLEXIBILITY TRIGGERS

5.1. Northern Europe Demonstrator

The Northern Region demonstration site combines both AC and DC EV charging infrastructure to validate a wide range of flexibility services under real-world conditions. The setup includes slow chargers located at Risø Campus (Roskilde, Denmark) and fast chargers installed at Risø Gateway, allowing the demonstration to cover different charging profiles and user behaviours. This dual-site configuration enables testing of flexibility services across various control layers and operational contexts.

The test cases designed for this demo focus on testing explicit, implicit, and autonomous demand response strategies, with particular emphasis on direct control via protocols like OCPP, dynamic capacity contracts, and AI-informed coordination.

Flexibility is activated through various triggers, including real-time signals from DSOs and TSOs, user preferences, market-based dispatch, and local energy constraints. The test cases explore scenarios such as frequency regulation using BESS, coordinated charging across multiple operators, and renewable prioritization to avoid curtailment. Key metrics such as control latency, user acceptance, SoC impact, and grid import reduction are used to evaluate system responsiveness.

This setup transforms EV charging stations into active flexibility providers, capable of supporting grid stability, peak load reduction, and renewable integration. The Northern Region demo showcases how smart charging, autonomous control, and distributed energy resources can be orchestrated to deliver scalable flexibility services aligned with the goals of the AHEAD project and user experience. The detail of proposed test cases for slow and fast charging stations demos is given in .

Table 5.1 – Overview of the flexibility triggers that will be tested in the Nordic Europe Demonstrator, either in real-world settings or through simulation.

<table>
<tr><th colspan="2">Trigger</th><th>Risø (slow charging parking lot)</th><th>Risø (battery-buffered fast charger)</th></tr>
<tr><td colspan="4">Distribution level</td></tr>
<tr><td rowspan="5">Variable network tariffs</td><td>Static</td><td>X</td><td>X</td></tr>
<tr><td>Dynamic</td><td>X</td><td>X</td></tr>
<tr><td>Real-time</td><td>X</td><td>X</td></tr>
<tr><td>Individual</td><td>—</td><td>—</td></tr>
<tr><td>Peak Power</td><td>—</td><td>—</td></tr>
<tr><td rowspan="3">Conditional Connection Agreements</td><td>Static</td><td>X</td><td>X</td></tr>
<tr><td>Dynamic</td><td>X</td><td>X</td></tr>
<tr><td>Real-time</td><td>X</td><td>X</td></tr>
<tr><td colspan="2">Autonomous LV voltage support</td><td>X</td><td>X</td></tr>
<tr><td colspan="4">Charging Site Level</td></tr>
<tr><td rowspan="3">Variable charging rates</td><td>Static</td><td>X</td><td>X</td></tr>
<tr><td>Dynamic</td><td>X</td><td>X</td></tr>
<tr><td>Real-time</td><td>X</td><td>X</td></tr>
</table>

5.2. Southern Europe Demonstrator

In the Milan demonstration site, an EV charging station will be installed and used as a testbed for flexibility functionalities with the distribution grid. The innovation lies in the dynamic interaction between the charging infrastructure and the DSO, enabling real-time responsiveness to grid needs. During the demo, the DSO will be able to send real-time flexibility requests to the charging station. These requests may include commands to reduce energy consumption during periods of grid stress or inject energy back into the grid when there is surplus capacity available in the connected battery system. Conditional connection agreements will be tested to modulate connection capacity as needed and to coordinate direct control of charging/BESS according to network conditions. This setup will allow the charging station to act not only as a consumer but also as a prosumer in the form of a distributed energy resource (DER), contributing to grid stability. The Milan demo will thus showcase how smart charging and bidirectional energy flows can be used to support the energy transition and enable more intelligent, responsive distribution networks.

The second location in Kranj, Slovenia operated by the Slovenian DSO will cover the Heavy Duty Vehicle (HDV) charging hub charging optimization. The hub is planned to be setup at the location near the Slovenian highway close to the city of Kranj. At the location the DSO will combine the real world network operating conditions with the future planned (partly simulated) charging hub in order to prepare the location for the smart charging functionalities. In this framework, operation will be steered through dynamic network tariffs and peak-power components to shape demand and respect MV constraints, with network safeguards implemented via static conditional connection agreements. At the charging-site level, static variable charging rates will align hub operation with network limits, while system robustness will be assessed through autonomous MV voltage support. Algorithms for the management and the detection of the needed flexibility on the specific MV network will be developed and tested in the demo. Additionally, the Elektro Gorenjska region is a demo site where planning of the charging infrastructure tools developed in WP8 will be tested. This wider demo site concept will span across the entire Elektro Gorenjska network both on the MV as well as on the LV network.

A summary of the flexibility triggers that will be tested in the two Southern Europe Demonstrator locations is presented in Table 5.2.

Table 5.2 – Overview of the flexibility triggers that will be tested in the Southern Europe Demonstrator, either in real-world settings or through simulation.

Trigger		Milan	Kranj
Distribution Level			
Variable network tariffs	Static		
	Dynamic		X
	Real-time		
	Individual		
	Peak Power		X
Conditional Connection Agreements	Static		X
	Dynamic		
	Real-time	X	
Autonomous LV voltage support			

Trigger		Milan	Kranj
Autonomous MV voltage support			X
Charging Site Level			
Variable charging rates	Static		X
	Dynamic		
	Real-time		

5.3. Western Europe Demonstrator

In the Western Europe demonstrator, existing and new charging stations will be used as a demonstrator across different locations, both in Funchal and in Lisbon. These include private residential garages, city-wide public charging networks, a touristic port area, and a semi-public parking lot with advanced EVSE testing, covering residential, urban, maritime, and controlled environments.

At the distribution level, variable network tariffs will be explored in real-world conditions (static and dynamic tariffs) and through simulations (real-time variable tariffs, individual peak power components, and grid peak power components) in Lisbon and Funchal. In Funchal's maritime-touristic port area, variable network tariffs will also be simulated, alongside tests to prevent overloading of the secondary substation (that also supplies power to commercial services in the surrounding area) and the integration of DERs such as solar PV and BESS. Conditional connection agreements will be tested mainly in the two parking lots, where connection capacity can be temporarily reduced to avoid peak loading at the secondary substation (Lisbon) or at the building installation (Funchal public parking lot). More advanced conditional agreements, reflecting the presence of RES and DER, will be simulated in the Lisbon semi-public parking lot and in Funchal's maritime-touristic area. Additionally, autonomous voltage control at LV level will be tested in Funchal's shared residential garage and public charging network.

At the charging site level, flexibility services will be tested both in practice and through simulations. Real-world testing will include static and dynamic variable charging rates at the Funchal public infrastructure, while real-time variable charging rates will be assessed via simulation. Direct control of chargers will also be demonstrated, in the Funchal shared residential garage and, in the Lisbon, semi-public parking lot, to prevent overloading of the installation and to coordinate EV allocation to chargers. In the Lisbon semi-public parking lot, simulations will further evaluate the impact of the three types of variable charging rates, combined with direct control strategies, on EV allocation, secondary substation loading, and RES self-consumption.

A summary of the flexibility triggers that will be tested in each of the four Western Europe Demonstrator locations is presented in Table 5.3.

Table 5.3 – Overview of the flexibility triggers that will be tested in the Western Europe Demonstrator, either in real-world settings or through simulation.

Trigger		Funchal			Lisbon
		Multi-Unit Garage	Maritime-Touristic Port	Public Charging	Semi-Public Parking Lot
Distribution Level					
Variable network tariffs	Static	X	X	X	X
	Dynamic	X	X	X	X
	Real-time	X	X	—	X
	Individual	X	X	—	—
	Peak Power	X	X	X	—
Conditional Connection Agreements	Static	—	X	X	X
	Dynamic	—	X	X	X
	Real-time	—	X	—	X
Autonomous LV voltage support		X	—	X	—
Autonomous MV voltage support		—	—	—	—
Charging Site Level					
Variable charging rates	Static	—	—	X	X
	Dynamic	—	—	X	X
	Real-time	—	—	X	X

6. CONCLUSION

Deliverable D3.1 has explored the development and deployment of flexibility services enabled by electric mobility, with a focus on the integration of EVs into distribution grids as active contributors to system stability, efficiency, and resilience. Through a structured methodology combining literature review, stakeholder analysis, and demonstrator validation, the task has identified a wide range of flexibility services across transmission, distribution, and charging site levels.

The findings showcase that EVs, when supported by smart charging infrastructure and interoperable communication protocols, can deliver both implicit and explicit flexibility services. These include frequency regulation, congestion management, voltage support, and resilience enhancement. The classification of services and triggers—ranging from market-based mechanisms to autonomous control—provides a foundation for future deployment and standardization.

Demonstrators across Europe will validate these concepts in practice. The Northern Region demo will showcase multi-level coordination using ACDC charging, AI-informed scheduling, and dynamic capacity contracts. Southern and Western sites will demonstrate real-time responsiveness to grid signals, renewable prioritization, and peer-to-peer energy trading. These pilots should confirm the technical feasibility and operational value of EVs as distributed energy resources (DERs).

Looking ahead, the integration of EV flexibility into grid operations will require continued collaboration between regulators, operators, and technology providers. Key areas for future work include harmonizing standards, enabling market access for distributed assets, and developing AI-based orchestration tools. The outcomes of Task 3.1 contribute directly to the AHEAD project’s overarching goal: enabling intelligent, responsive, and sustainable distribution networks through holistic EV integration.

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