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Electric Vehicles Management for carbon neutrality in Europe

Deliverable D4.2

Scheduling and Real-Time Operation Strategies to Control V2X Flexibilities

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Disclaimer

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

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[1] https://ev4eu.eu/

Executive Summary

With the increasing electrification of transport and heating and the associated uptake of both electric vehicles (EVs) and heat pumps, distribution system operators (DSOs) face significant operational challenges such as congestion and/or voltage violations. At the same time, the proliferation of distributed generation (primarily PV) at the distribution level creates new challenges (such as potential overvoltage) and opportunities. Due to this strong increase in both local consumption and generation, DSOs need measures to enhance their operational flexibility and align flexible consumption units with the intermittent, variable, and stochastic renewable generation.

Deliverable *D4.2 Scheduling and Real-Time Operation Strategies to Control V2X Flexibilities* first reviews various DSO flexibility mechanisms ranging from use-of-system tariffs to market-based approaches. The focus of this work is on examining the rationale and functioning behind *flexible capacity contracts* and *variable grid tariffs*, focusing on electric vehicles as flexible loads. Variable tariffs can be used to steer flexible consumption and achieve a more efficient network operation compared to their flat counterpart. However, they cannot guarantee that network constraint violations will not occur. For this reason, they are complemented by flexible capacity contracts, which limit the consumption of users (in return for financial compensation) and provide operational guarantees.

A detailed description of both mechanisms is provided, while illustrative examples showcase how they can be used by DSOs. Further, a formalised methodology in terms of designing variable grid tariffs in the presence of a local flexibility market using capacity contracts is developed. The synergies achieved by combining both mechanisms are showcased. In addition, the interaction between the DSO and charge point operators (CPOs) that aggregate the flexibility of individual EVs is detailed with a review of currently available communication infrastructure.

The insights of this deliverable will serve as a theoretical basis for the demonstration activities at the Greek site, and other activities within the project.

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Acronyms

BRP	Balance responsible party
CEER	Council of European Energy Regulators
CPO	Charge point operator
D	Deliverable
DER	Distributed energy resource
DSO	Distribution system operator
DUoS	Distribution Use-of-System
EV	Electric vehicle
EVSE	Electric vehicles supply equipment
FCC	Flexible capacity contract
ICT	Information and communication technologies
IDs	Identifiers
IEA	International Energy Agency
LV	Low voltage
MV	Medium voltage
NRAs	National Regulatory Authorities
OpenADR	Open Automated Demand Response
OSCP	Open Smart Charging Protocol
PV	Photovoltaics
RES	Renewable energy sources
TSO	Transmission system operator
V2G	Vehicle-to-grid
V2X	Vehicle-to-X (vehicle-to-everything)
VEN	Virtual end node
VTN	Virtual top node
WP	Work Package

1 Introduction

With the European-wide uptake of electric vehicles (EVs), distribution system operators (DSOs) face increasing challenges regarding managing the vast amounts of flexible loads in their systems and avoiding congestion. The aggregation of charging points in certain parts of a network in terms of parking lots, either at workplaces, public building, or shopping centres, enables the DSO to exert some operational flexibility in different parts of the network. This deliverable focuses on mechanisms that the DSO could use to increase operational flexibility and manage congestion with large shares of EVs and renewable production.

1.1 Scope and objectives

This deliverable presents the functioning of two strategies aimed at addressing congestion challenges within the distribution network with high shares of renewable production and the widespread deployment of EVs. Specifically, it explores the implementation of *flexible capacity contracts* and *variable grid tariffs.* The primary objective of this work is to detail the underlying goals of these two strategies, outline potential design options, and provide illustrative cases to demonstrate their impact.

Within this deliverable, the focus is on these two strategies, while a comprehensive examination of broader system integration issues or regulatory frameworks related to the DSO's operations are out of scope.

1.2 Structure of the deliverable

The present document is divided into 4 sections. After this introduction – Section 1, Section 2 provides a general definition of flexibility in distribution systems and describes the state-of-the-art of flexibility mechanisms for distribution system operators (DSOs). Section 3 examines two relevant strategies for DSOs to increase operational flexibility and manage congestion in highly renewable distribution systems. Section 4 gathers thoughts on the interaction between DSOs and charge point operators (CPOs) and gives recommendations for real-life implementation, while Section 5 concludes the deliverable.

1.3 Relationship with other deliverables

The work in this task is closely related deliverable *D4.1 Distribution network planning strategies considering V2X flexibilities* which is focused more on planning aspects in distribution networks [1]. This deliverable considers that planning has been completed and is thus concentrating solely on the exertion of strategies to control V2X flexibilities from the point of view of a DSO.

The present deliverable will serve as a theoretical basis for the demonstration activities at the Greek site, detailed in deliverable *D8.1 UC specifications and demonstrator deployment plan*, by providing two scheduling methods for procuring flexibility and handling network congestions. The architecture of a V2X management platform will be designed in D5.3 and developed in D5.5 Within WP8, this platform will be then tested at the Greek site, as detailed in *D8.3 Open V2X management platform test report*, for which this deliverable provides the theoretical backbone. Moreover, this deliverable will provide the foundation for the activities to be conducted within WP7.

2 Flexibility in distribution networks

Power systems are undergoing a transformation towards incorporating ever growing amounts of renewable energy resources (RES). The presence of renewables in transmission and distribution grids introduces a significant challenge due to their unpredictable nature. Moreover, the electrification of transport and heat sectors increase load volatility because of the increasing numbers of price-responsive distributed energy resources (DERs). These newly added resources increase consumption in distribution networks, often resulting in higher coincidence factors and pronounced peaks [2]. In this first part of this section, we will provide a short introduction to what flexibility is and why it is needed.

For DSOs, the effective management of the growing uncertainty and variability in power system planning and operation becomes of utmost importance for reducing peak load demand and avoiding congestion or even the restriction of power availability in a particular area [3]. The use of flexibility or flexibility mechanisms is emerging as a solution to provide much-needed adaptability in RES-dominated power systems. This can help mitigate the impact of integrating large amounts of DERs and avoid or delay investments in the grid. According to the International Energy Association (IEA) [4]

> *“Power system flexibility is the ability of a power system to reliably and cost-effectively manage the variability and uncertainty of demand and supply across all relevant timescales”.*

Flexibility can be defined as the modification of generation injection and/or consumption patterns, in reaction to an external signal (price signal or activation) to provide a service within the energy system [5]. The parameters used to characterize flexibility can include the amount of power modulation, the duration, the rate of change, the response time, and the location. The delivered service should be reliable and contribute to the security of the system [6].

A classification of flexibility is proposed in [7], along with some flexibility indices that can be used to classify the use of the different sources of flexibility. Concerning the use of EVs to provide flexibility services, the main barriers for the integration of EVs into distribution grids and a flexibility services framework is proposed in [8]. The authors provide an overview of EV control strategies, electric vehicles supply equipment (EVSE) infrastructure, and information and communication technologies (ICT) needed for the activation of EV flexibility.

2.1 Description of DSO flexibility mechanisms

The following subsection detail how flexibility can be obtained from the perspective of the DSO. According to the Council of European Energy Regulators (CEER), four main categories were devised regarding models for DSO flexibility procurement [6], namely:

- Rule-based approach,
- Connection/bilateral agreements,
- Distribution Use-of-System (DUoS) tariffs,
- Market-based approach.

The following sections provide a short overview of each category.

2.1.1 Rule-based approach

This approach is related to grid codes defining the technical requirements for grid connection of EVSE (or other types of flexible assets), thus maintaining the security and stability of the electricity grid. As an example, the autonomous management of reactive power in bidirectional EVSE (Vehicle-to-Everything - V2X) can be imposed by grid codes, in a similar fashion as the requirement for power-injecting DERs, and in particular PV units, in some countries [9]. This function is also supported by the new IEC 15118-20:2022 standard [10] that should be available in the near future for EVSEs. Additionally, the rule-based approach has the potential of shifting capital costs from the DSO to network users (which are typically given no direct compensation), while potentially minimising costs to the whole system.

2.1.2 Connection agreements

Under this mechanism, the DSO reaches an agreement with network customers for the provision of flexibility. Such agreements have been tested for congestion management using smart connections for RES in several countries, as stated in [11]. Under these agreements, system operators can temporarily reduce the power capacity of the installations. These bilateral agreements between the DSO and the asset owners are often called limited network connection agreements, because of the limited nature of grid access due to the ability of the DSO to restrict it. Users are typically offered monetary benefits, for example in the form of reduced grid connection fees, in exchange for this concession.

In the point of view of the owners of the installations (producers or consumers), the main advantage is the lower costs in the connection to the grid. For EVs, two approaches have been identified in [8], specifically, interruptible contracts and flexible capacity contracts (FCC). Under interruptible contracts, the EV charging can be curtailed according to system conditions, whereas in FCC, customers are subject to a variable maximum power they can withdraw from the grid according to a schedule set by the DSO. In turn, the customers are rewarded through lower DUoS tariffs. The Electric Nation Project implemented an aggregator-based FCC managing the charging of a 250+ EV fleet following a capacity limit curve set by the DSO [12]. Connection agreements are suitable to deal with grid congestion and investment deferral.

Considering that these types of contracts are defined and established during the planning phase, during the operation the DSOs need to have a strategy to the activation of these contracts. In some cases, these contracts can have an activation cost. However, in most of the cases, the activation is free for the DSOs [13]. Nevertheless, the contracts have some limits in their use meaning that if the DSO activates a contract today, the same contract cannot be activated in the following days. This means that in the operation, an opportunity cost function should be adopted in the contract’s activation process [14] and an effective strategy in utilizing this mechanism is needed.

2.1.3 Distribution Use-of-System tariffs

DUoS tariffs, sometimes simply referred to as *network or grid tariffs*, should cover the total costs associated with planning and operating distribution and transmission grids. They form a component of end-user retail prices, alongside energy costs, taxes, and levies. In Europe, network costs typically account for approximately 25% of the electricity bill [15]. These tariffs should accurately reflect the distribution system costs while providing incentives for the development of various demand-side response mechanisms [16]. To change the behaviour of costumers (producers or consumers) some changes in the DUoS tariff patterns can be introduced. Tariffs can be structured to vary based on time periods, such as peak and off-peak hours, or specific geographical areas, known as grid zones. This temporal and geographical differentiation allows for different tariff rates to be applied, accommodating the varying demand and supply conditions in different time frames and locations [8, 17]. Under variable DUoS tariffs, flexibility is provided not in an explicit but in an implicit manner.

2.1.4 Market-based approach

The main aim of the market-based approach is to establish short-term or long-term contracts avoiding or delaying grid investments. This mechanism resembles bilateral/connection agreements but fosters competition by procuring flexibility in market terms. Within a market-based framework, the DSO incentivises the facilitation of flexibility through temporary and usually binding tenders, according to nationally imposed guidelines or requirements. In this context, the DSO may procure flexibility via participation in an organised marketplace, operated by an independent market operator, where network users offer their flexibility and DSOs places bids to acquire it.

DSOs determine in advance the flexibility requirements to defer/avoid costly grid reinforcements, improve grid operation and secure flexibility through contracts. This type of contracts is signed between DSOs and flexibility providers, following a tender process. Such contracts have already been adopted in some countries such as UK following the "*flexibility first*" policy [18], France to avoid congestion constraints in the grids [19] or Portugal under the project “Flexibilidade Integrada em Regime de Mercado[2]" following Article 32 of the Clean Energy Package [20]. Non-wire alternatives programs are also being proposed tested in several regions such as New York [21] and Minnesota [22] in US or York region in Canada [23]. Piclo is the most mature independent marketplace for flexibility services at a distribution level in Europe.[3]

Short-term flexibility contracts have been proposed in the form of flexibility market platforms and local energy markets. Short-term local flexibility trading implementations in Germany and Netherlands allowed DSOs and TSOs to procure flexibility to manage RES-driven congestion. Moreover, demonstrator projects such as the INVADE[4] and Interflex[5] both developed day-ahead and intraday local flexibility markets, allowing the provision of flexibility services to DSO, such as congestion management and voltage regulation. The project OneNET[6] aims at creating a fully replicable and scalable system architecture that enables the whole European electrical system to be operated jointly. A variety of markets are covered allowing for the universal participation of stakeholders regardless of their physical location.

The issue of product definition and procurement is brought up by a market-based strategy. Specifically, the power, duration, and placement requirements should be specified for the flexibility products. Along with consumption baselines for flexibility settlement that need to be approved by all parties, a

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[2] English: “Integrated Flexibility in a Market Regime”. For more information, refer to https://www.e-redes.pt/en/firme

[3] For more information, refer to https://www.piclo.energy/

[4] For more information, refer to https://h2020invade.eu/

[5] For more information, refer to https://interflex.com/en/

[6] For more information, refer to https://onenet-project.eu/the-project/

settlement period according to the characteristics of the services and flexibility sources (preferably close to real-time to account for uncertainty) also needs to be determined [24].

The development of local flexibility markets is still limited around Europe. Most local flexibility markets are still pilots and trials, with very few commercial offers. Great Britain, the Netherlands and France are the only countries to have commercial markets [25].

All six DSOs in Great Britain have procured flexibility through market tenders. Additionally, several trials are also being conducted to identify additional services for DSO flexibility markets (including Reactive Power services). While contracted volumes of flexibility being procured by Great Britain DSOs are increasing annually, activations remain low. This is limiting the value of these flexibility markets to the flexibility service providers. Figure 1 presents the European-wide development level of market-based distribution system flexibility.

In April 2018 Great Britain's vehicle-to-grid (V2G) program began in a collaboration between OVO Energy, Kaluza, Nissan Motor Company, and others. 330 electric vehicle owners use a mobile app to register when they would like their car ready to drive, so the platform is informed about the car's availability schedule. They can see in real-time if their car is importing or exporting energy and how much it is earning them [26].

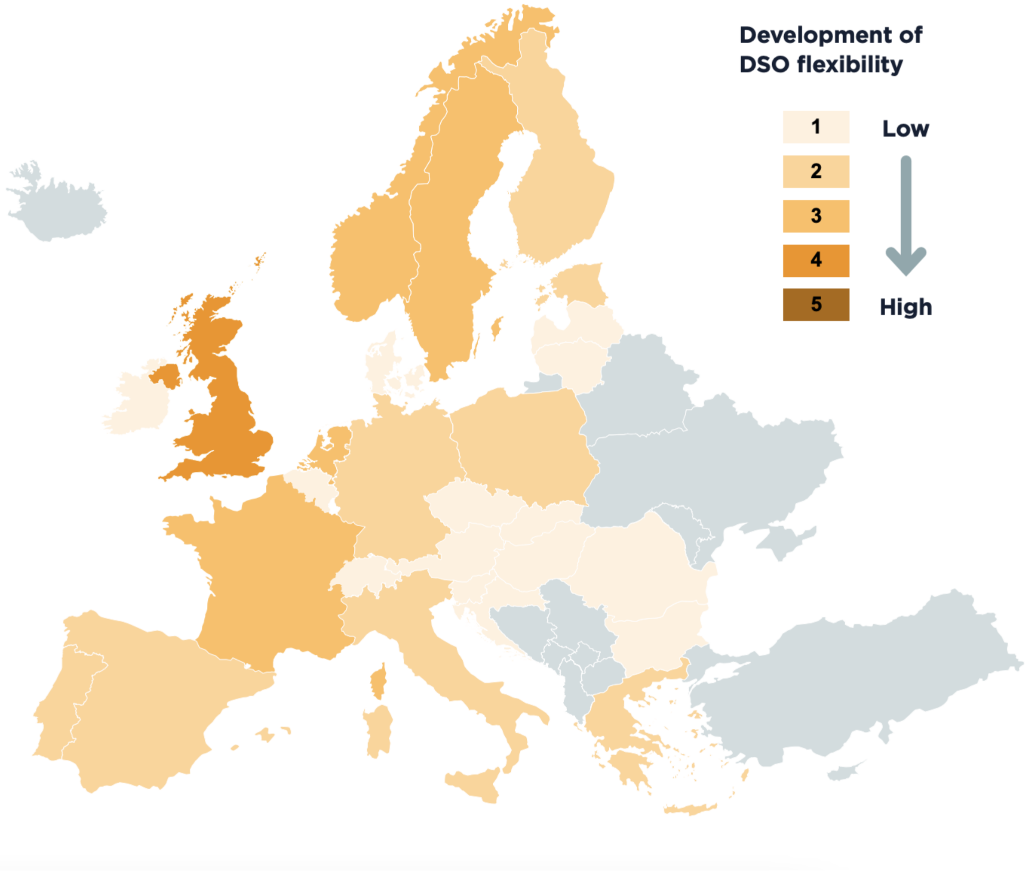

Figure 1: Development of distribution system flexibility by European countries [22].

During this pilot project some limitations were identified. First, as participants reported, they experienced delays in the V2G hardware gaining the necessary CHAdeMO certification. There were challenges around costs and processes associated with connecting V2G chargers to various distribution networks.

The second one is market access and value. Exploring monetization opportunities to scale domestic V2G also provided insight into the challenges that exist and the investment case outlook in the medium-term for technology like V2G. Ancillary market access for domestic flexibility is currently limited due to high entry thresholds, unscalable on-boarding and operational processes at a national level, and early-stage development at local networks level.

2.2 Proposed solutions for DSO flexibility utilization

The solution that has been conceived during the preparation phase of the project and was investigated during the execution of Task 4.2 is based on two of the available mechanisms for congestion management in distribution networks.

These mechanisms have several advantages over the rest and are better suited for provision via EVs. Rule-based mechanisms are not considered because they may incur high costs and discomfort for EVSEs and users. Furthermore, while bilateral/connection agreements may be useful tools for larger assets (such as very fast chargers (350 kW) or large industrial boilers), they are not so appropriate for large numbers of smaller assets because they do not promote competition and are complicated for DSOs to use and manage.

Consequently, the proposed solution is designed along two lines. First, *DUoS tariffs* with higher temporal and spatial resolution are envisaged. Such tariffs allow for a more effective use of flexibility, especially under the presence of both local PV generation and flexible demand [27]. The spatial differentiation of DUoS tariffs may incentivize the rerouting of EV users and shift of demand across space. This can allow the better utilization of local PV generation, a concept referred here as *Green Charging*. Green charging can reduce network losses and potential PV curtailment, by better matching EV charging needs and local renewable production. The basic principles behind this concept are presented in Section 3.3, along with an illustrative example.

The second pillar of the proposed solution is based on the use of *Flexible Capacity Contracts (FCCs)*. Local flexibility markets are advocated by EU legislators as a means of effectively using flexibility in distribution networks while fostering competition. While DUoS tariffs can provide incentives to shift demand across space and time, they do not provide guarantees in avoiding congestion. For this reason, redesigned DUoS tariffs need to be complemented by firmer measures that provide security to DSOs, so that grid reinforcements can be reliably postponed. DSO flexibility services take two forms: one is *relative* services, where a load reduction upon a defined baseline is requested, and the other is *absolute* services, where a temporary limitation upon consumption is imposed. Baselines are associated with numerous problems in terms of definition, transparency, uncertainty, gaming, and potential manipulation [28]. For this reason, in this task and the demonstrations of WP8, capacity limitation DSO services are considered, referred to as FCCs. The basic principles behind this concept are presented in Section 3.2, along with an illustrative example.

Finally, the synergies between flexible capacity contracts and variable DUoS tariffs are investigated, and a formal methodology in deriving them is proposed in [29]. Further, some practical issues related to the use, calculation and application of variable tariffs are also studied and tested. The proposed methodology in [29] expands on [27]. A bi-level optimisation model is proposed which captures the interactions between a distribution system operator designing variable DUoS tariffs and operating a local flexibility market based on FCCs, and aggregators of EVs with smart charging capability reacting to the designed tariffs and procured FCCs. The proposed methodology is presented in detail in Section 3.3.1.

The model is tested on a real 47-node distribution network which is part of the Greek demo site. The area has significant presence of PVs that can lead to overvoltage issues. Typical demand-based congestion is also present. The case studies illustrate cases where the two mechanisms synergistically resolve congestion phenomena and demonstrate that their combination results in a significant reduction of total system costs. For example, in cases where lower energy prices create sudden peaks in EV charging demand, procuring an FCC is preferred as the optimal solution. In more complex cases, where excess PV generation can be absorbed by EVs that shift their charging schedule, DUoS tariffs are more effective in motivating effective load shifting and reducing PV curtailment. As with previous works on variable DUoS tariffs, the higher their granularity, the more effective the tariff pattern is. For example, introducing nodal granularity can increase cost effectiveness by an extra 16% compared to a pattern with solely temporal granularity.

3 Flexibility activation strategies for the DSO

This section provides an overview of the strategies explored in this deliverable. After presenting the basis of the considered setup in Section 3.1, *flexible capacity contracts* and *variable grid tariffs* are detailed in Section 3.2 and Section 3.3, respectively. Each of these parts comprise a general description of the strategies, followed by an illustrative example of their functioning.

3.1 Considered setup

To provide flexibility, stakeholders can build a contractual bond. Flexible capacity contracts are one type of agreement between energy market participants, enabling the procurement and use of flexible resources to manage grid imbalances and ensure the reliability and stability of the electricity system by imposing capacity limits on individual CPOs. To ensure the efficient and reliable operation of the grid they can be procured either by Transmission System Operators (TSOs) or DSOs. Deliverable *D4.1 Distribution Network Planning Strategies considering V2X Flexibilities* [1] describes among other things procurement coordination mechanisms and key procurement parameters in detail.

The main stakeholders involved in flexibility markets are [30]:

- **TSO:** responsible for the operation of the transmission system and its stability, in particular frequency containment.
- **DSO:** responsible for the operation of the distribution system and power delivery to customers.
- **Balance Responsible Party (BRP):** market entity (wholesale supplier or retailer, etc.) or its chosen representative responsible for its imbalances. BRPs must pay penalties for their deviation from previously determined energy schedules.
- **Aggregator:** an entity that acts as intermediary between smaller entities (such as consumers) and the market, by pooling distributed resources through ICTs.
- **Retailer:** existing commercial entity buying electrical energy from their associated BRP or directly from the market for its customers.
- **Flexible assets:** Operator of flexible assets, e.g., battery storage, that may react to signals/requests from the DSO.
- **EV users:** EV owners that may adjust their charging operations/habits to act beneficial for the system, subject to their charging needs. Often pooled through an *Aggregator*.

A CPO, which can also have the role of an aggregator, could have an important role in local and flexibility markets due to the flexible capacity of EV batteries. Once aggregated, these can respond to DSO's flexibility requirements in areas where maybe another type of resources cannot. DSOs require flexibility to deal with congestion and avoid voltage increases in the grid. Through generation and demand adjustments, provision of reactive power, peak shifting, and manual or automatic curtailment is provided.

The DSO after analysing their grid needs will send a flexibility requirement to the local flexibility market operator. This requirement will contain information on what areas can be activated for the negotiation. This zonal limitation is necessary because only the assets located in that certain area can help the DSO to solve the congestion on the grid. In contrast to global electricity markets, in local markets, the exact location of the energy resources in the distribution grid is a very important factor.

For the following analysis, consider the stylized representation of a distribution grid as provided in Figure 2. The DSO has the responsibility to manage the network and provide a high quality of supply to customers. The CPO, as a DSO customer in specific parts of the network, has as its main goal the satisfaction of EV users in terms of charging experience, ranging from delivery of energy to cost of service.

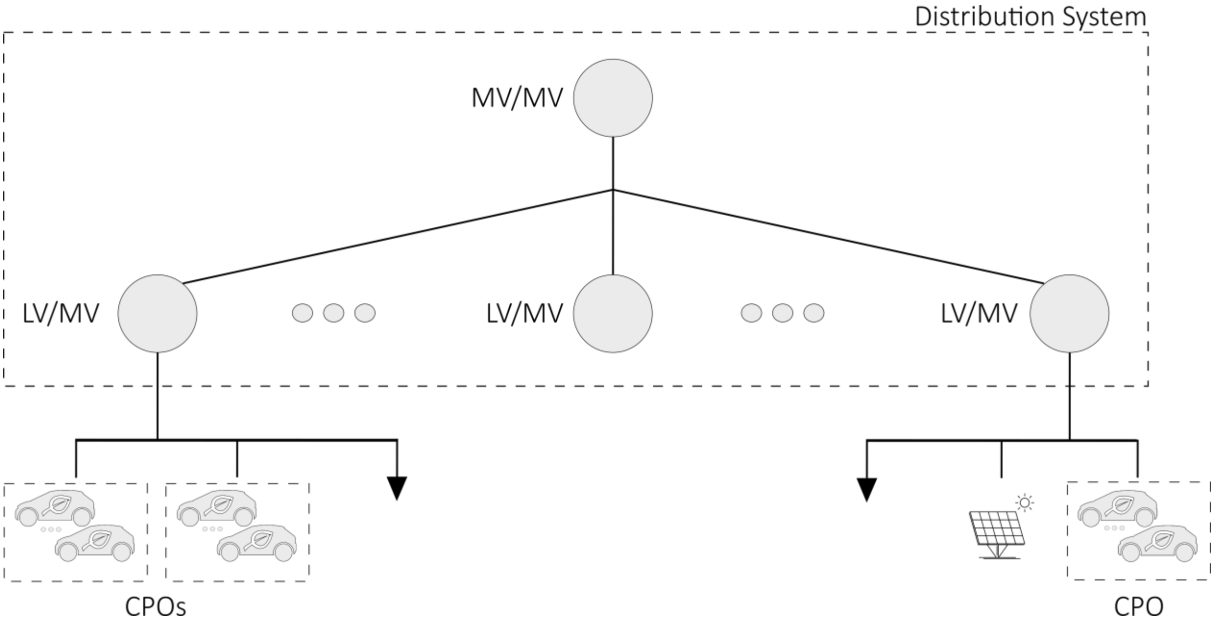

Figure 2: Responsibility Areas of the Distribution System and Charging Point Operators. MV, Medium voltage; LV, low voltage

If the DSO is forecasting congestion in one branch of the network on day ahead based on PV/load forecasts, different strategies could be exerted to shift consumption without being forced to curtail either load or generation. This deliverable illustrates the principles of both *flexible capacity contracts* and *variable grid tariffs* to achieve this in terms of operational aspects. Planning of such services is out of scope and extensively covered in deliverable D4.1 [1]. For different branches of the network, the DSO might have several CPOs which have their individual capabilities to react to certain flexibility requests associated with distinct costs.

3.2 Flexible capacity contracts

To avoid/manage congestion in parts of their network, DSOs can request (flexible) capacity limit services from specific areas or downstream any point in the distribution network they see fit. Such an example could be an individual branch with high levels of EV charging, e.g., due to numerous charging points. Another example could be flexible units connected to a specific secondary substation. These limits could be composed of contractual agreements between the DSO and CPOs, allowing for dynamic adjustments of flexible load. While being designed to enhance the operational flexibility of DSOs, they could also enable the cost-efficient steering of supply and (flexible) demand. The following sections provide an in-depth description of the idea of these contracts (Section 3.2.1), review potential design options (Section 3.2.2), detail the design considered in this deliverable (Section 3.2.3) and provide an illustrative example of their functioning (Section 3.2.4).

3.2.1 Description

Capacity limitation services can take two main forms: scheduled or activated. The former always impose a consumption limit to the providers during the service period. The latter are activated by the DSO on a reservation/activation basis similar to the regulating/balancing markets. Providers receive a reservation fee to be able to reduce consumption upon DSO notice, and an activation fee when the service is activated. Formally, a scheduled capacity limitation service that is requested by a DSO in a local flexibility market context is defined by four parameters [31]:

1. **List of service days:** containing a set of days when the capacity limitation is active.
2. **Start time:** defining the start time of the capacity limitation for each service day.
3. **End time:** defining the end time of the capacity limitation for each service day.
4. **List of flexible unit IDs:** defining the flexible units in the distribution grid that can deliver the service in question.

Every flexible DER, or EV charging point, is identified through a unique unit identifier that is associated with a specific network node. The DSO has knowledge of the grid topology and by specifying a list of unique IDs, the requested service can target specific parts of their network. Based on these parameters, flexibility providers can place their offers. Contracts that specify the amount of capacity limitation (e.g., a limitation to 500 kW of consumption) and the payment are issued according to the market-clearing outcome.

Capacity limitations can also be imposed by DSOs to consumers through subscription options, instead of procuring them in a local flexibility market. Customers may subscribe to *static* limits, meaning that they subscribe to a certain capacity limit and are financially penalised when they exceed their subscribed option, or *dynamic*, meaning that the capacity limitation is only activated by the DSO, triggered by eminent grid constraint violations [32].

Flexible capacity contracts have several advantages compared to other congestion management mechanisms. One is that they provide operational guarantees to DSOs, in contrast to variable grid tariffs. Those can only provide incentives for flexible customers to shift their consumption from (or injection to) the grid but cannot guarantee that enough load will be shifted to avoid congestion. The second advantage is that they provide a competitive framework for flexibility providers to offer their flexibility to DSOs, increasing efficiency, in contrast to capacity subscriptions. As a result, capacity limitation services have the potential to vary the consumption of EV charging stations in response to grid conditions, achieving a dynamic load management while providing financial incentives to CPOs in return. By design, these contracts can facilitate the integration and exploitation of energy storage solutions into the system, as key technologies to shift demand and helping integrate variable renewable energy sources.

To work efficiently, the implementation of flexible capacity contracts requires a reliable communication network and a central management system for coordination and control between the entities. CPOs must be able to control charging rates, shift demand or prioritize specific users/vehicles as needed to adhere to capacity limitations. For this, there must be an automated information flow between the CPO and DSO sharing real-time usage data of the charging stations and grid conditions. More details on the interaction between DSOs and CPOs are discussed in Section 4.2.

3.2.2 Design options

Designing flexible capacity contracts involves careful consideration of several factors. This includes the following main points:

- **Whether the services are scheduled or activated:** A scheduled service is also active, while an activated service imposes a capacity limit only when the DSO requests it. The second option provides more flexibility in the operation of the distribution network, but also complicates the offering strategies of the providers and the market clearing process.
- **Service days period:** The exact days in which the service is offered. This could be a whole month, or a week, or only the working days of a month etc.
- **Service period:** This is defined by the start and end time. For example, a service can be active for the whole day, or cover a smaller time period such as the evening peak (5pm to 9pm).
- **Activation mode:** In the case of activated services, the service can be partially or fully activated. For example, if a CPO has offered a capacity limit of 300 kW (i.e., a reduction of the installed capacity by 300 kW), a full activation would limit consumption to 200 kW, while a partial activation would limit consumption anywhere from 500 kW to 200 kW.
- **Activation compensation:** In the case of activated services, an activation limit or fee must be in place, otherwise a DSO would have an incentive to activate the service every day. One possibility is that the DSO has an activation budget so that the service can only be activated x times within the service days period. For example, maximum 3 times in a given month. Another possibility is that CPOs submit an activation price or activation price curve, which determines the fee per activated kW of limitation. Finally, the activation price can be determined by the DSO, and not be the result of the market clearing process.
- **Violation arrangements:** Penalties towards the CPO for violation of the requested limitation.
- **Market clearing options:** Different market clearing options exist. The combination of reservation price and activation price offers by the providers complicates market clearing because the DSO needs to take both aspects into account when choosing the amount of limitation to reserve from each provider.
- **Service procurement lead time:** This indicates when auctioning takes place. For example, the service may cover February and the auction may take place one or several months in advance.
- **Service activation lead time:** This indicates when the decision to activate (and by how much) the service is made and communicated to the providers. For example, the decision could be made latest at 6 pm for activation in the following day.

To ensure that the procurement of such DSO services is beneficial to all involved parties (DSO, CPOs and end users), the proper incentives and conditions must be established. First, DSOs must see a value in using such services instead of reinforcing their network. If the provision of services is very costly, then reinforcement would be preferable. Second, CPOs must be appropriately remunerated so that they are incentivized to offer the services. Offering the services will increase their costs because they may be forced to move part of their consumption to more expensive hours, or they may offer less energy to their customers and reduce their revenue. Finally, EV users may be affected by prolonging the charging process or by charging less than the requested amount by the set departure time. CPOs need to ensure appropriate quality of service and that either user discomfort is rather low and/or users are financially compensated.

3.2.3 Considered design in this task

The setup regarding the procurement and provision of capacity limitation services considered in this task is defined next. The DSO procures monthly services for the areas of interest. If required, the service is "activated" one day ahead and covers a specific time of the day, e.g., 9 am to 6 pm. The DSO decides the day before the amount of limitation that is asked by each provider. For example, assume that provider 1 has an installed capacity of 500 kW and the DSO reserved 200 kW of the service. The same values for provider 2 are 200 kW and 100 kW, respectively. The DSO may decide to ask for a limitation of 100 kW from provider 1 and 50 kW from provider 2, at their respective costs. This way, the DSO can guarantee that their combined load will not exceed 400 kW + 150 kW = 550 kW.

At the auctioning phase, each provider submits a reservation price curve, which shows the requested price for the amount of capacity limitation, and an activation price curve, which shows the activation price for each kW of activated service per day. Figure 3 visualises considered the transactions and interactions between DSOs and CPOs.

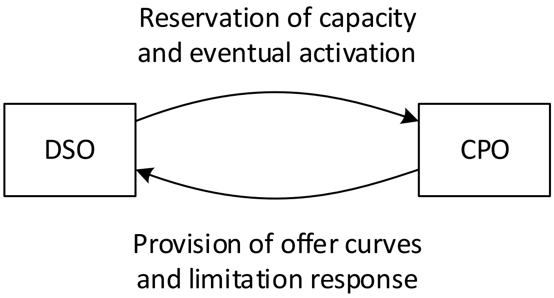

Figure 3: Transactions between DSOs and CPOs with respect to flexible capacity contracts.

3.2.4 Illustrative example

The basis for this illustrative example is Figure 2, which details a stylised MV/LV distribution network with several secondary substations that connect both renewable generation (e.g., PV systems) and charging stations managed by aggregators/CPOs. First, the DSO performs an exploratory analysis (which requires load forecasts) to assess whether any flexibility services are needed for an upcoming period. If that is the case, CPOs are called to submit their offers. The reservation cost is a constant cost per kW reserved by the DSO, while the activation cost is increasing progressively with the amount of limitation set, see Figure 4. The set of [c_1^{res}; c_2^{res}; c_3^{res}] defines the reservation costs for a certain requested reserved power level, while the set of [P_1^{res}; P_2^{res}; P_3^{res}] marks the reservation quantities for each of the three CPOs in this example. These quantities are lower or significantly lower than the installed capacity of the charging stations. The reservation auction is based on the contract design and could be adjusted on a monthly/quarterly/yearly basis.

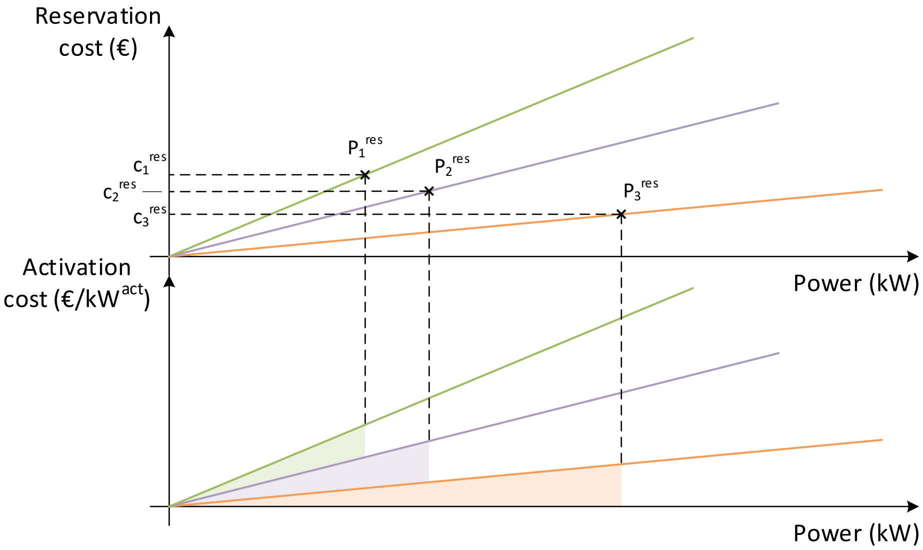

Figure 4: Stylised offer curves for reservation (res) and activation (act) from different flexible end-users (e.g., CPOs).

Then, when it comes to the activation of these reserved quantities, the DSO can – based on the offer curves for the activation costs from the CPOs – decide the amount of limitation to impose for each CPO. The activated capacity is a non-negative amount and always lower or equal to the reserved quantity ($P_1^{act} \leq P_1^{res}$), as the DSO cannot activate more than what was reserved beforehand, but also not all the reserved quantity must be activated. P_1^{cap} denotes the installed power capacity of CPO 1.

If a congestion is forecasted in one part of the network during the period when the capacity limitation services are reserved, the DSO could activate the reserved quantity needed for eliminating the congestion. This can be done by reducing, e.g., the consumption of charging stations to the set capacity. The DSO then needs to pay the activation cost (on top of the one-off reservation cost to the CPOs) according to the CPO activation offer curves. To decide which CPOs to activate, the DSO could make a min-cost calculation considering the impact of the reduction of the specific charging points on the congested branch. Figure 5 visualises the functioning of a capacity limitation service activation based on a forecasted load, and the respective individual response of three CPOs following an activation from the DSO.

To make this example more illustrative, as can be seen in the top plot of Figure 5, the forecasted load comes close or surpasses the total capacity limit of the branch. Accordingly, the DSO would like to act upon this forecast and aims to avoid interrupted operation of the network by activating a reserved capacity limit of available CPOs (reservation phase is already concluded). In advance of the real-time operation (it is a design option of the services when exactly), the DSO imposes individual limits on the consumption of the CPOs in that period (i.e., the set of [P_1^{act}; P_2^{act}; P_3^{act}]). For instance, if a CPO has 10 chargers at a specific charging station with a charging power of 50 kW each (maximum equal to 500 kW), the activation could be, e.g., 200 kW, translating into only 6 out of 10 chargers functioning at full power, or each of the chargers is limiting their power to 30 kW (total 300 kW of maximum load).

As the CPO faces a restriction, they get paid for the activated quantity: the more the DSO restricts the operation of the charging station the more the CPO is compensated. As this might affect the charging experience of the EV users expecting to charge with 50 kW, the CPO could in turn could lower the prices to transfer the extra compensation they obtain to the EV users. This could become a necessity in the contract to not be left with the pure belief of good will of the CPOs. Even with lower prices which might attract new EV users, the capacity limit will not be breached due to a technical restriction (as opposed to working with variable tariffs for incentivizing or disincentivizing EV charging).

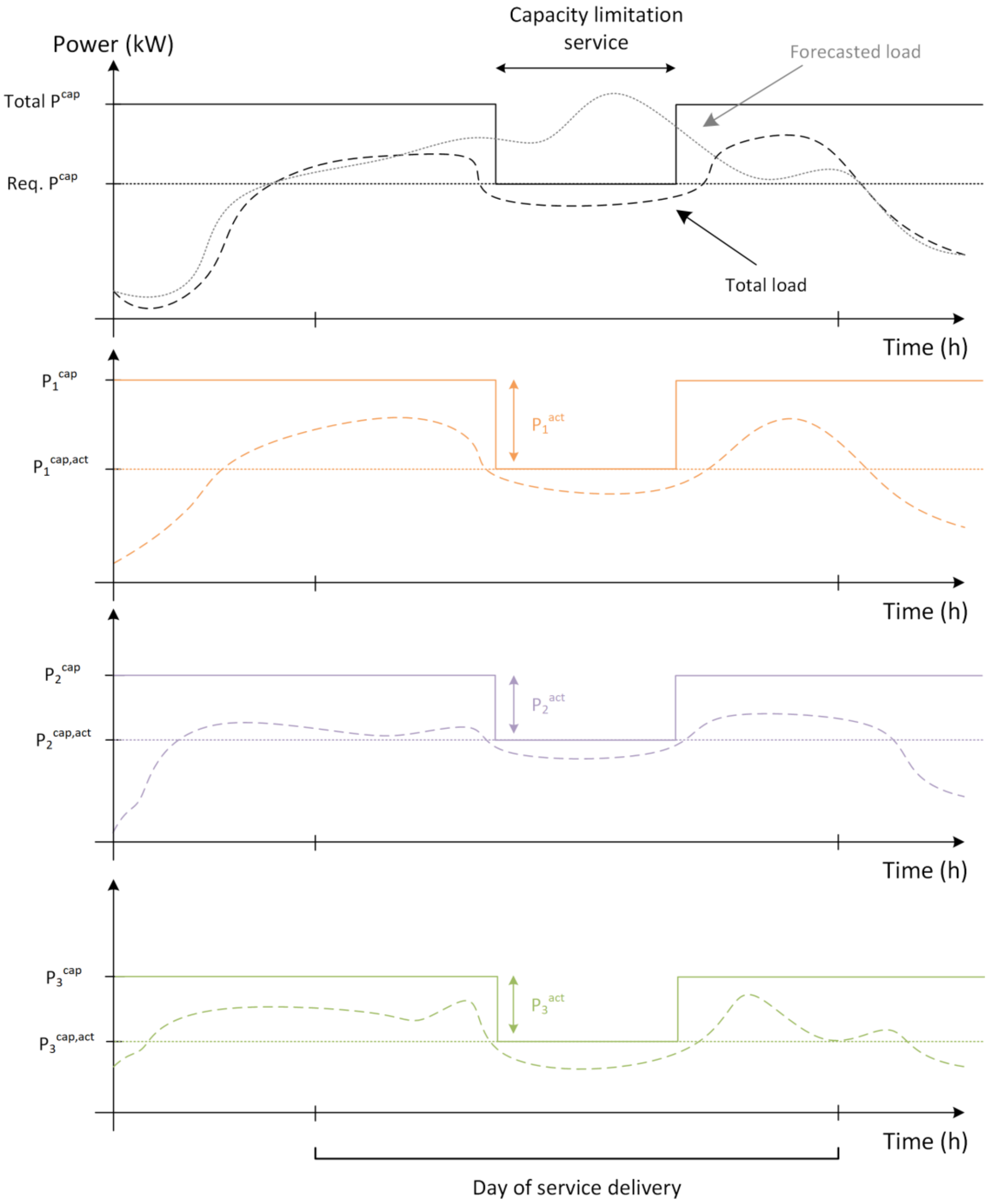

Figure 5: Top plot – forecasted and total load on a specific branch with included capacity limitation service to a requested power cap; remaining plots – the load response from three different CPOs that have their individual restrictions based on their activated capacity limitation.

3.3 Variable Distribution Use-of-System tariffs

DUoS tariffs are a component of the final retail price of electricity, which corresponds to the use of the distribution system by the customer. It is the main source of income with which DSOs recover operational, maintenance and upgrade investment costs. DUoS tariffs are usually set by National Regulatory Authorities (NRAs) in cooperation with DSOs. The total DUoS tariff revenue should be sufficient to cover said DSO costs augmented by a regulated profit margin. Traditionally DUoS tariffs have been flat, with one component being volumetric and one other based on capacity. Capacity-based tariffs can be calculated on installed capacity (effectively becoming a fixed charge) or on peak consumption over a predefined period. In the example of Greece, monthly peaks are used for the calculation but solely on MV industrial customers [33]. In some cases, DSOs have introduced time-of-use style DUoS tariffs to achieve simple demand shifting goals. These tariffs are designed for large intervals of time and apply to all customers, regardless of their location and individual network conditions [34].

So far, few works have studied the effectiveness of tariffs that are designed with consideration: a) of the specific conditions under a MV feeder, and b) the response of DERs, while retaining traditional DUoS tariff attributes such as simplicity, intelligibility, and cost recovery [35]. It is important to highlight that DUoS tariffs are not energy tariffs or locational marginal prices; therefore, they should have as limited variability as possible. The following sections provide an in-depth description of the idea behind DUoS tariffs (Section 3.3.1), review potential design options (Section 3.3.2), and provide an illustrative example of their functioning (Section 3.3.3).

3.3.1 Description

In recent years, DUoS tariffs have been involved in the discussion on DER flexibility as a potential tool for its incentivisation [36]. While past works have attempted to tackle the DUoS tariff design problem [37] [17] [38], considering DER response, [27] has presented a method where the DSO can decide both their temporal and spatial granularity, ranging from none to full hourly and nodal. In addition, the method presented in [27] allows the DSO to objectively quantify the effectiveness of each granularity level before deciding. The goal of the variable DUoS tariff design method is to produce tariff patterns that are effective in yielding flexibility potential, taking into consideration conditions in individual MV feeders, while recovering DSO operational, maintenance and investment costs.

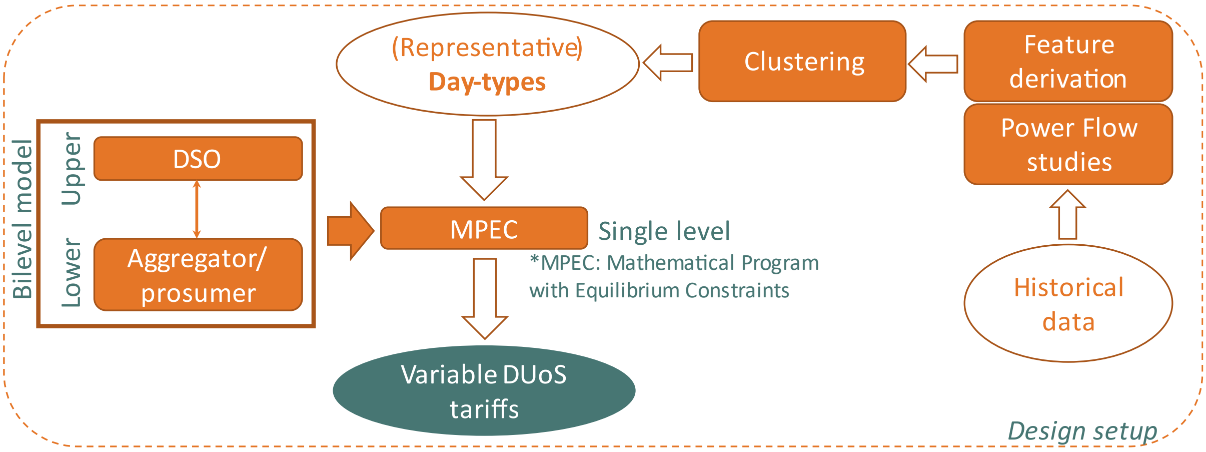

Figure 6: DUoS Tariff design methodology.

Figure 6 illustrates the proposed methodology for the design of DUoS tariffs. First, an analysis is performed on historical data. The input dataset includes hourly active and reactive power injections on each node of the distribution network, as well as the voltage level at the substation. Patterns are identified and the dataset is augmented with new features, such as voltage and line limit violations. Then, the derivative dataset is used as input for unsupervised learning where the days are clustered into day-types represented by their cluster centre. The number of clusters *k* is a hyperparameter decided by the designer. Representative day-types are now used as proxy for an entire year of operation and tariff patterns are designed for each day-type.

A bilevel optimisation model is employed for the design; see also Figure 7 for an illustration of the model when tariffs co-exist with flexibility products such as capacity limitations, similar to what has been discussed in the previous section. In the upper level, a DSO is minimising total system costs, consisting of flexibility procurement, remedy action and aggregator charging energy costs, while being constrained by the need for cost recovery via revenue (*revenue adequacy*), conditions for tariff simplicity, and distribution network physical limits. In the lower level, an aggregator (or prosumer) minimises energy, use-of-system and other DER related costs constrained by DER properties and limitations. The main output of the DUoS tariff design methodology is *k* daily tariff patterns, one for each day-type.

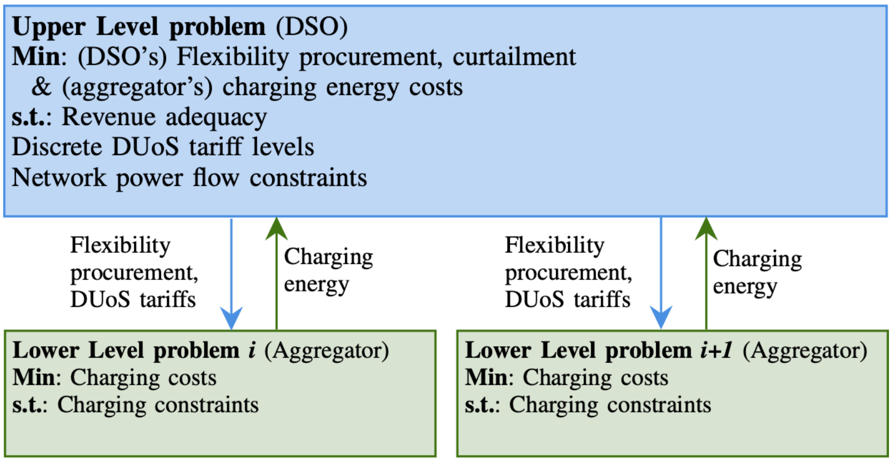

Figure 7: Structure of the proposed bilevel optimization mode when DUoS tariffs co-exist with capacity limitations in local markets.

The timeline of the proposed methodology for DUoS tariff design is presented in Figure 8. The methodology is implemented on fixed medium-term intervals (i.e., yearly). The DSO performs analyses on historical data and creates the day-types which are shared to all stakeholders. With consideration of the day-types, aggregators create their flexibility bid curves (see Section 3.2) and send them to the DSO. The DSO employs the model of Figure 7 and produces the tariff patterns along with procuring capacity limitations. In daily operation, the DSO forecasts, and shares which day-type applies to the next day and aggregators schedule their DERs accordingly.

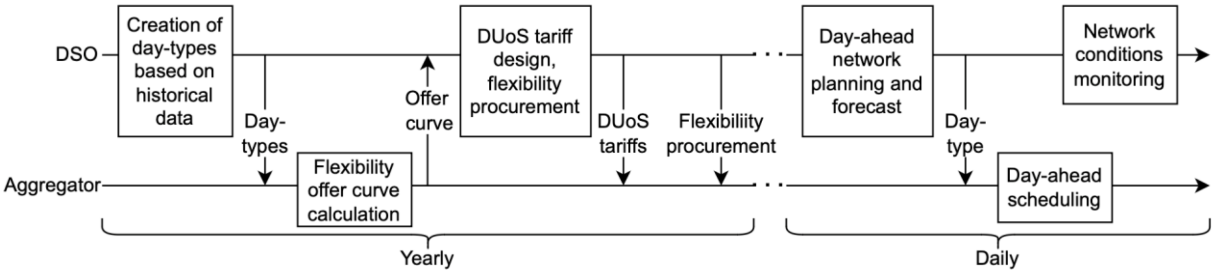

Figure 8: Timeline of the proposed methodology [39].

3.3.2 Design options

The DUoS tariff design model presented above has several design options that can be selected by the end-users (most likely a DSO in cooperation with the NRA). Some options are closely linked to the level of tariff **effectiveness** and other to regulatory constraints the DSOs must abide to. From our past research, there is an engineering trade-off between **tariff complexity** and **effectiveness**, albeit with diminishing returns as complexity increases. If tariffs are fully granular and each day belongs to a separate cluster, effectiveness reaches the theoretical optimal, which in this case is centralized control of DERs by the DSO. Below we present the most important design options:

- **Type**: DUoS tariff type refers to whether it is volumetric, installed-power/peak-power, or fixed. Volumetric is expressed in euro/MWh, installed-power and peak-power in euro/MW, and fixed in euro. In recent research, the focus has been on volumetric tariffs due to their capacity for targeted demand shifting compared to peak-power tariffs.
- **Temporal granularity**: Tariffs can be flat, very per day-type, time period (an hour in our case studies) or any restriction among these options. Less variation results in simpler tariffs, whereas flat volumetric tariffs are, by definition, incapable of motivating flexibility.
- **Spatial granularity**: Tariffs can be uniform across all nodes or vary per node. This option has a meaningful impact on effectiveness but, also, adds complexity. Moreover, a different tariff per node raises questions on tariff fairness (distribution of costs incurred among customers) and adds regulatory complexity. However, uniform tariffs should raise similar questions, considering that not all customers have the same impact in distribution network cost induction. The question of fairness will be addressed in future research.
- **Tariff levels**: Tariffs can take a limited range of values; usually a range of discrete, equidistant levels. The range and step of the levels is a hyperparameter of the method. Deciding the levels perquisites studying aggregator (and prosumer) cost characteristics. If the range is too short, or the step too large, it can be the case that tariffs have no impact on demand. The trade-off is again complexity. It is worth noting that the range can be set to include negative and zero tariffs if the regulatory ecosystem allows it.
- **Day-types:** We already discussed how the user can define the number of day-types, hence, tariff patterns, that the method is employing sacrificing simplicity for effectiveness.
- **Period of application:** Tariff patterns can be designed for a predefined time horizon. We suggest a yearly horizon and use it in our case studies.
- **DER types:** The proposed method can include all types of flexible DERs in its modelling step. Our research has modelled generic load shifting capabilities and EV public charging points.
- **Cost to be recovered:** As we explained, DUoS tariffs must recover DSO costs. Which costs are considered and in what detail is a trade-off with computational complexity. Common cost types are remedy (curtailment) actions and grid investment. Moreover, costs can be **sunk**, i.e., cost that were or will be incurred regardless of model decisions and prospective, i.e., affected

by model decisions. The latter is the target for cost reduction via optimisation, but it adds mathematical complexity to the final model.

3.3.3 Illustrative example

Consider one more time that a DSO has a network similar to Figure 2, containing different charging stations and renewable generation. Suppose that the DSO has analysed historical data of the network and based on that created several day types. For simplicity in this illustrative example, we consider two distinct day types: one with significant and one with insignificant PV production in the network. To incentivize renewable-based EV charging, the DSO would like to adjust its DUoS tariffs during the day according to the renewable generation or the general system stress (peak load). Figure 9 exemplifies the according tariff structures for these two days. In the top plot, the tariffs are lowered during the day to provide an incentive to customers to use the grid, while disincentivising the use during peak hours (17:00 – 21:00). In the bottom plot, there is insignificant amount of PV generation during the day.

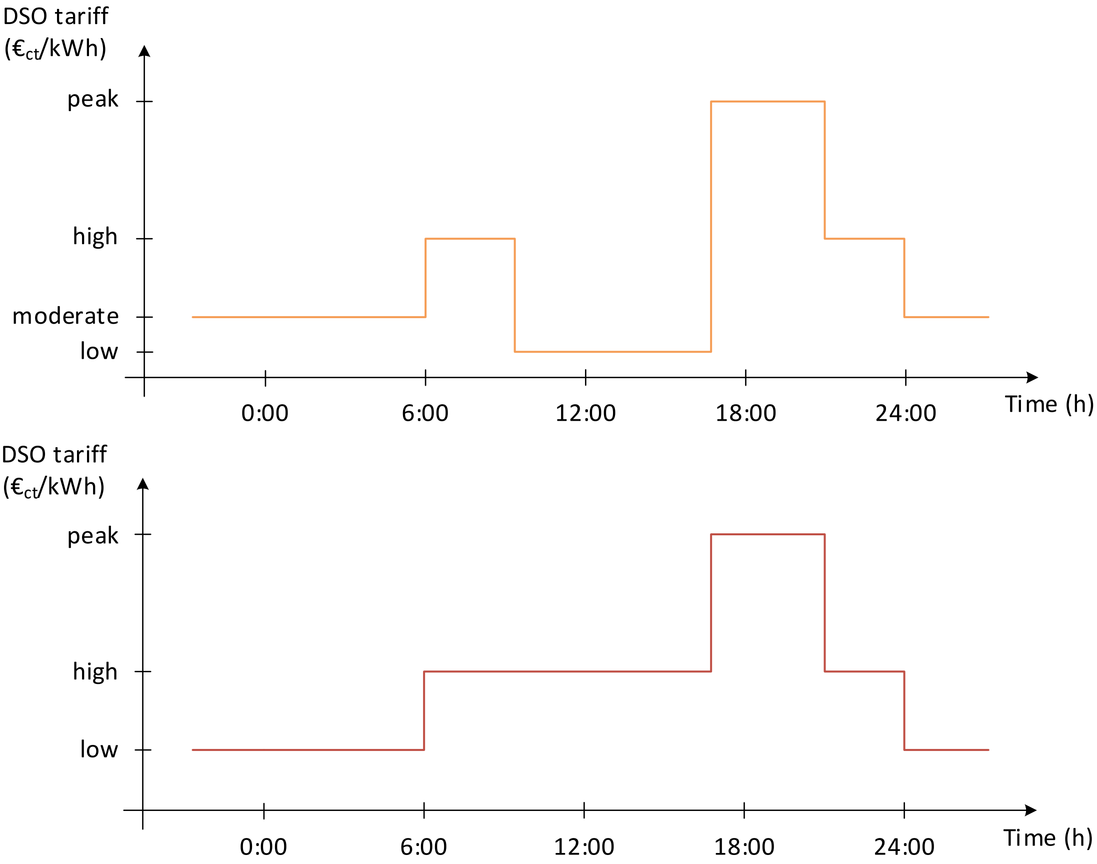

Figure 9: Two distinct tariff structures for days with (top plot) and without (bottom plot) PV generation.

These DUoS tariff structures could then be published by the DSO one day ahead in anticipation of the renewable generation. The CPOs, as aggregators of EV charging stations and in the future responsible for managing a large share of the load, then adjust the prices offered to their customers for charging accordingly and inform EV users (e.g., via an App) about their anticipated charging prices. As opposed to flexible capacity contracts discussed in the previous section, this measure of indirect DSO flexibility activation does not guarantee the seamless operation of the network, as charging is still technically possible, although expensive. Figure 10 provides a schematic drawing of how different tariff structures could affect the load curve in a network, with the main goal of reducing the peak load and shifting demand to those periods where the DUoS tariff is lower.

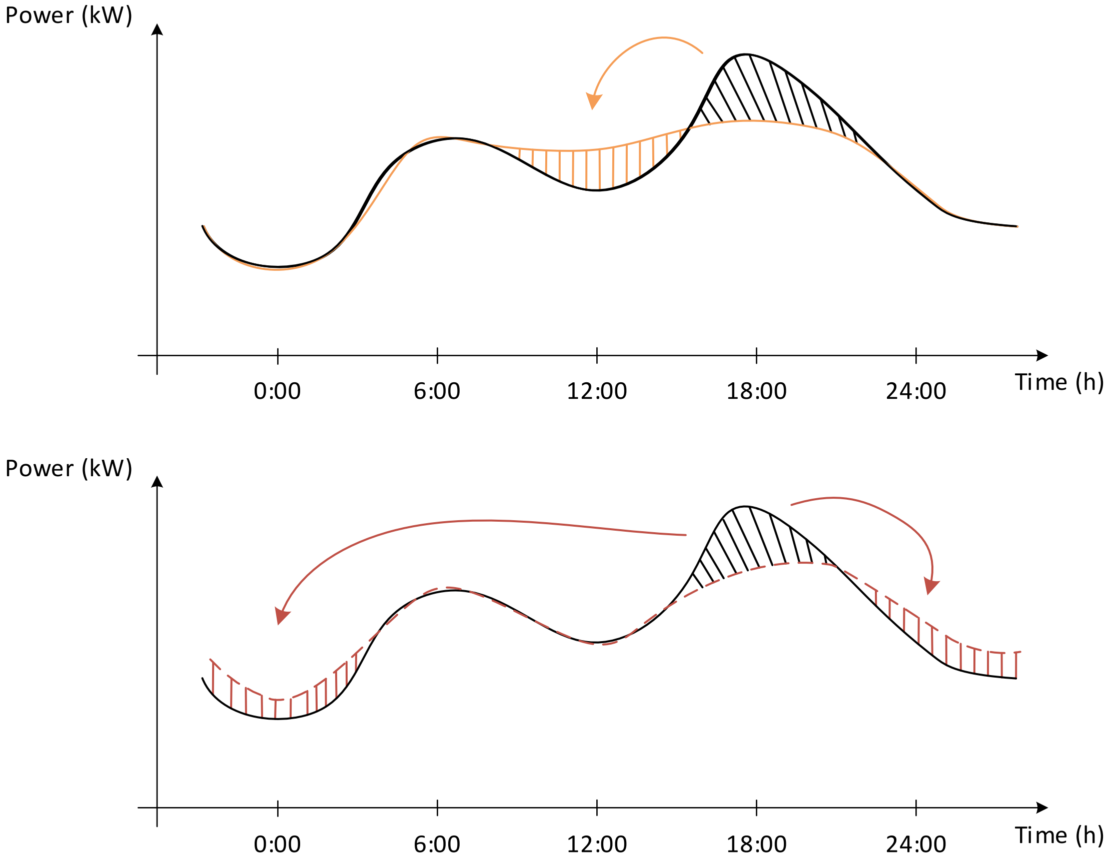

Figure 10: Schematic change in load due to imposed tariff structure for a day with PV (top plot) or a day without PV generation (bottom plot).

As a design option and depending on the size and structure of the network, the imposed tariffs could also differ within a network to better reflect the true congestion issue. This would give an incentive to consume directly in parts of the network where there is, e.g., high renewable generation and potentially to move flexible loads (e.g., EVs) to different parts of the network. With an appropriate notification or steering, journeys with an EV could be planned to exploit cheap charging prices in different parts of the network while helping the DSO in managing grid loading. Figure 11 exemplifies this situation. Some, although certainly not all, EV users might be triggered to move their charging to other areas of the network that has regional renewable generation abundant and where the DSO incentivizes charging using DUoS tariffs.

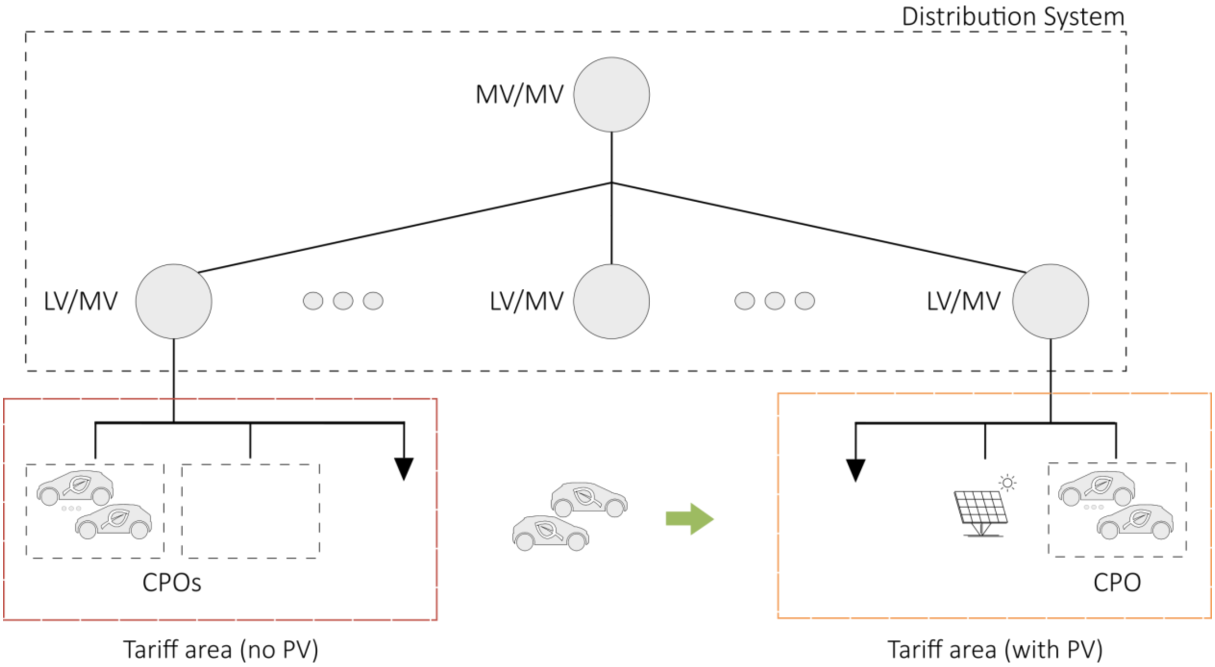

Figure 11: Potential steering of load within a distribution network through tariff zones.

4 Recommendations for real-life applications

The theoretical framework of the previous section with the respective illustrative examples must be extended with real data to make these considerations more realistic and tangible. Section 4.1 details the data requirements needed to test and implement said strategies, both from the perspectives of DSOs and CPOs. Section 4.2 comments on the interaction between these two entities with respect to communication infrastructure. To bridge the gap from the more theoretical concepts for the DSO to enable V2X flexibilities to the real life, Section 4.3 provides an example of the Slovene national flexibility platform.

4.1 Data requirements

Implementing the investigated strategies requires various datasets for both the DSO and CPOs.

CPOs need to have detailed historical EV data, which would allow them to place their offers in auctions of flexible capacity contracts, so that they can offer services which they would be able to offer reliably and at the appropriate cost. EV user behavioural models would also be useful because abiding by capacity limitations may require the postponement of EV charging and/or a reduced charging service (i.e., offering less energy to users).

DSOs need comprehensive network data about their grid topology, as well as historical and real-time operational data. EV user behavioural models would be helpful for DSOs to estimate the load shifting potential of DUoS tariffs. DSOs can incentivise the increase/decrease/shift of EV consumption by adjusting DUoS tariffs but estimating the effect of these changes requires the appropriate models. Historical load and generation data are necessary for the implementation of flexible capacity contracts. Using those (including EV consumption data), the DSO can forecast the services needs and reserve the required capacity by the CPOs. Forecasted are also at the day-ahead stage, where the DSO decides on which network tariff structure to use and whether services should be activated. Electricity spot prices, weather data and other data sources can be used to enhance the accuracy of load forecasting.

4.2 DSO – CPO interaction

EV charging stations have the potential to strongly impact the performance of the distribution networks. Primarily due to uncontrolled charging, the additional load imposed by EVs may degrade voltage profiles, increase peak load consumption, and increase harmonic distortions. To ensure the reliable operation of distribution grids, especially when looking at high-power charging points, the efficient coordination between DSOs and CPOs is crucial, e.g., with respect to capacity limits and supply-demand balances in specific instances. Currently, two protocols are in use to facilitate this [40]: *Open Smart Charging Protocol* (OSCP) and *Open Automated Demand Response* (OpenADR).

Open Smart Charging Protocol* (OSCP)*:
OSCP facilitates the negotiation between DSOs and CPOs. DSOs create a supply and demand forecast at 15-minute intervals, informing CPOs about their allocated capacity and available spare capacity. CPOs can then negotiate for more or less capacity and create charge plans for their stations, specifying power limits per time slot. This information is transmitted to the charge points using protocols like *Open Charge Point Protocol* (OCPP). Key messages exchanged through OSCP include [41]:

- Heartbeat: The charging point sends a heartbeat message to the DSO periodically to indicate that it is still operating normally.

- Update Cable Capacity Forecast: This message is meant for the DSO to send out the forecasted cable capacity and the backup capacity for the CPO.
- Request Adjusted Capacity: This message is meant for the CPO to request extra capacity when necessary.
- Get Capacity Forecast: This message enables a CPO to request a new forecast.
- Update Aggregated Usage: This message is for communicating the total usage CPO back to the DSO. This information is necessary for the DSO to verify how much capacity CPO has used.

These messages enable efficient communication between DSOs and CPOs to manage capacity and charging effectively.

Open Automated Demand Response **(OpenADR)*:***
OpenADR is a protocol developed by the OpenADR Alliance for automated demand response and dynamic price communication. It provides DSOs with direct control over equipment, allowing them to manage energy demand effectively. OpenADR provides a non-proprietary, open, standardized and secure demand response (DR) interface that allows electricity providers to communicate DR signals directly to existing customers using a common language and existing communication infrastructure, such as the Internet. Key services within OpenADR include[7]:

- *Event Service*: Used by OpenADR servers or virtual top nodes (VTNs) to send demand response events to clients or virtual end nodes (VENs), and used by VENs to indicate whether resources are going to participate in the event. Events can contain one or many different segments (intervals) for different prices, curtailment levels, or other signals pertinent to the DR program.
- *Report Service*: Used by VENs and VTNs to exchange historical, telemetry, and forecast reports. Resources can report their status, availability, and forecasts, but also real time energy and curtailment readings.
- *Opt Service*: Used by VENs to communicate temporary availability schedule to VTNs or to qualify the resources participating in an event. This helps both the DR program operators and the participants to better plan their resources.
- *Registration Service*: Initiated by the VEN and used by both VEN and VTN to exchange information required to ensure interoperable exchange of payloads.
- *Poll Service*: Used by VENs to poll the VTN for payloads from any of the other services. This is specifically important for simpler devices that cannot fully support additional messaging.

To use charging stations in the context of OpenADR, the CPO must agree with a party interested in managing the stations as demand response assets. Once the conditions are settled, these are two ways to enable charging stations with OpenADR[8]:

1. Registering every charging station with the OpenADR VTN server.
2. Having the OCPP central server register with the OpenADR VTN server as an OpenADR VEN and aggregating the participating charging stations.

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[7] More information: https://www.openadr.org/assets/docs/DTECH2015/what%20is%20openadr.pdf

[8] More information: https://www.ampeco.com/blog/what-every-cpo-needs-to-know-about-openadr/

In the second scenario, the OCPP central server plays a pivotal role by translating OpenADR event signals into valid OCPP smart charging messages and sending them to the network's relevant charging stations.

The integration of EV charging stations with distribution networks requires effective coordination protocols like OSCP and OpenADR. These protocols enable efficient management of capacity, demand, and grid stability, ensuring the reliable and secure operation of the electrical grid with respect to the growing presence of electric vehicles.

4.3 Example of a flexibility platform from the Slovenian demo

In the Slovenian demo (WP7), work will build on a previously developed flexibility platform, namely the Slovene national flexibility platform, which will be further extended within the *EV4EU* project. Deliverable D4.4 "Impact of mass deployment of V2X in energy markets and services" will define services focusing on EV participation in flexibility markets both on local and regional levels. To create a link between the theoretical work done in this deliverable and D4.4, we will provide a glance on how the Slovene national flexibility platform functions. However, in this deliverable (D4.2) we only provide the theoretical foundation of how two strategies work towards enabling flexibility from a DSO perspective, and this is not intended to be included as is in the Slovenian flexibility platform.

The flexibility platform facilitates the activation of flexibility resources for the DSO through a unified system that integrates billing and metering data. Consumers, acting as flexibility providers, can register their flexibility resources on a web portal. During registration, consumers can authorize an aggregator to trade their flexibility. The platform supports various functionalities, including tendering, purchasing, contracting, activation, and billing. Each activation is closely tied to a contract, ensuring clear terms and accountability.

Data requirements in the flexibility platform are as follows:

- **Registration:** Consumers provide their flexibility power in kilowatts (kW) during registration, along with the selected aggregator. Other necessary data is already available in the billing system.
- **Flexibility Tender:** For tender submissions, specific data is required, including Tender ID, Due date of the tender, Area of the grid (e.g., HV/MV substation, MV feeder, MV/LV substation), Substation/feeder ID, Tender name, Ramp-up time, Maximum number of daily activations, Maximum duration of a single activation, Contract duration, Total flexible power of the tender, Minimal offered flexibility in kW, Maximal price for the bid (cap), and a Daily activation schedule (for workdays and weekends).
- **Bidding:** During the bidding phase, participants provide data such as Tender ID, Offered flexibility in kW, and Bid/price for the activated energy.

The flexibility trading process operates on a seasonal basis, where tenders are published with a submission deadline. Consumers and aggregators registered on the platform submit their bids. After the tender period closes, the best bids are selected, and contracts are finalized. Only the delivered flexibility energy is compensated, as the platform does not support the reservation of flexibility resources.

In the Slovenian context, the integration of flexibility solutions is expected to have a significant impact on DSO congestion management. This impact includes the implementation of a real-time traffic light system for monitoring voltage profiles and the utilization of community batteries. The traffic light system allows for the prompt identification of congested areas within the distribution network, facilitating proactive measures to alleviate congestion and ensure grid stability. Community batteries, connected to renewable energy sources and equipped with advanced control systems, offer a decentralized approach to store and distribute energy. These batteries act as buffers, absorbing excess energy during periods of high generation and releasing it during peak demand. By optimizing energy flows, improving grid reliability, and mitigating congestion, the integration of flexibility solutions enhances the efficiency and resilience of the energy infrastructure.

5 Conclusions

With the increasing electrification of transport and heating and the associated uptake of both EVs and heat pumps, DSOs face significant operational challenges such as congestion and/or voltage violations. At the same time, the proliferation of distributed generation at the distribution level creates both new challenges and opportunities. DSOs need measures to enhance their operational flexibility and align flexible consumption units with the intermittent, variable, and stochastic renewable generation.

The focus of this deliverable *D4.2 Scheduling and Real-Time Operation Strategies to Control V2X Flexibilities* was on examining the rationale and functioning behind *flexible capacity contracts* and *variable distribution system of use tariffs*, focusing on EVs as flexible loads. Besides comprehensively discussing design options that a DSO can take, we provide illustrative examples of their functioning and potential impact on distribution grid loading.

Variable DSoU tariffs can be used to steer flexible consumption and achieve a more efficient network operation compared to their flat counterpart (no variable tariff structure). However, they cannot guarantee that network constraint violations will not occur. For this reason, they are complemented by flexible capacity contracts, which limit the consumption of users (in return for financial compensation) and provide operational guarantees. In addition, we have investigated the synergies between flexible capacity contracts and variable DUoS tariffs, based on a formal methodology. This work shows that in certain conditions congestion can only be resolved through the synergetic effects of both flexibility mechanisms, besides decreasing reduction in system costs.

The theoretical framework presented in this deliverable with respective illustrative examples must be extended with real data to make these considerations more realistic and tangible. We hence provide recommendations for data requirements to design and test these mechanisms in both a model environment and real-life, and comment on coordination issues/needs between DSOs and CPOs.

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