ebalanceplus

Guidelines for new market mechanisms and tools for incentivizing electric energy flexibility

Deliverable D1.1

DATE: 30/7/2021

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

Technical References

Project Acronym	ebalance-plus
Project Title	Energy balancing and resilience solutions to unlock the flexibility and increase market options for distribution grid
Project Coordinator	CEMOSA
Project Duration	42 months

Deliverable No.	D1.1
Dissemination level [1]	PU
Work Package	WP1
Task	T1.1
Lead beneficiary	DTU
Contributing beneficiary(ies)	DTU, UNC, CEMOSA
Due date of deliverable	30/07/2021
Actual submission date	30/07/2021

1 PU = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

Document history

V	Date	Beneficiary(ies)	Author(s)
1	19/05/2021	DTU	Mohsen Banaei, Francesco D'Ettorre, Razgar Ebrahimy, Pasquale Vizza, Anna Pinnarelli Juan Jacobo Peralta Escalante
2	17/06/2021	DTU	Razgar Ebrahimy
2.1	29/06/2021	DTU	Mohsen Banaei
3	09/07/2021	ESCI, UNC, CEMOSA	Review (Mara van Welie, Anna Pinnarelli, Diego Ballesta Andres)
4	19/07/2021	DTU	Razgar Ebrahimy
5	29/07/2021	CEM	Review Juan Jacobo Peralta
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7	12/11/2021	DTU	Disclaimer change

Summary

1.1 Summary of Deliverable

This deliverable identifies existing and possible market-based solutions to incentivize end-users for providing energy flexibility in the ebalance-plus project. ebalance-plus aims to exploit the flexibility of distributed energy resources (DERs) and end-users using different market mechanisms in the power system. To this end, it is necessary to have a clear understanding of electricity market ideas, their regulation, types, components, challenges and opportunities. Understanding electricity markets also help us to develop new market places for trading the products e.g., energy and flexibility, that can fit into the existing structure and have no conflict with existing market places. Achieving this goal requires a comprehensive study of electricity market structures, identifying the opportunities for trading end-user flexibility in power systems, studying the existing and ongoing flexibility market projects, and determining the requirements for implementing flexibility markets. These requirements are discussed as below:

Section 1 provides an introduction to energy flexibility, the necessity of procuring flexibility from the demand side of the system, system requirements, challenges, and opportunities.

Section 2 reviews the general structure of electricity markets including the concept, market players, system operators, energy and ancillary service markets, energy flexibility, flexibility markets idea, social acceptance of demand response programs, and ongoing flexibility market projects.

Section 3 discusses the requirements for implementing flexibility markets. The focus is on reviewing the available flexible resources at the distribution grid level, hardware and software requirements of a flexibility market, and market players' actions and behaviour in the flexibility market.

Section 4 concludes the deliverable.

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Table of Contents

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°864283

List of tables

List of figures

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N°864283

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Acronyms

ARERA	Regulatory Authority for Energy, Networks and Environment
BRP	Balance Responsible Party
CCHP	Combined Cooling, Heating, and Power
CEER	Council of European Energy Regulators
CHP	Combined Heat and Power
CMU	Customer Management Unit
DER	Distributed Energy Resource
DERMU	Distributed Energy Resources Management Unit
DNO	Distribution Network Operator
DSO	Distribution System Operator
ENTSO-E	European Network for Transmission System Operators for Electricity
EPEX	European Power Exchange
ERDF	Électricité Réseau Distribution France
EV	Electric Vehicle
FACTS	Flexible Alternating Current Transmission System
G2V	Grid to Vehicle
HVAC	Heating, Ventilation, and Air Conditioning
HVDC	High Voltage Direct Current
ISO	Independent System Operator
LFM	Local Flexibility Market
LMO	Local Market Operator
LVGMU	Low Voltage Grid Management Unit
MI	Mercato Infragiornaliero
MCP	Market Clearing Price
MGP	Mercato del Giorno Prima
PX	Power Exchange
RES	Renewable Energy Source
RTE	Réseau de Transport d'Electricité
TES	Thermal energy storage
ToU	Time of Use
TSO	Transmission System Operator
UCTE	Union for the Coordination of the Transmission of Electricity
VPP	Virtual Power Plant
V2G	Vehicle to Grid

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1 Introduction

Global concerns about climate change have led to the design of decarbonisation policies by governments. The European Commission aims to reach 40% cuts in greenhouse gas emissions (from 1990 levels) by 2030 and climate-neutral by 2050. These policies have led to growing attention on increasing the share of renewable energy sources (RESs) in producing electric energy. Despite the environmental benefits of RESs, the uncertain and uncontrollable nature of these resources mean the power systems are facing new challenges. On one hand, the higher share of RESs requires higher capacity for the reserve to provide energy flexibility and keep the system supply and demand in balance. On the other hand, increasing the share of RESs means reducing the share of conventional thermal power plants in the supply sector and consequently, reducing the reserve capacity in the grid. Moreover, since most important RESs, i.e., wind and solar, are inverter-based generation units, their growth will reduce the system inertia which means higher sensitivity of the system frequency to small power imbalances. Higher needs for reserve capacity also cause suboptimal operation of more generating units and increase their maintenance costs and consequently result in increased electricity prices for end-users.

So, it is clear that to solve these issues new sources of flexibility should be used in the grid. Three new flexible resources can be defined alongside the traditional thermal power plants as follows:

- Storage units such as large-scale batteries and pumped-storage hydropower units;
- Transmission and distribution grids expansion plans;
- Demand-side flexibility using controllable and shiftable loads.

High investment costs for batteries and pumped storage units limit their applicability in terms of large-scale flexibility provision. Moreover, pumped storage units require geographical features and water sources that are not available in many countries. Transmission and distribution grids expansion plans can solve the congestion issues and release more power capacity to be used as flexible resources. However, this plan is also expensive, taking a long time to build and is only effective for the grids with congestion issues. Plus, it is suggested in different policy/legal frameworks, e.g., the "Clean Energy for all Europeans" also known as Clean Energy Package, to use the flexibility of the demand-side to avoid or postpone grid expansion plans. In this regard, demand response has been shown to be an effective solution to provide flexibility services in the grid.

One of the main objectives of the ebalance-plus project is to utilize the energy flexibility of the end-users for solving the grid issues by defining new business models that incentivize all stakeholders including end-users, retailers, energy aggregators, and system operators. To achieve this goal, first, we should have a clear understanding of flexibility definition and its categories and then identify market places for trading the flexibility.

1.1 Flexibility definition and its categories

According to the International Energy Agency, the flexibility of a power system refers to "the extent to which a power system can modify electricity production or consumption in response to variability, expected or otherwise". Another source described it as "the modification of generation injection and/or consumption patterns in reaction to an external signal (price signal or activation) in order to provide a service within the energy system" [1]. In general, flexibility is categorized into two main groups [2][3]:

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- **Implicit flexibility** or price-based flexibility, which is related to a long-term expected reduction in load demand due to systematic changes in end-user behaviour. Incentives for implicit flexibility are mainly in the form of price signals and consumers react to dynamic market or network pricing signals. Implicit flexibility will always have an uncertain response. Price incentives may affect normal behaviour in such a way that end-users tend not to use their full capacity of electricity demand. However, there is no guarantee that it will happen when flexibility is needed in the system. This flexibility can be part of the long-term planning process, but not for real-time operations.
- **Explicit flexibility** or incentive-based flexibility that can be mobilized in real-time or at short notice, and where the volume is controllable. In this type of flexibility program, the aggregated flexibility of a set of consumers can be traded in different markets like wholesale, ancillary service, or even capacity markets to solve grid issues like frequency control or voltage regulation. Consumers are being paid to change their power consumption pattern upon request. This kind of flexibility is useable for short-term system operation and congestion management purposes.

Explicit and implicit flexibility impacts are illustrated in Figure 1 [2].

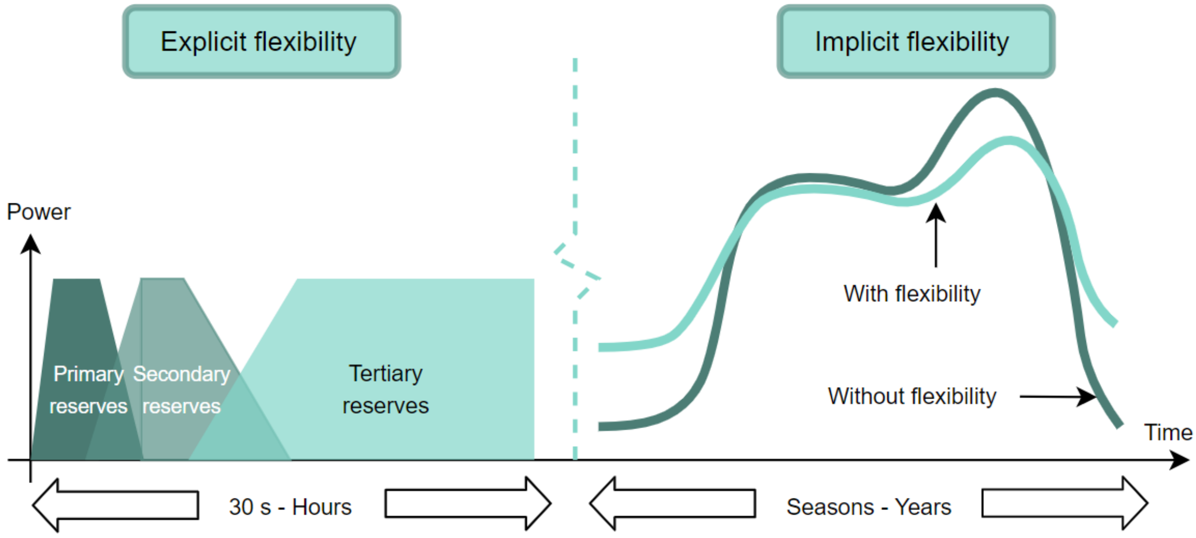

Figure 1. Comparing the operation time and impacts of implicit and explicit flexibilities

Implicit flexibility programs have been implemented in systems for decades through price tariffs such as the Time of Use (ToU) scheme. The application of demand response for frequency control and voltage regulation is a recently introduced approach for utilizing the explicit flexibility of end users.

1.2 Market places for trading flexibility

In order to incentivize stakeholders to be a part of these flexibility mechanisms, a clear vision about existing and possible market places for trading end-user flexibility should be provided. To this end, first, principles of the electricity markets including the rules and regulations, market operators and participants, and energy and ancillary services market places should be identified. This helps us to know where the flexibility of end-users can be traded and to identify the challenges ahead of market designers and decision makers to achieve the participation of demand-side flexibility in electricity markets. This task is performed in Section 2.

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Then, the concept of future flexibility markets is explained, and different ongoing flexibility market projects are reviewed. This will help us to design new marketplaces for trading the flexibility of end-users and makes the stakeholders familiar with their financial opportunities in the future. This study is also performed in Section 2 of the deliverable.
Finally, different requirements for implementing these new flexibility markets should be identified and discussed. This could be useful for market designers and decision-makers to find out different challenges and requirements in implementing a new flexibility market. These requirements are reviewed in Section 3.

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2 Electricity Markets Principles

ebalance-plus aims to exploit the flexibility of distributed energy resources (DERs) and end-users using different market mechanisms in the power system. To this end, it is necessary to have a clear understanding of electricity market ideas, their regulation, types, components, challenges and opportunities. Understanding electricity markets also help us to develop new marketplaces for trading the products e.g., energy and flexibility, that can fit into the existing structure and have no conflict with existing marketplaces. Hence, in this section, the principles of the electricity markets are investigated.

2.1 Electricity market concept

Restructuring in the power industry has changed the business and operational model of power systems since the late twentieth century. Traditionally, the power system has been viewed and operated as a vertically integrated monopoly, regulated by national governments. The latter was also the owner of generation facilities and transmission and distribution infrastructures. Lack of competition in this monopoly structure caused inefficient operation of the power system which imposed additional costs on the system and higher electricity prices for end-users [4]. In addition to the inefficiency of the traditional model, some technological improvements in the power generation sector made the necessity for changes in the operational structure of the power system inevitable. During the mid-eighties, cost-effective gas turbine power plants started generating power. This provided opportunities for private market players to generate power and sell it to the customers, but in the traditional model, this was impossible [4]. In this situation, restructuring or deregulation was introduced as a promising solution for increasing the efficiency of the power system operation. In general, restructuring the power system refers to unbundling the generation, transmission, and distribution sectors, providing a fair and competitive environment for participation of private market players in electric energy trading, and reducing total operating cost and electricity prices for consumers [5]. In a restructured environment, trading energy in both generation and consumption sides is performed by private market players and all market players have non-discriminatory and open access to the transmission and distribution system. On the generation side, private market players can sell their generated power at competitive prices and on the consumption side, customers can choose among different retailers in the electricity retail market. Large end-user customers are allowed to buy their required energy directly from the power generation side [6].

In the restructured power systems, trading power among power producers and retailers is performed in three main ways [5]:

- **Bilateral contracts:** Producers and retailers directly negotiate on amount and price of the electric energy to be exchanged. Today, different types of contracts like forward, futures, and options are used for trading energy.
- **Wholesale electricity market:** This method is based on the Pool-Co model in which all power producers and retailers submit their power and price bids to a marketplace operated by a third party, i.e. an independent system operator (ISO). Once the bid-offer process of buyers and sellers is concluded, the market operator clears the market by maximizing social welfare and determines the market clearing price, hence the volume of power/energy to be produced/bought from sellers and buyers, respectively. More explanations about the ISO and its responsibilities will be provided in the next subsections.

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- **Hybrid of bilateral contracts and wholesale electricity market:** The hybrid method combines the various features of the above-mentioned methods. All market players are allowed to trade energy through both bilateral contracts and the electricity market. This method is the most commonly adopted method for energy trading in today's power systems. Both bilateral contracts and electricity market power transactions are transmitted through unique transmission and distribution grids. The transmission and distribution grids have some limitations due to stability issues. So, to prevent exceeding these limitations, transactions of both bilateral contracts and the electricity market should be under the supervision of the system operator. However, the price and quantity of contracts are usually confidential. So, in general, as a solution, market players are obligated to bid, in the electricity market such that they win the sum of their contracts and their scheduled power in the electricity market. Then, each producer and retailer settles their contract price based on the difference between the contract price and market clearing price. This settlement method is called a contract for difference [7]. In this situation, from the viewpoint of the system operator, the hybrid method is the same as the wholesale electricity market method.

A graphical presentation of today's electricity markets is illustrated in Figure 2.

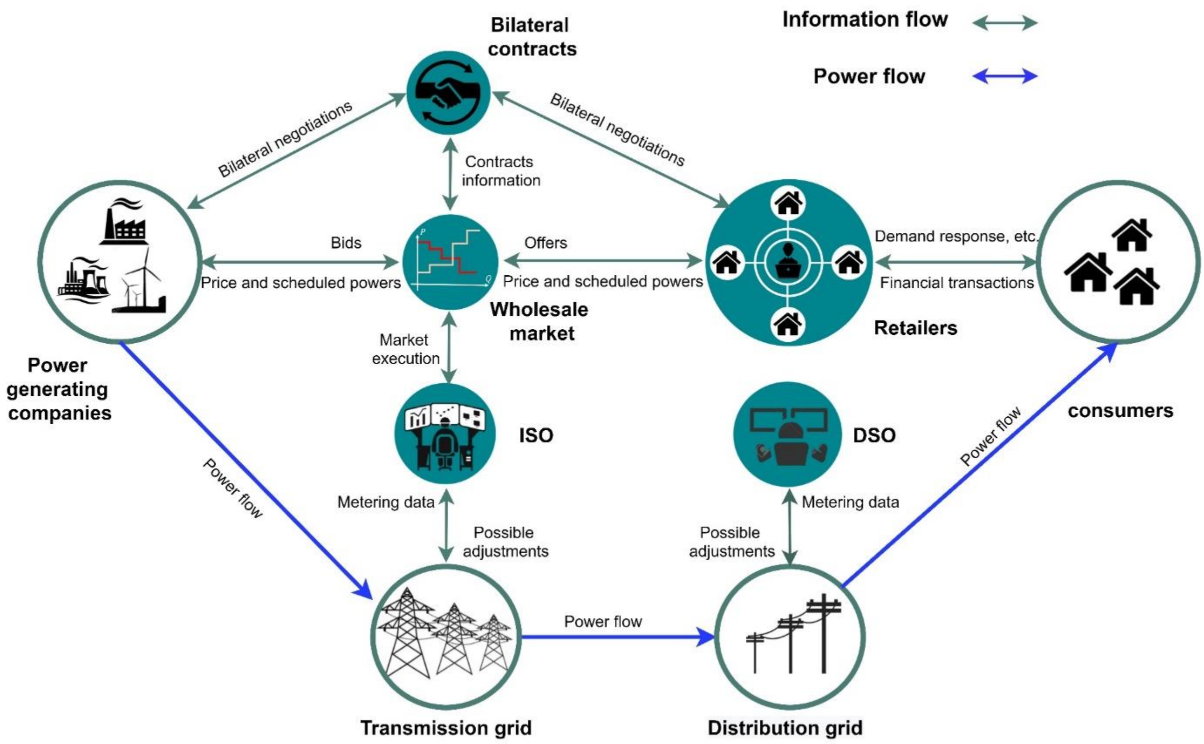

Figure 2. The general structure of today's electricity markets

In today's electricity markets, alongside the power, ancillary services and capacity are also traded via the market mechanisms that are discussed in the next sections.

2.2 Electricity market objectives

The main goals of restructuring and moving from a monopoly structure toward competitive electricity markets are the following [5]:

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- **Reducing the electricity price for consumers:**
  Competition among the market players leads to lower electricity prices for consumers compared to the monopoly system. Indeed, in a competitive environment, producers are incentivized to increase the efficiency of their power generation units and reduce the electricity generation cost in order to be more competitive in the market [8]. Moreover, the extension of access to the market for private players increases competition and reduces the market prices.
- **Providing different choices for electricity consumers:**
  Consumers can choose among different retailers based on the proposed prices and services that are offered to them. These services could include better plans, better reliability, better quality, etc. [8]
- **Creating a customer-centric structure:**
  A monopoly system cannot have a customer-centric paradigm, but in a competitive system, all retailers try to provide the best services for their customers with the competitive prices that lead to a customer-centric structure.
- **Innovation:**
  In a monopoly structure, there is no incentive to improve efficiency or take the risk on new ideas that benefit the customers. In competitive electricity markets, both producers on the supply side and retailers on the demand side of the system try to increase their profit in competition with their rivals by applying innovative ideas in power generation, bidding in the bilateral contracts and electricity market, and providing new services for the customers.
- **Procuring ancillary services from the electricity demand-side of the system:**
  Traditionally, ancillary services have been provided by the supply-side. In the restructured environment, the ancillary services can be traded in competitive markets, which are open to both the supply- and demand-side. It should be noted that, as for the wholesale market, increasing the number of market players in the ancillary market improves the reliability of the system and the cost-effectiveness of these services.
- **Increasing the share of DERs in the power generation:**
  Reformed electricity markets also incentivize the development of small-scale distributed generation. The investment cost of these units is much less than the large-scale power plants, so, many more private market players can invest in these generating units. Some of these units are based on renewable energy resources like wind and solar. Moreover, DERs are usually located at the distribution level and very close to their consumers. This means fewer power losses and more efficient power transmission.

2.3 Electricity market players

Although all the electricity markets share the same theoretical basis, their implementation can be different among different countries worldwide. This can lead to different definitions for the electricity market players and services in various electricity markets. The present section presents an overview on the different market players, together with a description of their main role and responsibilities.

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2.3.1 Transmission System Operator (TSO)

The grid's independent operation is guaranteed with an independent entity that in general is called the ISO. In European electricity markets, the concept of TSO is used instead of the ISO. The basic purpose of a TSO is to ensure fair and non-discriminatory access to transmission services and ancillary services to maintain the real-time operation of the system and facilitate its reliability requirements. A TSO is mainly responsible for maintaining system integrity by acquiring resources necessary to remove transmission violations, balance the system in a second-to-second manner, and maintain system frequency at an acceptable level to retain stability. Some other duties of the TSO are summarized below [5]:

- Providing ancillary services for the grid using market mechanisms, bilateral contracts or assigning commitments to market players.
- The security of electricity supply by ensuring the secure operation of the power system and an appropriate transmission system capacity in the transmission grid.
- Maintenance and repairs of the grid, installations and equipment, including the connections of the grid with other power systems.
- Ensuring long term operability of the power system in order to satisfy the substantiated needs of national and cross-border transmission of electricity.
- Cooperation with other systems operators or energy enterprises to ensure the reliable and effective operation of electricity systems and their coordinated development.
- Purchasing system services indispensable to the correct operation of the power system, its reliability and the maintenance of quality parameters of electricity.
- Purchasing electricity to compensate the losses suffered in the transmission grid [6a].

In ebalance-plus, TSO as the ancillary service markets operator is one of the key elements in procuring the flexibility of DERs and end-users for ancillary service purposes. TSOs also have information about the transmission system issues like congestion and voltage regulation and in collaboration with DSOs they can use the DERs and end-user flexibility to solve these issues (more information about the TSO role in project demo sites is presented in Section 2.5).

2.3.2 DSO

DSOs are the operating managers (and sometimes owners) of whole or portion of the energy distribution networks, operating at low, medium and, in some member states, high voltage levels (LV, MV), which delivers power to the end-users. A DSO securely operates and develops an active distribution system comprising networks, demand, generation, and other DER. As a neutral market facilitator, it enables competitive access for all parties to the markets. Moreover, DSOs ensure security, sustainability, and affordability in support of the whole system optimization. A DSO enables customers to be both producers and consumers, by enabling their access to networks and markets and also provides and maintain systems, processes, and data to facilitate markets and services [11].

DSOs usually achieve their objectives by installing new grid lines and equipment, and reinforcement of the devices without using the potential of end-users and DERs. One of the main goals of ebalance-plus is to design a platform that expands the options of DSOs in solving distribution grid issues with a focus on the role of end-users and DERs. For instance, DSOs can use the flexibility of DERs and end-users to solve distribution grid congestion issues and postpone grid expansion plans instead of installing new lines or equipment. The designed structure should be such that both DSO and end-users have enough incentives to be a part of

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the plan (more information about the DSO roles in project demo sites is presented in Section 2.5).

2.3.3 Generating company or power producer

Generating companies are the supply side of the electricity market. They are owners or operators of one or more power generator units. At the moment power producers are the source of flexibility in the power system. By increasing the share of renewable energy resources, the necessity to use flexibility in the grid increases and flexibility capacity of the supply side decreases. So, new sources of flexibility will be needed in the near future. ebalance-plus aims to exploit this required flexibility from DERs and end-users.

2.3.4 Aggregator

An aggregator is a grouping of agents in a power system (i.e., consumers, producers, prosumers or any mix thereof) to act as a single entity when engaging in power system markets (both wholesale and retail) or selling services to the operator. Aggregators are relatively new market players whose aim is to enable the aggregation of small end-users in order to enable them to participate in the energy or ancillary service markets. Aggregators can set up agreements with several consumers, based on which they can temporarily decrease or increase end-users' electricity consumption. Then they can trade this aggregated flexibility capacity in different energy and ancillary service markets [12]. To this end, aggregators will require access to specified markets and market instruments. Nowadays, the regulatory framework for aggregators and their role/participation to the electricity markets is fragmented across Europe. For example, in Germany, aggregators require agreement with customers' suppliers before they can access the market, though this may be changing [13]. In UK, aggregators can access the wholesale market and the balancing market only through the supplier. They can directly access the remaining markets i.e., the ancillary services market and the capacity market [14]. In contrast, in France and Italy aggregators can access all available markets without negotiating first with a supplier [13]. The aggregator is therefore the entity who acts on behalf of the community and interfaces distribution-transmission grid operators and regulated market operators with the aim of achieving the community goals. Aggregators are one of the most important actors in ebalance-plus. They play the role of intermediary between DERs/end-users and different market places for selling their flexibility and also exploit the flexibility commitments from DERs and end-users using different methods like direct load control or price base methods.

2.3.5 Retailers

A retailer is an electric energy supplier that concludes an electricity supply contract with a customer [5]. Retailers procure electricity for their customers through financial contracts, like bilateral forward, futures, and options, as well as participating in the wholesale electricity market. In Europe each end-user can freely choose its retailer. Although retailers are not a key part of ebalance-plus, their interactions with aggregators can affect them in terms of the proposed structures in ebalance-plus and hence, should be included in the studies. More explanations about aggregator and retailer relations will be presented in Section 2.7.4.4.

2.3.6 Electricity consumers

Electricity consumers are all end-users (residential, industrial, tertiary, etc.) of electricity. They receive their required power from retailers or distribution companies. Consumers can also have a contract with aggregators to provide flexibility for the power system. The most attention in

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ebalance-plus is on these market players as end-users and the important role they can play in the future of the power system.

2.3.7 Prosumers

Prosumers are market players that both consume and produce electric energy. With the growth of new technologies and the steady increase of more renewable power like solar and wind, smart meters, electric vehicles, home batteries, and other smart devices, prosuming offers the potential for consumers to play the role of both producers and consumers in the system [15]. Prosumers are also another group of end users that are studied in ebalance-plus from the viewpoint of the flexibility provision.

2.3.8 Micro-grids

A micro-grid is a group of interconnected loads and DER within clearly defined electrical boundaries that act as a single controllable entity with respect to the grid. All types of consumers, prosumers, and DER can be included in micro-grids. A micro-grid can connect and disconnect from the grid to enable it to operate in either grid-connected or island mode. A micro-grid can be owned and operated by the DSO or work as an independent entity. DSO micro-grids are usually found in non-liberalized markets where the DSO owns the distribution and retail of the energy, and in turn, is solely responsible for the costs and benefits of micro-grid operation. Independent micro-grids can operate as electricity market players that trade energy in the electricity market and try to maximize their profits [16].
From the viewpoint of ebalance-plus, micro-grids can also be treated as end-users that can provide flexibility in a larger volume compared to small scale residential buildings. ebalance-plus demo sites in France, Spain and Italy are most likely to be micro-grids.

2.3.9 Virtual power plants (VPPs)

A VPP is defined as a controlled and coordinated aggregation of DERs and loads that can participate in energy markets and provide flexibility services in the grid as conventional power plants. A VPP can be regarded as a power resource coordination management system that combines and optimizes the energy storage system, controllable load, electric vehicle, and other DERs based on advanced information and communication technology. A VPP acts as a special plant that participates in the power market and power grid operation, helps DERs to realize grid connection, and improves the capability of the power grid to exploit electricity from renewables. Thus, it is an effective system for improving energy efficiency and promoting renewable energy development [17]. VPPs are categorized into two groups: commercial VPPs and technical VPPs. VPPs provide a flexible capacity mainly to the energy market and in some cases to the ancillary service markets. DERMs can provide ancillary services including scheduling and re-dispatching, reactive power and voltage control, congestion management, load-frequency control, imbalance management, etc. to the TSO or DSO [18]. From the ebalance-plus perspective, VPPs can play the same role as aggregators and provide flexibility services for the grid on behalf of their loads and DERs.

2.3.10 Balance responsible parties (BRPs)

BRPs are players in some markets such as the Danish and Belgian electricity markets. In Denmark, all power producers and consumers operating in the electricity market that have not entered into an agreement on balance responsibility with Energinet (the Danish national TSO for electricity and natural gas), and thus do not undertake balance responsibility for their own activities, are obliged to assign their balance responsibility to an approved BRP. A BRP must have entered into an agreement with Energinet. The BRP is responsible for:

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- Deviations between reported trading schedules and actual consumption/production for the metering points for which the BRP holds balance responsibility.
- Costs relating to the purchase of balancing power which Energinet, in its capacity as TSO, must make to uphold the balance [19].

BRPs are not the main actors in ebalance-plus. However, their conflict with aggregators should still be investigated in the project. More detail about the conflicts between aggregators and BRPs is presented in section 2.7.4.4.

2.4 Electricity markets

According to the proposed structure in ebalance-plus, end-user flexibility should be exploited by market mechanisms. So, it is very important to know the rules and structure of different marketplaces in the power system. The present section provides a description of the main structure of electricity markets, although differences can exist across different countries. According to their operating time scale, electricity markets can be classified as: financial futures and forward (the market open years before the delivery to the customers), day-ahead, intraday, and ancillary service markets. Figure 3 shows the time scale at which these markets occur [20]. The market players' and market operator's actions in each of these markets are described in the next subsections.

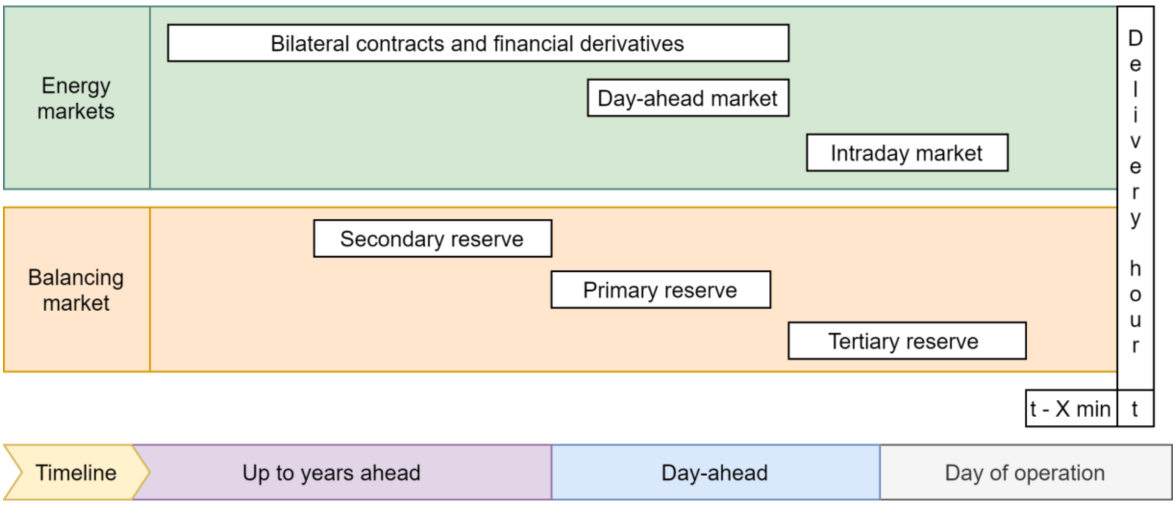

Figure 3: Basic market architecture in restructured power systems [20]

2.4.1 Financial derivatives

In power systems, market players are usually faced with the risk of undesirable spot market price fluctuations that can affect their profits significantly. Market players try to hedge against these financial risks by involving themselves in different types of financial derivatives like futures, forward, and options contracts. According to these derivatives, contract parties agree to trade a specific volume of energy in a time in the future at an agreed predetermined price. Forward contracts are bilateral contracts between two market players. Futures that are traded in the futures market are standard contracts in terms of the volume and delivery period that can be traded among different market players in the futures market during the trading period [21]. An option contract provides more flexibility than a forward or a future contract since the holder of an option has the right to exercise the contract depending on different conditions like the pool price behaviour [22].

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2.4.2 Day-ahead market

In the European day-ahead markets, producers and consumers can sell or buy energy for the next 24 hours in a closed auction. This auction is held for each hour of the next day separately. All generation bids and consumption offers are placed at the same time and no-one knows about others' bids and offers. At the market closure, ISO or TSO runs an economic dispatch program with the goal of maximizing the social welfare of the system, considering the bids and offers of market players and operating constraints of the grid like voltage regulation and transmission lines capacities. By solving this problem, scheduled power of generation units and retailers and Market Clearing Price (MCP) is determined. In an uncongested transmission grid, solving the social welfare maximization problem is equivalent to sorting the bids and offers in ascending and descending order for supply and demand, respectively, determining the intersection of the two curves as MCP, and accepting the bids of generating units that are lower than or equal to the MCP and offers of retailers that are higher than or equal to the MCP. This process is depicted in Figure 4 [23].

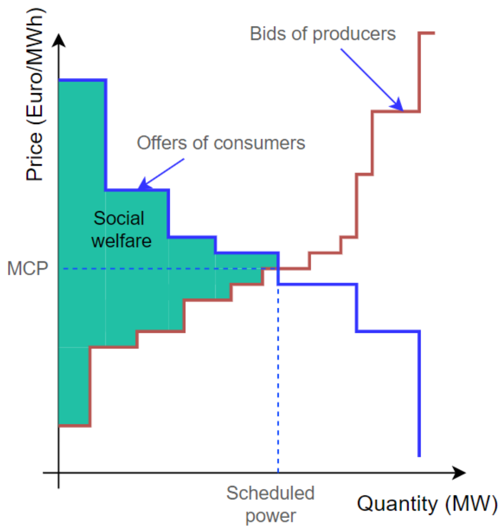

Figure 4. A simple representation of the day-ahead electricity market auction (source [23])

The execution times in different markets are different. In particular, in the NordPool day-ahead, the electricity market that is known as Elspot, at 10:00 CET the available capacities on interconnectors and in the grid are published. Buyers and sellers have to submit their final bids to NordPool for the auction for delivery hours the next day until 12:00 CET. Hourly clearing prices are typically announced to the market at 12:42 CET or later. Following the publication of the prices, the individual results are reported to each buyer and seller [24].

2.4.3 Intraday market

The intraday market starts after the day-ahead market closure. Intraday trading enables market players to adjust the bids made in the day-ahead market based on newly available information. For instance, an owner of a wind turbine will be able to forecast the turbine generation with great accuracy when the forecast refers to the next hour rather than the next day. Therefore, the intraday market offers an opportunity to adjust forecast errors as soon as better predictions are available. Similarly, a power plant operator can cope with the unforeseen shortage by buying additional power from other participants on the market and maintain the balancing group. Intraday trading is therefore a key component for direct marketing of power produced by renewable energies when quickly changing weather forecasts result in an unplanned shortfall or surplus of power from solar or wind power plants [25].

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The intraday market is a continuous market, with trading taking place every day around the clock until one hour before delivery. Prices are set based on a first come, first served principle, where best prices come first i.e., highest buy price, and lowest sell price [26].

2.4.4 Balancing market

Balancing market, also known as real-time market, is where ancillary services are procured by TSO or ISO. Ancillary services are defined as all grid support services required by the transmission or distribution system operator to maintain the integrity and stability of the transmission or distribution system as well as the power quality. These services are provided using market auctions, bilateral contracts or as a mandatory service by market players. Connected generators, controllable loads, and/or network devices can fulfil these needs [28]. Ancillary services are categorized into three main groups:

- Frequency control;
- Voltage control;
- System restoration.

These services are reviewed in the next subsections.

2.4.5 Frequency control ancillary services

Ancillary services for frequency control aim to ensure continuous balance between supply and demand. This service is mainly provided by the supply side of the power system. However, flexible loads and storage units can also contribute to keeping the grid balance, and their role will be increasingly important with the increasing level of intermittent and stochastic renewable generation, like wind and solar, and with the retirement of synchronous generators. According to Union for the Co-ordination of Transmission of Electricity (UCTE), ancillary services for frequency control refer to:

- Primary reserves;
- Secondary reserves;
- Tertiary reserves.

In order to provide frequency control ancillary services, market players can be paid for providing both capacity and energy. The capacity that is used for an ancillary service cannot be used for selling energy in day-ahead electricity markets [29].

2.4.5.1 Primary reserve

Primary reserves are used to respond to the frequency deviation in the system. Power Generator units with fast response ability to frequency deviation can be used as primary reserves. The maximum activation time for this reserve is 30 seconds. Usually, daily auctions are executed in the primary reserve market to determine the market players that provide this service, and market players are paid only on the basis of their available capacity for the primary reserves [29]. However, in some countries, primary reserve service is mandatory for generators and they are not paid for availability. In this situation, only the energy provided during the services is paid for.

2.4.5.2 Secondary reserve

Secondary reserves are activated after the primary reserves. The activation time of these reserves is between 30 seconds and 15 minutes. As shown in Figure 5, by activating the secondary reserves, the primary reserves are relieved to be used for future disturbances in the

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system. Secondary reserves are paid for both capacity and energy. The TSO provides these reserves mostly using monthly bilateral contracts with the producers [29].

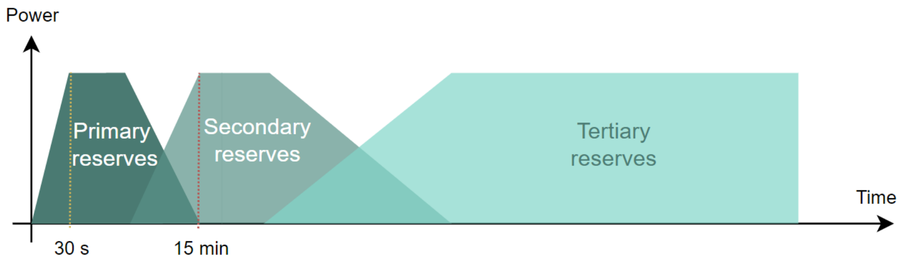

Figure 5. Comparing the activation time of the frequency control ancillary services

2.4.5.3 Tertiary reserve

Tertiary reserves, also known as manual reserves, are activated from 15 min to hours after initiating the disturbance [28]. By activating the tertiary reserve, the secondary reserve is deactivated as shown in Figure 5. Tertiary reserves are provided based on daily auctions in the balancing market. Market players are paid for providing both capacity and energy [29].

The gate closure of this market is typically in the range between one hour and minutes before actual energy delivery and it is a single-period market that take place just minutes before actual energy delivery. In order to procure this service, first all market players including producers and consumers submit their bids. The TSO or ISO sort all the bids as shown in Figure 6. Then based on the type of power imbalance in the system i.e., excess demand or generation, the market operator decides to use the bids of a group of market players until all power imbalance is covered.

The market price is determined using a uniform pricing mechanism. This means that the bid price of the last market player that wins power in this market is chosen as the balancing market price [27]. This fact is illustrated in Figure 6.

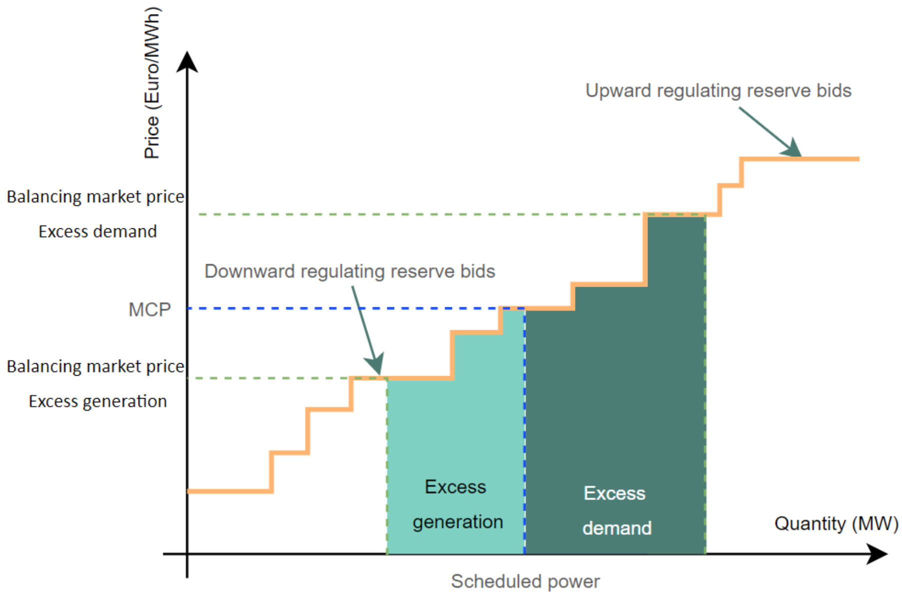

Figure 6. Balancing market operation description

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2.4.6 Voltage control

Ancillary services for voltage control can be classified into two main groups as follows [28]:

- **Steady-state reactive power/voltage control:** This control is commonly achieved by injecting or absorbing reactive power at a voltage-controlled node using synchronous sources, static compensation, tap changing transformers in the substations, transmission line switching, virtual power plants including demand facilities, and, if necessary, load shedding.
- **Fast reactive current injection:** This control can be provided by spinning generators and synchronous compensators, reactors and capacitors, static VAR compensators, high voltage direct current (HVDC) substations, and other flexible alternating current transmission system (FACTS) devices, or other equipment capable of fast regulation.

2.4.7 System restoration

Two services are considered under the term system restoration: Black start and Islanding operation [28].

2.4.7.1 Black start

Black start is defined as "a set of actions implemented after a disturbance with large-scale consequences to bring the system from emergency or blackout system state back to the normal state". The restoration process has several stages: re-energization from blackout, frequency management, and resynchronization. Black start capability is usually considered at plant design. In power systems, not all power stations have or are required to have this black start capability. Presently, wind and solar PV are not providing this service.

2.4.7.2 Islanding operation

Most current generators are not designed to perform in islanding conditions, i.e. separated from the main grid. This could be a future service from generators, especially connected to distribution networks. The ability of the islanded operation of distributed generation would improve the reliability of the grid.

DERs and end-user flexibility can be used in all above-mentioned energy and ancillary service markets. The main focus of ebalance-plus is to trade the flexibility of end-users and DERs for balancing services and congestion management. So, it seems among the existing markets, frequency related ancillary service markets are suitable places to utilize the flexibility of DERs and end-users. A hindrance might be that existing markets are mostly dealing with problems in the transmission system level, however, many of the challenges of the future power system will be related to the distribution grid level. In cases where existing markets cannot solve these issues new markets will be needed. This subject will be addressed in Section 2.6.

2.5 Reviewing the structure of electricity markets in ebalance-plus demo sites

As mentioned before, electricity markets can show differences across EU countries. In view of this, the present subsection provides a short description of the electricity markets in the countries with demo sites in the ebalance-plus project: Denmark, France, Italy and Spain. The

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main focus is on the roles and responsibilities of TSO and DSO in each country, the structure of wholesale and ancillary service markets, and demand-side response through aggregators.

2.5.1 Denmark

Main responsibilities of TSO and DSO are summarized in Table 1 [30].

TSO main responsibilities:	• Energinet is Denmark's TSO, i.e., the enterprise responsible for the operation of the transmission grid and the electricity system in Denmark. Energinet's core service is the security of supply; in other words, ensuring that the Danish population is supplied with electricity now and in the future. In practice this is done by ensuring the balance between consumption and generation in the electricity system around the clock, all year. • It is also Energinet's responsibility to set the framework for a well-functioning electricity market that ensures fair prices for both consumers and producers and promotes climate-friendly energy solutions.
DSO main responsibilities:	• Measuring the consumption and generation of electricity in their grid area. The task to collect, validate, send and receive meter data can be delegated to independent metering point administrators. • Paying the electricity taxes to SKAT (central Danish tax administration) of the amount of electricity consumed in the grid company's grid area. Electricity suppliers must pay the DSOs for transporting electricity to the customers. Danish Energy Regulatory Authority regulates the DSOs in order to ensure that the price they charge is proportionate to the costs associated with the operation of the network. • Operation of the network comprises tasks, such as the connection of new customers, specification of electricity consumption as well as development and maintenance of the physical plants. DSOs are also responsible for a number of ad hoc tasks, such as re-establishment of live cables that have been damaged and establishment of live cable at new plants.

Table 1. Main responsibilities of TSO and DSO in the Denmark national grid

Denmark is a member of the Nord Pool electricity market. Sixteen countries trade power in this market. The day-ahead and intraday markets in the Nord Pool are called ‘Elspot’ and ‘Elbas’. The structure of the markets and the amount of energy traded at each market are presented in Figure 7. As shown in Figure 7, about 97% of the total energy is traded in the day-ahead market and only 3% of energy is delivered through the intraday market. The intraday market is a single continuous market that closes one hour before the delivery period [31]. Denmark's power system is divided into two main areas, DK1 and DK2 which are connected by an HVDC link called the ‘great belt’. DK1 is synchronous with the grid of Continental Europe and DK2 is

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synchronous with Nordic. The frequency control ancillary services in DK1 and DK2 are reviewed in Table 2. By FCR-N we mean frequency containment reserve for normal operation and by FCR-D we mean frequency containment reserve for disturbance situations [32].

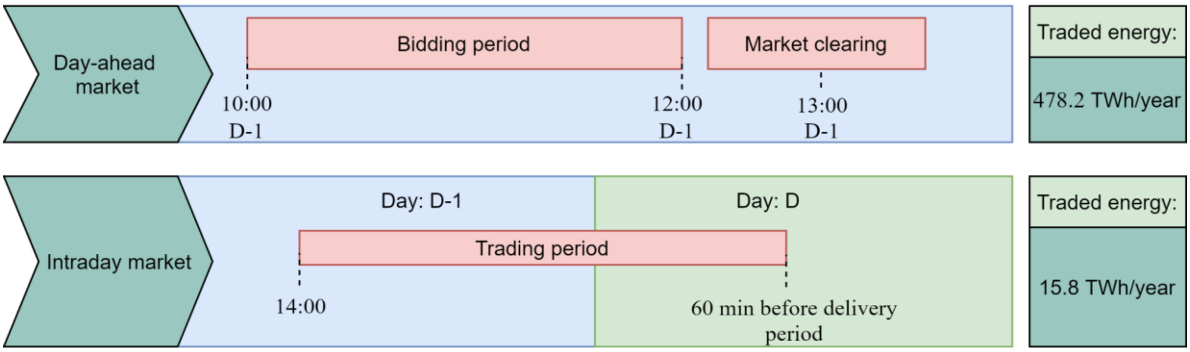

Figure 7. The day-ahead and intraday market structures in the Nord Pool electricity market

	Minimum size	Market size	Activation time	Access
Primary Reserve	0.3 MW	21 MW in DK1, 44 MW FCR-D in DK2 and 18 MW FCR-N in DK2	FCR-N: 2-3 min FCR-D: 30 sec	Daily auction
Secondary Reserve	1 MW	90 MW in DK1 and 20 MW in DK2	<15 min	Contracted with Norway
Tertiary Reserve	5 MW	684 MW in DK1 and 623 MW in DK2	>15 min	Daily auction

Table 2. The frequency control ancillary services in Denmark

To provide a suitable situation for the participation of private sectors in the ancillary service markets, minimum sizes for primary, secondary, and tertiary reserves are supposed to be reduced to 0.1, 0.5, and 1 MW, respectively [32]. Power generators are obligated to provide voltage regulation and reactive power ancillary services.

Aggregators are partially active in Denmark. In theory, demand response can enter the energy and ancillary services markets, but this is very limited due to little demand from the TSOs and DSOs. Low economic benefits for end users and regulatory issues like minimum bid size in reserve markets, online measurement capability, and symmetric bids also affect the participation of demand-side and aggregators in the markets. However, the aggregators are allowed to participate in the energy and ancillary service markets, but they should have bilateral agreements with consumers BRPs and retailers. At the moment, it is mostly the BRPs and retailers that provide the aggregation services [33].

2.5.2 France

In France, the role of TSO is carried out by Réseau de Transport d'Electricité (RTE). The distribution grid is mostly operated by Électricité Réseau Distribution France (ERDF) which now is known as Enedis. Main roles and responsibilities of the RTE and ERDF are described in Table 3 [34][35].

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TSO main responsibilities:	• RTE owns and operates the transmission grid. As the TSO, RTE is a public service operator in charge of operating, maintaining, and developing the high and extra-high voltage grid, as the concessionaire chosen by the government.; • RTE guarantees the reliability and the proper operation of the grid in a neutral, fair, and non-discriminatory way. It is also a member of European Network for Transmission System Operators for Electricity (ENTSO-E), the organization that coordinates the European TSOs; • RTE also controls the reliability of the electricity transmission system; • RTE has to cooperate with the neighbouring TSOs and is bound by obligations relating to cross-border interconnections. RTE must establish coordination and information exchange mechanisms to ensure the security of the grids in the case of congestion; • RTE must inform the participants to the markets involved in interconnections and solve any congestion issues using non-discriminatory methods; • RTE organizes exports or imports between France and its interconnected neighbours, and so contributes to the optimization of the electricity transmission systems;
DSO main responsibilities:	95% of the distribution grid is operated by Enedis. Enedis has two main responsibilities: 1. To operate and maintain electricity delivery on its network; 2. To guarantee non-discriminatory access to the public electricity network, meaning that whoever your energy supplier might be, you will benefit from the same service. Enedis's activity is essential for customers: 1. Enedis installs new electricity service for newly built homes; 2. Enedis takes care of technical interventions on electric meters: reactivations, deactivations, power modifications, change of rate option; 3. Enedis reads your meter: once or twice a year so that your supplier can adjust your monthly payments to your actual electricity consumption; 4. Enedis takes care of breakdowns on its network: response to power outages and downed lines on its network. The remaining 5% of distribution systems are owned and operated by the relevant local corporations and by companies belonging mainly to them.

Table 3. Main responsibilities of TSO and DSO in France

France is a member of the European Power Exchange (EPEX) spot market. Figure 8 shows the structure of day-ahead and intraday markets and the amount of energy traded at each market in France [36][37]. The general structure of the EPEX is similar to Nord Pool (see Figure 7),

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however, there are differences in details. The main difference is about closure time of the intraday market which lets the market players adjust their positions until 30 min before the delivery period.

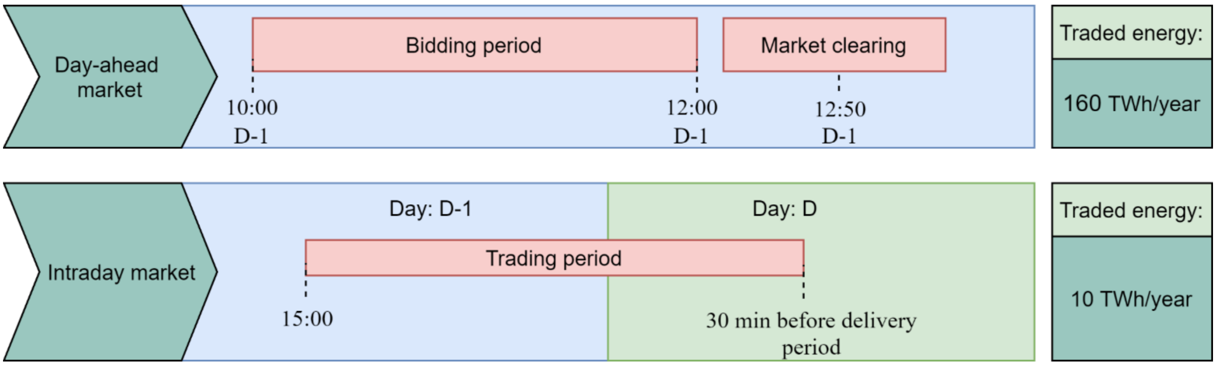

Figure 8. The day-ahead and intraday market structures in France.

Frequency control ancillary services in France are described in Table 4 [3]. Voltage and reactive power ancillary services are mandatory for generators.

	Minimum size	Market size	Activation time	Access
Primary Reserve	1 MW	600 MW	30 sec	Mandatory
Secondary Reserve	1MW	600 – 1000 MW	<400 sec	Mandatory for generators, market-based for demand-side
Tertiary Reserve	10 MW	1000 MW	<13 min	Auction

Table 4. The frequency control ancillary services in France

France is one of the leading countries in the participation of demand-side of the system in ancillary service markets. Industrial, commercial and residential consumers can offer their flexibility to the markets through the aggregators. Aggregators are allowed to bid into all markets without any pre-determined arrangements between aggregators and suppliers/BRPs [33].

2.5.3 Italy

The main roles and responsibilities of the TSO and DSO in the Italian national grid are listed in Table 5.

	The TSO is responsible for national electricity transmission management and development. It is responsible for planning, developing and maintaining the national transmission grid and managing the electricity flows that pass through it. It ensures that the supply of electricity released into the grid constantly matches demand in terms of power consumption. Dispatching refers to all its activities needed to maintain this balance 365 days a year, 24 hours a day. In addition to this, it designs and develops the grid following a ten-year development plan. It operates as a monopoly according to the rules defined by the Italian Regulatory Authority for Energy, Networks and

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TSO main responsibilities:	Environment (ARERA) and in the implementation of the guidelines of the Italian Ministry of Economic Development. It is the sole entity responsible for balancing the electricity system with the possibility to activate dispatching orders for each unit; the TSO is: • Central counterparty of the capacity markets • Central counterparty of the balancing market • Subject responsible for the real-time activation of the contracted capacity from the HV connected plants and from the plants connected to the distribution networks. The goals of the TSO are: • encourage the integration of renewable sources which are not programmable; • reduce grid congestion; • develop the critical zones; • improve the voltage profiles and the quality of the service; • development of the grid, potentiate interconnections with abroad, improving connections with the different market areas; • guarantee the safety of the electricity network and continuity of supply.
DSO main responsibilities:	The DSO is the operator of an energy distribution network. It is a public utility service entrusted by the State to market operators. Distribution system operators have a responsibility to offer high quality services to users through the development, use and maintenance of the efficiency and safety of energy distribution networks; it: • is the subject responsible for the safe management of the distribution network; • measures and monitors energy consumption through proper smart meters; • is responsible for the connection to the grid for new prosumer and consumers. • has no responsibility for the energy market, for dispatching or balancing services.

Table 5. Main responsibilities of TSO and DSO in the Italian national grid

In Italy, the day-ahead and intraday markets are known as Mercato del Giorno Prima (MGP) and Mercato Infragiornaliero (MI), respectively. The structure of these markets is presented in Figure 9. Market players can bid into the day-ahead market up to nine days before the power delivery period. The day-ahead market closure is at 12:00 of the day before the delivery period and the market is cleared at 12:55. The intraday market starts just after clearing the day-ahead market and is closed at 15:45 of the power delivery day. As shown in Figure 9, unlike the

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intraday markets in Denmark and France, the intraday market in Italy is divided into seven sessions: MI1, MI2, MI3, MI3, MI4, MI5, MI6, MI7 [38]. About 90% of the power is traded in the day-ahead market and the rest is exchanged in the intraday market.
Table 6 reviews the properties of the frequency-related ancillary services in Italy. Providing primary reserve service is mandatory for each unit that participates in the electricity market. Secondary and tertiary services are procured through auctions [39].
Total power transactions in the ancillary service market are about 11% of the total traded power in wholesale markets.

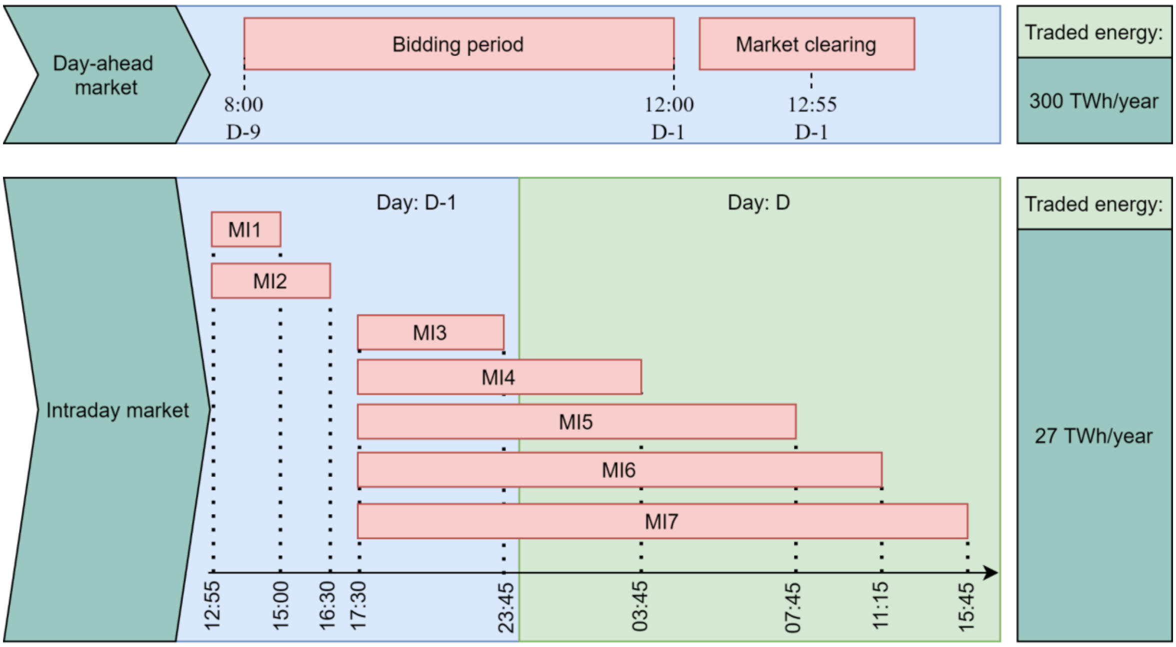

Figure 9. The day-ahead and intraday market structures in Italy

	Minimum size	Market size	Activation time	Access
Primary Reserve	±1.5% of nominal power	±1.5% of the total installed capacity	Auto reaction	Mandatory for each unit
Secondary Reserve	Hydro units: ±15% PMAX Thermal units: Max (±10 MW, ±6% PMAX)	568.41 MW	Max 180 s	Auction
Tertiary Reserve	10 MW	3713.62 MW	Spinning tertiary control reserve: 15 min Replacement tertiary control reserve:120 min	Auction

Table 6. Frequency-related ancillary services in Italy

The participation of aggregators in the energy market is evolving, but it is not final. There are several pilot projects. Recently, Italy too, through the introduction of Resolution 300/2017 by ARERA, has launched a series of pilot projects with Terna to allow distributed generation to participate in the dispatching services market. The enabled virtual units and the new nodal figure of the aggregator were therefore introduced, as an enabler of the participation of non-

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relevant units in the dispatching services market. Aggregators can also operate in the balancing market.

2.5.4 Spain

TSO in Spain is called the Red Eléctrica de España. The main roles and responsibilities of the TSO and DSO in the Spainish national grid are presented in Table 7.

TSO main responsibilities:	• Operation of the electricity system • Electrical planning • Grid Management and transmission agent • Island grid management • Real-time demand-generation control • Control of International Exchanges • Exchanges of measures and objections
DSO main responsibilities:	• Planning and maintenance of distribution grids (MV/LV) • Control of distribution grid • Billing energy distribution costs to energy retailers • Investments and settlements in distribution grids

Table 7. Main responsibilities of TSO and DSO in the Spanish national grid

The Day-ahead and intraday markets are known as ‘Mercado diario’ and ‘Mercado intradiario’, respectively. These two markets are operated by OMIE, the market operator for the Iberian region (Spain and Portugal) and their structures are presented in Figure 10 [40][41].
As shown in Figure 10, the bids in the day-ahead market are submitted one day before the delivery period and the market is settled at 12 p.m. The intraday auction market is currently structured into six sessions with programming horizons for each session. In Spain, there is also an intraday continuous market. Like the intraday auction market, the intraday continuous market, also called single intraday coupling, gives market agents the chance to manage their energy imbalances with two fundamental differences with regard to the auction [40]:

- In addition to gaining access to market liquidity at the local level, agents can benefit from the liquidity available in markets in other areas of Europe, given that cross-border transportation capacity is available between the zones.
- The adjustment can be made up to one hour before the moment of delivery.

The frequency control ancillary services in Spain are reviewed in Table 8. The primary reserve is procured under the ENTSO-E regulations and is mandatory for power producers. This means that there is no market for procuring ancillary service and each power producer should keep a specific capacity free and respond to frequency deviations automatically. Secondary and tertiary reserve services are allocated by market mechanisms using the economic merit order method. Voltage control ancillary service is mandatory for all power generators with output power greater than 30 MW.

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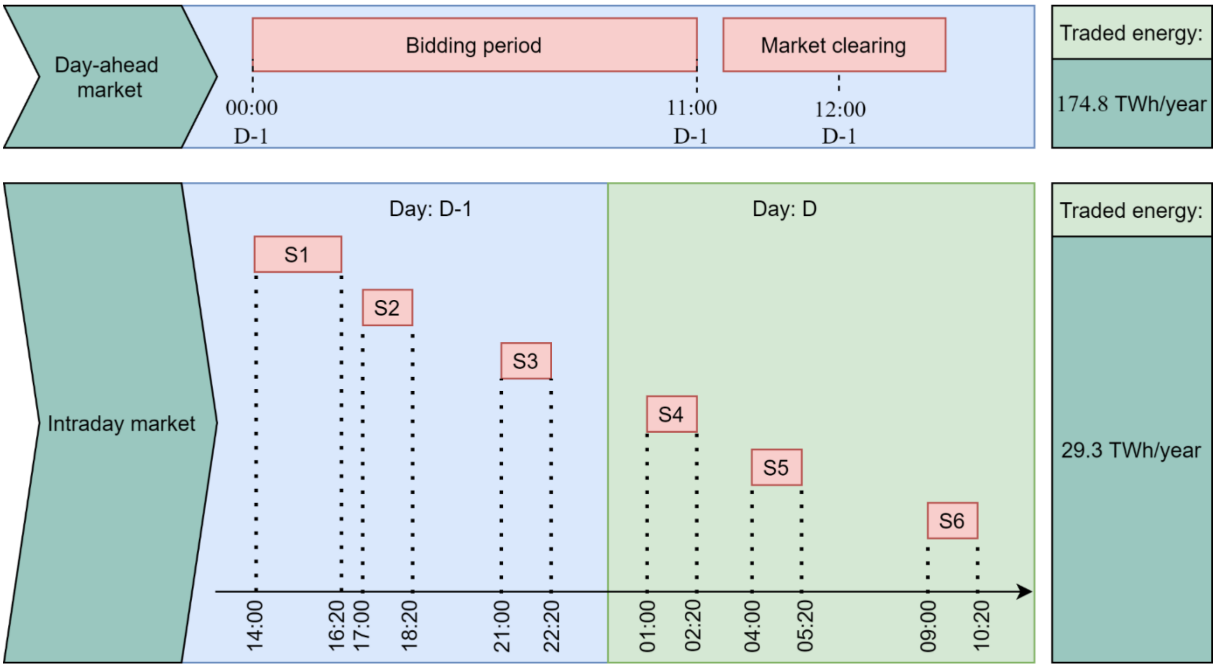

Figure 10. The day-ahead and intraday market structures in Spain

	Minimum size	Market size	Activation time	Access
Primary Reserve	1.5% of nominal power	1.5% of the total installed capacity	15 sec if < 1500 MW 15-30 sec if > 1500 MW	Mandatory
Secondary Reserve	10 MW	2.559 GW	100 sec-15 min	Auction
Tertiary Reserve	5 MW	4.753 GW	15 min-2 h	Auction

Table 8. The frequency control ancillary services in Spain

The aggregator role is relatively new in the Spanish market and it is still under discussion. The Royal Decree 23/2020 mentions this figure seven times as 'independent aggregator', but the role and regulations are not present. Currently, ENTRA is the Spanish association that is promoting and discussing the legal role of this figure in the Spanish Electric Market.

2.6 Flexibility market

In the previous section, different markets for trading energy and ancillary services were reviewed. This section will discuss why a new flexibility market is required in the power system. To this end, at first, the necessity of designing a new flexibility market is explained. Then, the types and applications of this market are reviewed, and finally, challenges and possible solutions for implementing a flexibility market are discussed.
In terms of definition, trading flexibility means paying market players to change or shift their pattern of energy production or consumption for a given period of time [42]. In general, all kinds of active grid users like consumers, producers, and storage are possible flexibility providers. In the concept of a flexibility market, the focus is on procuring the flexibility through DERs and end-users in the distribution grid [43].

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2.6.1 The necessity for providing flexibility from DERs and implementing a flexibility market

Nowadays, power grid flexibility is mainly provided by the supply side, by using conventional thermal power plants [44]. However, different factors are motivating power system regulators to design mechanisms for procuring the flexibility from DERs.
For instance:

- The electricity demand is constantly growing and this can lead to issues like voltage regulation and congestion at the distribution grid level. To cope with this increasing demand and its related issues, installing new power generation capacities and investing in grid expansion plans can be very expensive. In the e-Directive of the Clean Energy Package, it is proposed that DSOs shall procure services in a market-based manner to exploit the flexibility of different resources such as distributed generation, demand response, or storage and use it as an important tool to reduce future grid expansion costs;

- The share of renewable energy resources in producing electric energy is increasing. This reduces the amount of spinning reserves since conventional thermal power plants are either forced to be turned off or to retire. As a consequence, the overall power system flexibility decreases, thus stressing the need for new flexibility resources;

- Increasing the installed capacity of renewable energy resources also increases the uncertainty in the system due to their intermittent output power. This leads to an increase in the required flexibility in the power system that could be provided by the distribution grid [43].

The previous points outline that flexibility from DER will play a key role in the balancing and management of future power systems. Now the question is why a new ancillary service market called ‘flexibility market’ is needed when the flexibility of DERs and end-users can also be traded in the existing ancillary service markets.
Distribution grids may be confronted with congestion or voltage regulation issues. Traditionally, DSO coped with grid congestion and voltage violations by upgrading grid infrastructure, e.g. installing new lines. This imposes costs to DSOs. Using a market for trading flexibility of DERs and end-users at the distribution grid level can help the DSOs to use market mechanisms for solving the grid issues instead of investing in grid expansion.
Existing ancillary markets are operated by the TSOs to ensure voltage and frequency control and system stability at the transmission level. On the contrary, DSOs are mainly interested in solving local grid congestion and voltage violations. So, a new market is required to provide the DSOs a marketplace for procuring resources needed to solve issues in distribution grids.
Another point is that in existing ancillary markets the TSO is the only buyer of flexibility while in flexibility markets the flexibility can also be traded among the market players.
All these reasons have led to introducing the concept of flexibility markets. In Europe, flexibility markets have been introduced as a tool to make better use of DER resources and end-users to support grid operation. Different entities like Council of European Energy Regulators (CEER), the ENTSO-E, and the major associations for European DSOs have emphasized the need for a market-based procurement of flexibility from flexibility resources in distribution grids [45].

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2.6.2 Different viewpoints for using the flexibility in the system

Flexibility can be used in three different ways [44]:

- **Market-based trading:** For portfolio optimization of supply and demand before the settlement date. In this use, market players benefit from trading flexibility to maximize their profit;
- **System-oriented:** Balancing on settlement date (not regional restricted). In this case, flexibility is used for keeping the balance between power generation and consumption in the system;
- **Grid-oriented:** To avoid local grid congestions (localized) on settlement date. In this use, flexibility enables DSOs to allocate available flexibility of active grid users to comply with local grid-related restrictions. Thereby flexibility becomes an economical option to defer or even substitute grid expansion. A basic requirement for cost-efficient use of flexibility, to substitute such grid expansions, is long-term availability for a grid-oriented use of flexibility. Also, flexibility has to be calculable and predictable, if grid expansion should be reduced.

ebalance-plus aims to cover all above-mentioned three viewpoints. The flexibility of end-users and DERs is supposed to be procured using market mechanisms that incentivizes all market players (market-based trading), and the procured flexibility is going to be used for power system stability (system-oriented) and congestion management in the grids (grid-oriented).

2.6.3 Central and local flexibility markets

The ancillary markets for frequency control, such as primary and secondary reserve markets and regulating power markets, are flexibility markets. Since these markets are controlled centrally by the TSO they are classified as central flexibility markets. However, there are some issues about these markets that make clear the need to implement local flexibility markets. Actual market regulation is one of the main barriers to market access for DER. For instance, high minimum bid sizes, necessity to submit symmetrical bids, or the duration of providing the flexibility represent entry barriers for most of the available demand-side resources. So, market players in these markets are mostly the large-scale power plants or in some cases market players from the demand side like aggregators with sufficient flexibility capacity or large industrial consumers. Additionally, in ancillary markets, flexibility is only traded between the TSO and the authorized market players. The latter are not able to trade flexibility among themselves.
Another point is that even if the possibility of including DERs and end-users in the central flexibility market is provided, this could provide issues for the distribution grid operation. Since the TSO is not responsible for the stable and secure operation of the distribution grid, trading flexibility by DERs and end-users directly or indirectly via aggregators may cause issues like grid congestion for the distribution grid. So, there should be a structure that provides the possibility of trading flexibility of the DERs and end-users under the supervision of the DSOs. This leads to the introduction of the concept of Local Flexibility Markets (LFM). In this case, the entire distribution grid is divided into several LFMs which are operated by the DSO or a local market operator (LMO). These LFMs can be considered as the market-based mechanism solutions for procuring the flexibility of end-users and DERs in the ebalance-plus project. The main benefits of the LFMs are listed below:

- **Stable and secure operation of the distribution grid:** Running LFMs under the supervision of the DSOs provides opportunities for the DSOs to consider operation

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constraints like distribution line capacities and voltage regulation limits in the flexibility transactions and provide a more stable situation for the operation of the distribution grids;

- **Trading small volumes of flexibility in a marketplace:** bidding flexibility into the market places under the supervision of the TSO requires pre-qualifications that not all the aggregator are able to meet. LFMs provide a marketplace for the participation of all aggregators on behalf of their consumers. This releases more flexibility in the power system;
- **Regulating the net position of the local area:** The net position is defined as the total production minus the total consumption of the distribution grid area at a given time. LFMs can be used by the DSO to regulate the net position of the area of the DSO. This reduces the need for external energy resources and could also be used for managing the congestion for the lines that connect the distribution grid to the transmission grid;
- **Reduction of overall energy losses:** Reducing the need for injecting power from the transmission grid reduces the loading of the transmission system lines and consequently leads to a reduction in total losses of the system. However, this is not the case in all situations and might lead to different results in different cases;
- **Contributing to energy efficiency:** Advance metering infrastructure needed to enable end users to participate in LFM can also be used to increase end users' awareness of their energy habits and promote the adoption of energy efficiency measures.

2.6.4 Challenges and possible solutions for implementing LFMs

Different structures can be proposed for LFMs in ebalance-plus. Analysing the challenges that LFM will be faced with is very important for a successful implementation. The latter is described in the following paragraphs.

2.6.4.1 Financial incentives for participation of end-users in flexibility trading

Changing the amount of energy consumption or shifting the energy use to a different time or different energy carrier implies a cost. This cost can be a reduction in comfort or the cost caused by deviating the asset operation point from the optimally scheduled point based on other variables like electricity spot prices. These costs should be identified and the LFM should provide an environment to compensate for them [42]. Different classes of incentives can be proposed to encourage the DERs and end-users to participate in the LFM such as:

- **A DSO or a LMO as a buyer of local flexibility:** In this case, the DERs and end-users are being paid as long as they provide flexibility to the grid. The source of this payment comes from consumers or the monetary saving caused by grid flexibility instead of investing in grid expansion.
- **DSO as an intermediary for trading flexibility with other marketplaces:** In this case, part of the money that is going to be paid to DERs and end-users comes from trading the available flexibility on other market places at TSO level like the regulating power market considering the distribution grid constraints and keeping it in stable condition. DERs and end-user consumers receive TSO level marketplace prices for proving flexibility.
- **Trading flexibility with other market players:** Instead of buying the flexibility from DERs and end-users directly, the DSO can provide a marketplace in which different DERs and end-users can trade their flexibility over specific time scales like hourly time intervals while the distribution grid constraints are also considered in the flexibility transactions.

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It should be noted that in this subsection the focus is only on the resources for providing the financial incentives for LFM players and the details about the structure of LFM, sequence of actions, and flexibility estimation are not the subject of this subsection. However, all these issues should be considered in the design and implementation step of the LFM.

2.6.4.2 The complexities of trading in the LFM

Participating in LFMs needs understanding of some requirements such as being familiar with the structure of the LFM, rules, and regulations, the ability to estimate the available flexibility, and being an expert in bidding strategies in the markets. Obviously, most end-users are not qualified in these aspects and these complexities will create challenges for them to participate in the LFM market.

In order to solve this issue, intermediaries like aggregators can participate in the LFM market on behalf of the DERs and end-users. The aggregators group all their contracted DERs and end-users, estimate their total flexibility, and bid into LFM or any other markets that allow them to trade the flexibility.

2.6.4.3 Evolution of the DSO's role

Today, DSOs are mainly responsible for maintaining the distribution grid in resilient, stable and secure conditions, and providing fair access to the distribution grid and enough capacity for supplying the end-users. However, to implement the LFM, the regulatory framework of DSOs' responsibilities in the distribution grid should be changed. This fact is widely recognized in different researches and reports. One of the recognitions of this trend is the article concerning the use of flexibility by the DSO included in the proposal for a directive of the European Commission regarding common rules in the internal electricity market. It declares the need for a change that "allows and incentivizes DSOs to procure services to improve efficiencies in the operation and development of the distribution system, including local congestion management". Furthermore, it indicates that DSOs "shall procure these services according to transparent, non-discriminatory, and market-based procedures" [43]. This market-based mechanism has two aims: in the short-term, it is a tool for DSO to manage local problems by exploiting flexibility from the distribution level; in the long-term, the aim is to defer or avoid grid investments on additional transfer capacity. Executing these LFMs can be performed directly by the DSOs or by defining new entities in the distribution grids like LMOs under the supervision of DSOs [42]. Alongside changing the role of DSO, the ICT infrastructures of the distribution grid should also be developed for providing a proper environment to enable data exchange and automatic control between involved parties.

2.6.4.4 Conflict of interests between different market players' operations

End-users or DERs should have a contract with retailers or BRPs to buy their required energy and also a contract with aggregators to provide flexibility for central and local flexibility markets. This might bring about economic conflicts between retailers/BRPs and aggregators as illustrated in Figure 11. Retailers must follow the generation schedule resulting from the day-ahead market, otherwise, they incur penalties for imbalances. At the same time, an aggregator may ask its customers to modulate their energy consumption/generation to provide flexibility to the grid. This would produce an imbalance to the retailers of its customers. Therefore, while the aggregator benefits from trading flexibility the retailer or BRP may confront additional costs due to the power imbalance caused by the aggregator. It should be noted that the aggregators' operation may also benefit the retailers or BRPs in the case that the imbalance caused by the aggregator reduces the net imbalance of the retailer or BRP portfolio. To solve the problem of conflict between the operation of aggregators and retailers or BRPs, in some countries like

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Germany, the aggregators are obligated to have agreements with the energy suppliers before engaging with the related customers.

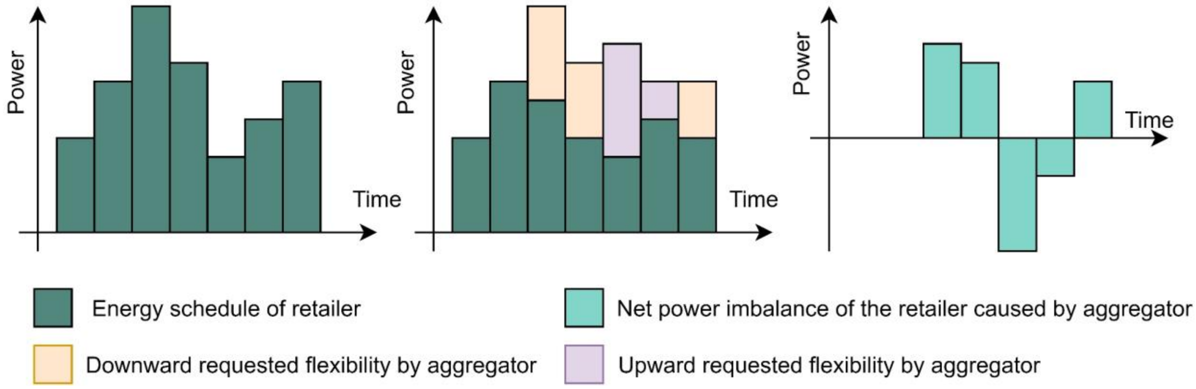

Figure 11. Graphical representation of contradiction between the retailers/BRPs and aggregators

2.6.4.5 TSO-DSO coordination

In the case of implementing LFMs, both TSO and DSO will have markets for trading the flexibility and market players like aggregators are allowed to participate in both markets. In this situation, bidding in the markets under the supervision of TSO and winning flexibility services by the aggregator may lead to congestion of voltage regulation violation in the distribution grid and vice versa. So, there should be coordination between the operation of TSO and DSOs such that the requirements of both sides for the stable and secure operation of transmission and distribution grids are satisfied.

Different approaches are proposed in the literature for coordinating the operation of TSO and DSO in providing ancillary services. One of the well-known approaches is providing a single joint TSO-DSO ancillary service market. This approach reduces the number of different bidding processes for procuring ancillary services and limits the possibility of arbitrage between different market platforms [46]. It is demonstrated that the joint procurement of ancillary services can also lead to greater total system benefits compared to separate procurement [47]. However, implementation of this market results in an overwhelming burden being carried by only one central system operator. Moreover, TSO and DSO have extremely different needs, and aggregating them into a single market with equivalent goals and objectives can be challenging. Another approach for coordinating TSO and DSOs is a decentralizing approach in which several local ancillary service markets are operated by the DSOs and are coordinated with a traditional central ancillary service market that is operated by the TSO. In this case, the computational burden is shared among different markets. However, data exchange and coordination are needed between DSO and TSO to ensure that the constraints of both transmission and distribution networks are not violated while running different market platforms [48][49].

2.6.4.6 Social acceptance of demand response programs

The flexibility market concept is based on adapting end-users' loads to the flexibility needs in the grid. While most discussions in this field are concentrated on the technical aspects of procuring flexibility from end-users, end-users' perspective on LFM is not taken into account. Flexibility market designers should pay attention to how end-users see and react to different pricing structures and direct control of their appliances. Comparing what end-users earn from their flexibility and the comfort they lose may discourage them from being flexibility market players. Noises from appliances activity at low price hours especially late at night could cause conflicts with household members and neighbors. It is difficult for some families with small

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children to curtail the laundry activity during on-peak and mid-peak periods [50]. In [51], it is shown that 53% of respondents do not switch electricity usage to night time because of comfort reasons. Shifting the electricity consumption of cooking and entertainment is not accepted by most families. Households with elderly or sick residents found increasing or decreasing the buildings' temperature difficult. It has also been established that the ability of end-users in providing flexibility varies in different seasons of the year [50].
End-users also have some concerns about their privacy and the performance of control systems. Some studies have highlighted that end-users are worried about the data privacy of smart meters [52][53]. In another study on direct control of heating systems, 45% of respondents have concerns about the control systems functioning in the agreed manner and 30% of respondents are worried about dropping the temperature of rooms and water [54].
Considering the above-mentioned examples it is clear that the knowledge, concerns, habits, and behaviours of consumers impact the possible flexibility that can be provided by the demand side of the power system. So, before implementing a plan for the flexibility market, social acceptance studies should be performed to be sure about the success of the designed market in the implementation step.

2.6.5 Examples of implementing flexibility markets

In this section, some of the current projects in the field of flexibility markets are reviewed which are also closely related to some of the ebalance-plus objectives. This will give us a vision about the current structures of flexibility markets and how they work.

2.6.5.1 Positive City ExChange (+CityxChange)

+CityxChange is a smart city project that has been funded by the European Union's Horizon 2020 research and innovation program in the call for 'Smart cities and communities'. The Norwegian University of Science and Technology (NTNU) is the host and leads the +CityxChange consortium together with the Lighthouse Cities Trondheim and Limerick [49]. In the project, the flexibility market is one of the main topics. It is proposed to use LFMs in distribution grids to trade the flexibility. The main objective for trading flexibility in LFM is providing a useful tool for DSOs to solve distribution grid issues like congestion. The high-level overview of the proposed LFM is shown in Figure 12, however, different implementation methods can be applied.

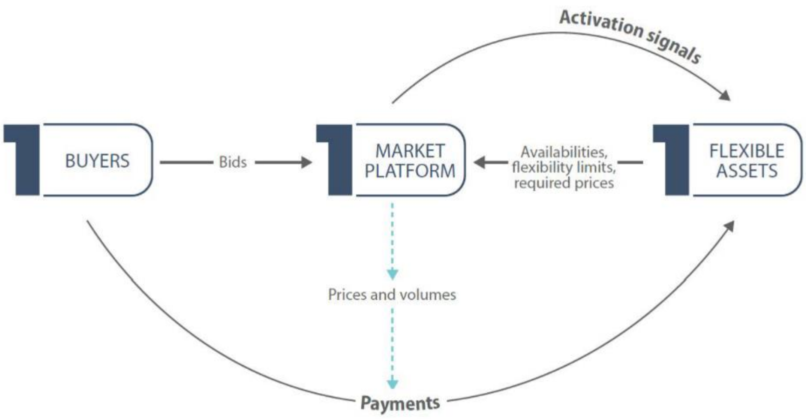

Figure 12. High-level overview of LFMs [42]

To implement this model, the role of DSO should be evolved to that of a market operator or new entities like LMO or distribution network operator (DNO) should be defined to run and supervise this market platform.

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2.6.5.1.1 Flexibility trading pathways

According to Figure 13, prosumers can offer the flexibility of their assets in several ways:

1. Through intermediaries like aggregators or energy service companies;
2. Directly to "local needs" (meaning typically the DNO/DSO or other market participants);
3. Directly to external markets (e.g. an aggregator serving BRPs and/or the TSO);
4. Or to these final (local and external) buyers via a local market platform.

The purple lines in Figure 13 illustrate the trade that goes through the local market platform. These are the main focus of this report.

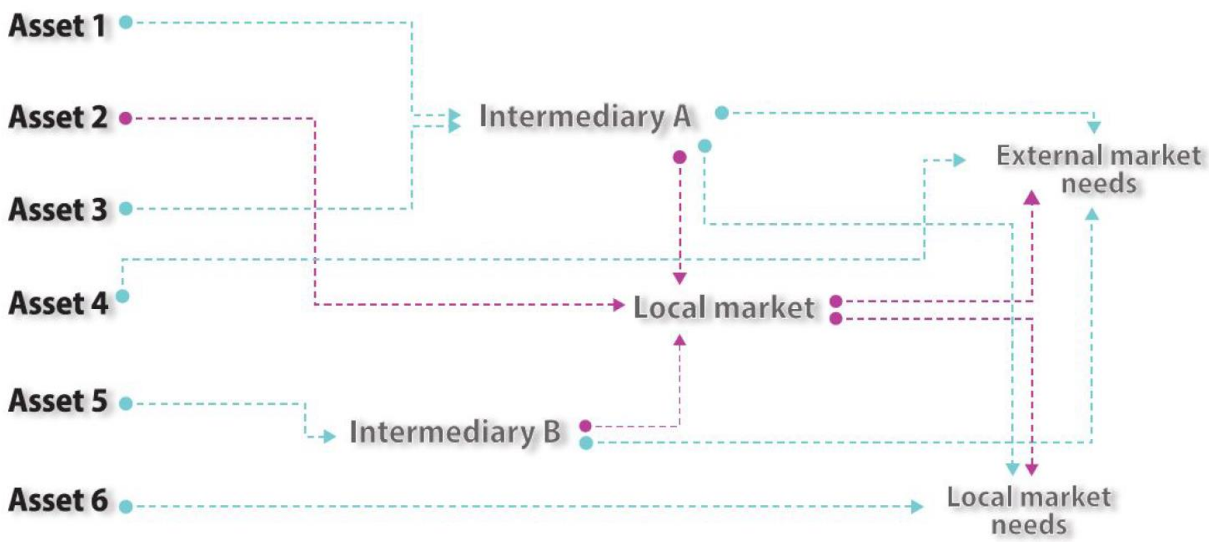

Figure 13. Different pathways for flexibility in a local market area [42]

2.6.5.1.2 Flexibility providers' involvement methods in the LFM

The three options below are proposed for flexibility providers to trade flexibility into the LFM [42]:

- **Unpriced contracts**: In this method, a consumer sets limits for a flexible asset and offers it as available to the local marketplace or an intermediary with the hope of minimizing his or her energy bill, but with no upfront or agreed payment. So, the flexibility providers do not know their revenue from providing this flexibility. By increasing the experience of participating in the market and receiving feedback, consumers will learn how much their flexibility is worth.
- **Reservation pricing:** In this method, consumers provide flexibility based on their agreed process with an intermediary, SDO, or LMO. Flexibility providers are only being paid according to keeping the flexibility capacity available and are not being paid according to the activation of their assets.
- **Activation pricing:** Here, flexibility providers or intermediaries submit detailed prices for their available flexibility at different times. These bids can be expressed as a price per kWh of reduction or increase in their net position at a given time. The activation pricing method

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is more complicated than unpriced contracts and reservation pricing methods. In the case that flexibility providers have contracts with aggregators, the contract between flexibility providers and aggregators can be in the form of unpriced contracts or reservation pricing. Then the aggregators can participate in the LFM using the activation pricing method.

2.6.5.1.3 Proposed price-setting mechanisms for the LFM

Three options are proposed for price-setting mechanisms to be tested in +CityxChange which are reviewed as below [42]:

- **Local energy market mechanisms:** In this method, the market operator applies market mechanisms to manage the net position of its area. In more detail, if the LFM needs to absorb the excess power generation, the market operator pays the market price for extra power generation and then considers a discount for the electricity consumption price to encourage the consumer to consume more power. Similarly, if the LFM needs to absorb the excess power consumption, the market operator charges the consumers with prices greater than the market price to force them to reduce their power consumption. If the imbalance is not settled in this mechanism, the rest of the imbalance is traded by the outside of the distribution grid.
- **Flexibility trading between LFM participants:** Here, market players trade some 'quotas' in the LFM to have permission for surplus power generation or consumption. For instance, a producer is not allowed to have extra power generation more than a specific limit compared to the scheduled values. If producers need to produce more power than their limits, they have to buy "production quotas" in the LFM to temporarily raise their individual limits. Each production quota could be equivalent to 1 kWh energy production. Other market players sell these quotas. Any market player that has 1 kWh excess power consumption can sell a production quota to the producers. If the number of available quotas is equal to or greater than the request for quotas the prices of these quotas are equal to zeros. In case the request for quotas is more than the available amount of quotas, some market players should increase their consumption to provide these quotas. Increasing consumption means deviating from the optimal operating point and hence imposes costs. Market players bid prices for their available quotas based on the cost imposed on them for changing their power consumption profile. The bids with the lowest prices will be accepted by the market players that need these quotas.
- **The DSO or LMO as a buyer of flexibility:** In this method, DSO or LMO can buy the flexibility with 1) only reservation pricing or 2) both reservation and activation pricing. In the first option, the buyer buys long-term, reservation-price based flexibility from LFM participants through auctions. These auctions could be yearly auctions. Using only reservation pricing may be less complicated compared with the second option, it may be easier to establish as a complement to the existing market infrastructure and mitigates the risk of extreme activation prices. However, the consumers might be placed at risk of shifting their demand to high price hours by the flexibility buyers and this may reduce their incentive for participating in this market. In the second option, market players submit price and power bids for providing the flexibility in the LFM. Then according to the required flexibility, the DSO or LMO determines the bids that are accepted. The uniform pricing mechanism is used

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to determine the price of scheduled flexibilities and is obtained by intercepting the flexibility supply curve of flexibility providers and DSO or LMO flexibility demand curve. A simple illustration of the price formation process is shown in Figure 14.

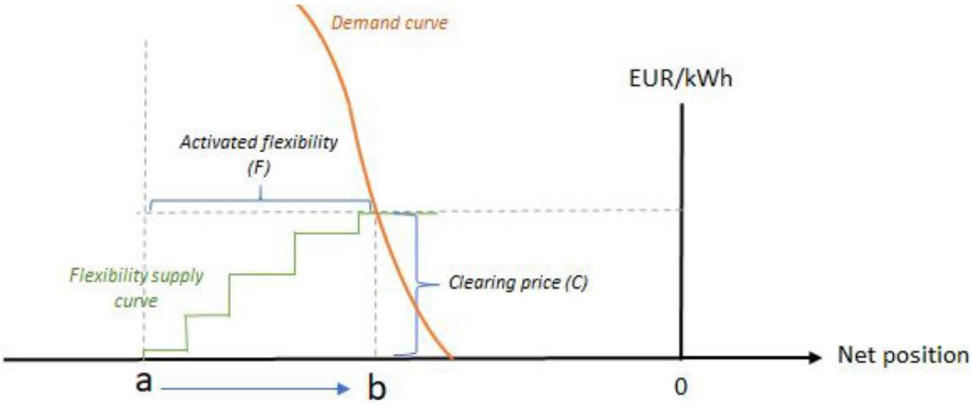

Figure 14. Example of a market cross where the buyer is willing to pay to shift the LFM's negative net position from point a to point b [42]

2.6.5.1.4 Proposed structures for LFM

In this section, three proposed structures in the report for designing LFMs are reviewed [42].

- **DSO-operated LFMs:** In this method, the DSO holds both the system operator and market operator roles as depicted in Figure 15. The DSO buys flexibility from the LFM participants and signs contracts with flexibility providers. The DSO could introduce incentives for internal trading in the LFM and should be coordinated with "external" flexibility requests from the TSO, BRPs, or aggregators.

Figure 15. DSO-operated LFM model [42]

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- **Market operation by an LMO:** In this model, a third party called the LMO is responsible for running the LFM and the DSO is the buyer of system services. Moreover, in many cases, the role of being a prosumer contract counterparty could be more naturally held by an intermediary like an aggregator or an energy service company. The LMO could also sign flexibility contracts directly with asset owners, without an intermediary. This market model is illustrated in Figure 16.

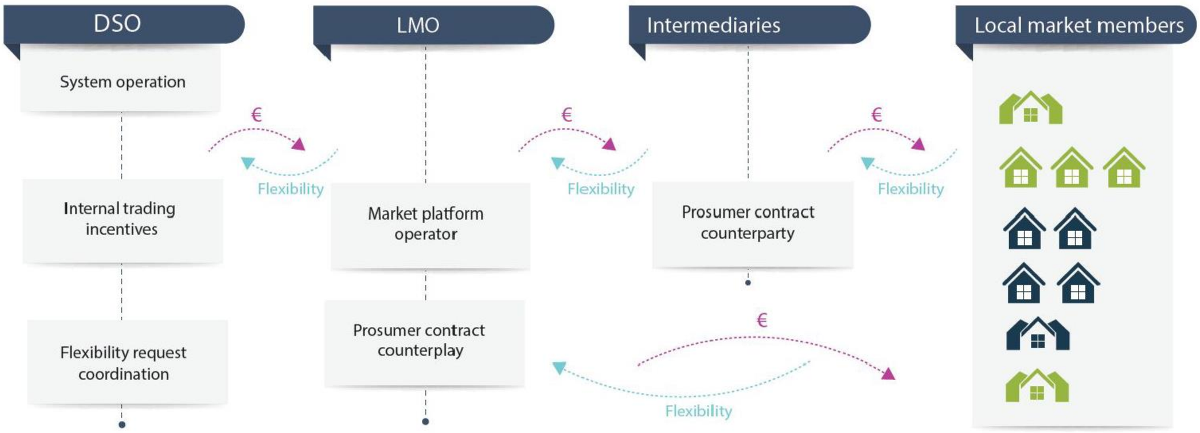

Figure 16. Graphical representation of the LFM model operated by the LMO [42]

2.6.5.2 NODES

NODES is an independent marketplace for a sustainable energy future where grid owners, producers, and consumers can trade decentralized flexibility and energy [55]. The platform is now installed in two locations in Norway and Germany [56]. The main goal of the NODES project is to increase value for flexibility providers in the distribution grid, help DSOs by providing a new tool for grid management, reduce costs for the DSO, and also allow flexibility that is not used locally to be sold to the TSO and/or BRPs at the transmission grid to solve imbalance issues there. The proposed structure for this market is illustrated in Figure 17.

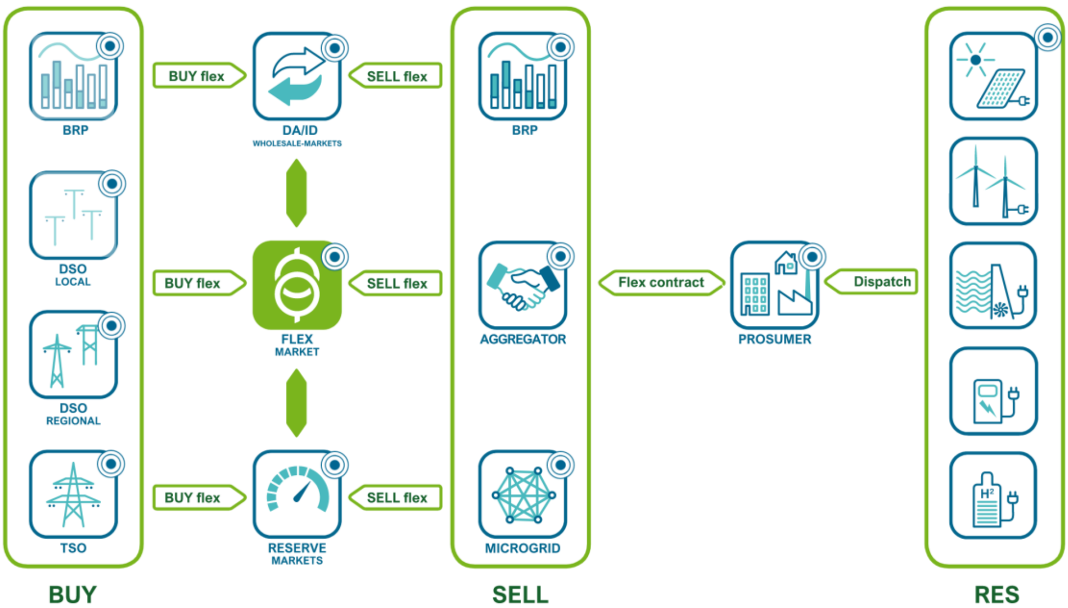

Figure 17. Market design for NODES project [44]

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As can be seen in Figure 17, in this structure, the flexibility market is operated alongside the day-ahead, intraday, and reserve markets. Moreover, the flexibility market is not operated by the DSO or TSO and is an independent entity.

The NODES marketplace is prepared for this development. The main shortcoming with the current market design is the lack of market-based flexibility that DSOs can use in their grid management. The day-ahead, intraday, and reserve market cannot be used for managing the distribution grid because the bids in these markets are not location-dependent. In the proposed flexibility market, the flexibility assets are tagged with their location and the DSO and TSO can exploit this information to use the flexibility of specific flexibility providers to manage the grid. The integrated market model in the NODES project is depicted in Figure 18.

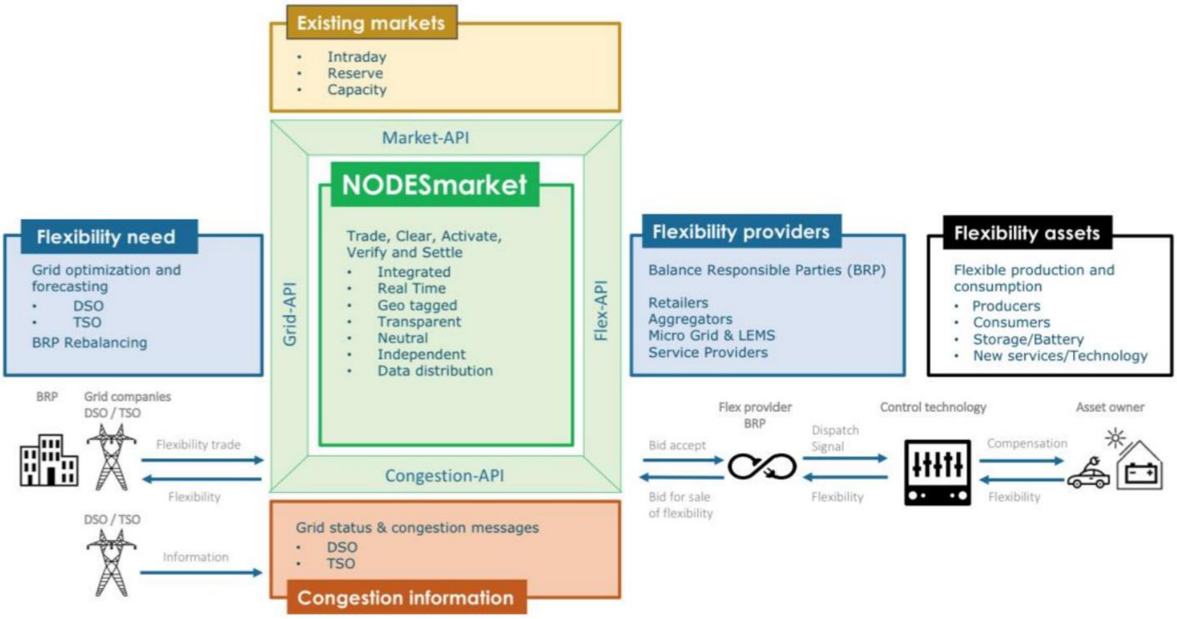

Figure 18. The integrated market model for NODES project [51]

On the right side of Figure 18, we have the flexibility assets and flexibility providers. Each prosumer has a contract with an intermediary that could be BRP, aggregator, or a micro-grid. Then the available flexibility of prosumers can be traded in the existing markets i.e., day-ahead, intraday, or reserve markets, and NODES flexibility market. This flexibility can be used for both congestion management in transmission and distribution grids and balancing the power system. The flexibility providers can differentiate their offers depending on whether the flexibility assets are sold locally or centrally. Selling locally at one specific grid location in many cases can be riskier, as there are fewer alternatives if the seller needs to rebalance due to the unforeseen unavailability of some assets. Contractual positions in the intraday market are much easier to rebalance. Thus, the price for flexibility is foreseen to be cheaper in the intraday market than at a specific grid location [56].
To the left in the figure above are those who need flexibility: DSO and TSO. In addition, BRPs might re-trade committed flexibility with other BRPs which offer cheaper flexibility. These buyers will have to define their willingness to pay for the activation of flexibility at particular grid locations and feed this information continuously into NODES via an API. The flexibility is made available by the flexibility providers who will act on behalf of the owners of the flexibility assets and feed these offers into NODES via another API. The flexibility providers will need to have a business model with the asset owners in place, and technology that makes

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it possible to activate the flexibility by those who have bought it. For the majority of operating hours during a year, the flexibility is not needed locally at the actual grid location – often it is needed for only a few hundred hours a year. But it can still have a value in the rest of the system, for balancing purposes by the TSO or in the intraday market for the BRPs. NODES will establish an interface that makes the flexibility available for these markets [56].
By utilizing NODES market information about local bottlenecks at DSO level, TSOs and DSOs can coordinate activation of flexible assets via the NODES market platform [57].

2.6.5.3 Other examples of ongoing flexibility platform projects

There are some other active projects for utilizing the flexibility of end-user consumers and DERs in the form of market environments in Europe and other countries in the world. Some of these projects are listed in Figure 19.

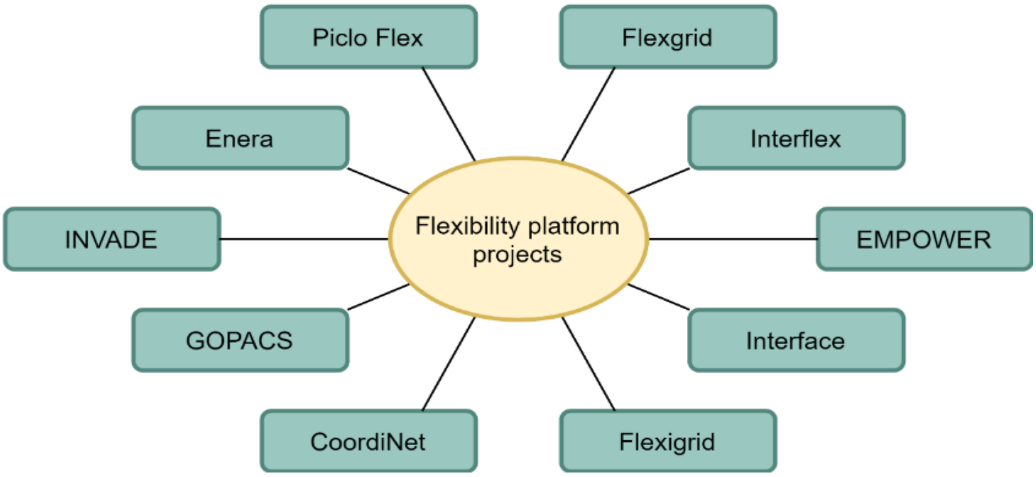

Figure 19. Current flexibility platform projects

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3 Requirements of flexibility markets

The principle of flexibility markets and the key role they are expected to play in future power systems was discussed in Section 2. The present section introduces the different flexibility resources available at the distribution grid level, together with the infrastructure (both hardware and software) needed to exploit their energy flexibility potential in flexibility markets. First, ebalance-plus architecture and demo-sites are briefly introduced, together with the different physical assets in the distribution grids that can provide flexibility in the power system. Then, required hardware and software infrastructures for implementing the flexibility market are discussed, and finally, market players' engagement and behaviour in the flexibility market are investigated. Although this new flexibility market can be categorized as a LFM, hereinafter it will be referred to as flexibility market for the purpose of generality.

3.1 Overview on the ebalance-plus project and demo-sites

The ebalance-plus project aims at developing an energy balancing platform to increase the flexibility and resilience of the power grid, by exploiting the synergies among smart production, consumption and storage technologies. Through innovative automation and control solutions, the ebalance-plus platform could also enable DSOs to exploit resources located in the distribution grid to procure flexibility in a market-based approach, and, on the other hand, DER assets and end users to support the grid by offering their flexibility to the flexibility market. The architecture of the balancing platform is shown in Figure 20.

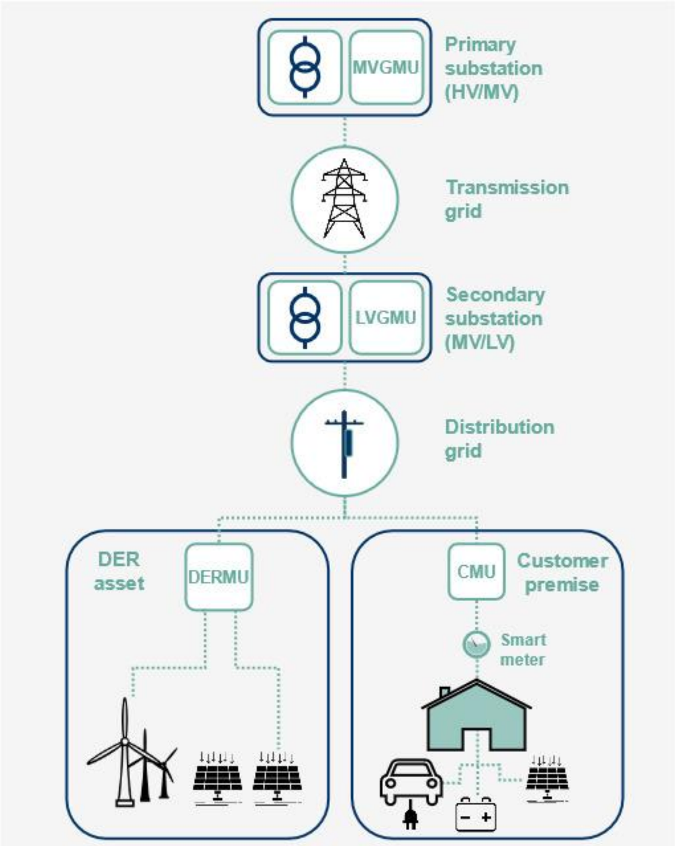

Figure 20. Hierarchical ebalance-plus architecture

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It replicates the existing hierarchical grid topology with a bidirectional communication framework, assuring the scalability of the proposed solutions. The platform consists of the following technologies:

- **Customer management unit (CMU):** it is the core of energy management systems at customer premises. It controls smart appliances, collects consumption data and information about power quality from smart meters, and controls the inverters supplying local renewable generation. It is also responsible to provide information about the available energy flexibility to the ebalance-platform.
- **Distributed energy resources management unit (DERMU):** likewise CMUs, DERMUs provide services to exploit DERs. It will be installed on each DER asset and will enable communication and data exchange with the ebalance-plus platform, as well as the control of the DER operating point on the basis of the optimized ebalance-plus power flow solutions.
- **Low-voltage grid management unit (LVGMU):** control units installed in the secondary substation at low-voltage (LV) level and responsible for controlling the operations of all CMUs and DERMUs within the same LV distribution grid. Besides controlling the CMUs and DERMUs operations, the LVGMU also collects information about the status of the distribution grid (e.g. power flows, voltage levels, etc.) from CMUs, DERMUs and the smart-grid technologies installed in the LV grid and secondary substations.
- **Medium-voltage grid management unit (MVGMU):** this management unit will be installed in the primary substation at the medium voltage (MV) level and will be responsible for controlling all the LVGMUs in order to provide the available flexibility to both DSOs and TSOs, provide resilience mechanisms to optimize power flows and apply FDIR services (Fault Detection, Isolation and Restoration).
- **Data-exchange middleware:** it is the software solution enabling the interoperability of the different technologies (characterized by different communication protocols) and databases of the ebalance-plus platform.
- **Security and privacy technology:** encryption technology aimed at protecting end-users' data and privacy.
- **Silicon-carbide high-efficient power converters:** power converters based on cutting edge silicon-carbide semiconductor technology. They offer the possibility to cost-effectively manage DER, like PV, in DC voltage networks with a high level of energy efficiency and reliability.
- **Vehicle-to-grid infrastructure:** This facility exploits the electric storage embedded in EVs to support grid operation and minimize charging costs by exploiting the available renewable generation.
- **Smart battery energy storage systems (BESS): l**ike batteries embedded in EVs, stationary batteries installed at customer premises can increase energy flexibility, by deploying services based on energy arbitrage, and reduce energy costs thanks to a cost-optimal utilisation of the available distributed generation.

All the services provided by the platform will be tested in the different ebalance-plus demo-sites. The latter are summarised in Table 9.

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	Country	Demo site objectives	ebalance-plus technologies
University of Calabria (UNC)	Italy	Implement smart grid automation and control solutions to unlock/exploit energy flexibility of buildings and increase distribution grid observability and resilience.	CMU, DERMU, LVGMU, MVGMU, BESS, IoT devices
University of Malaga (UMA)	Spain	Exploit V2G solutions combined with high-efficiency DC networks supported by power inverters at district level and distributed energy storage to increase energy flexibility and maximize the use of local renewable energy resources.	CMU, DERMU, LVGMU, BESS, V2G charging points, Power converters
Junia – Catholic Institute of Lille	France	Testing the interoperability and replicability of the ebalance-platform in existing energy management systems.	CMU
Jutland summer houses	Denmark	Provision of implicit (price-based) demand response services through the optimal control of heat pumps coupled with thermal energy storage (i.e. water of swimming pools).	CMU
In-Lab Emulator (IHP, Innovation for High Performance)	Germany	Test, through simulations, the behaviour of the energy-plus platform under operating conditions which are hard to produce within a real energy network (shortcuts or cutting lines).	All the components that define the ebalance-plus platform.

Table 9. Overview of ebalance-plus demo-sites

3.2 Assets of a flexibility market

3.2.1 Batteries

In general, batteries are defined as devices made with a series of electrochemical cells that convert the chemical energy into electrical energy and vice versa. Batteries provide the possibility of storing electric energy and using it when it is needed. They are known as one of the key elements to enable the widespread integration of renewable energy. From the viewpoint of application, there are two main types of energy storage systems, standalone batteries, and embedded batteries that are described briefly in the next subsections.

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3.2.1.1 Standalone batteries

Standalone batteries are independent energy storage systems that could work as single units to provide flexibility for the system. Charging and discharging of these batteries are performed based on the signals received from energy management units. Standalone batteries are usually installed along with renewable energy resources to cope with the uncertain output power of these units as shown in Figure 21. From the system operation perspective, the benefits of using standalone batteries include the reduction of power flow congestion on transmission lines, supplementation or replacement of peak power generation, short-term balancing of the generation with consumption referred to as frequency regulation, and smoothing renewable energy generation, which is generally uncontrollable. From the consumers' perspective, the benefits of this solution include the reduction of peak demand charges, and energy arbitrage (buy low and consume high) [58].

In the ebalance-plus project, demo sites at University of Malaga in Spain and Catholic Institute of Lille in France are equipped with these assets.

3.2.1.2 Embedded batteries

Embedded batteries are known as the batteries that are embedded in devices and equipment. In this regard, embedded batteries include everything from mobile phones to electric vehicles (EVs). Similar to the standalone batteries, this category of batteries can also be used to provide flexibility by being charged and discharged at different time periods. Nevertheless, there are differences between embedded and standalone batteries in terms of using their flexibility. First, since the main purpose of using embedded batteries is supplying the equipment in which the battery is placed, using these batteries for providing flexibility causes comfort loss in using that equipment. Second, the equipment and consequently the battery can be moved to different locations inside or outside the flexibility market area, which makes it difficult to use its flexibility especially for the grid location-dependent ancillary services. Third, in many cases, the batteries cannot be used for anything else than running the equipment in which they are placed.

Among equipment-embedded batteries, electric vehicles seem to be the best option for providing flexibility in the power system. These batteries have a proper capacity and if the technical infrastructures are available, they can provide both grid to vehicle (G2V) and Vehicle to Grid (V2G) services [42]. However, it should be noted that due to the mobility of electric vehicles part of the charging or discharging process of these batteries may happen outside the LFM as illustrated in Figure 22.

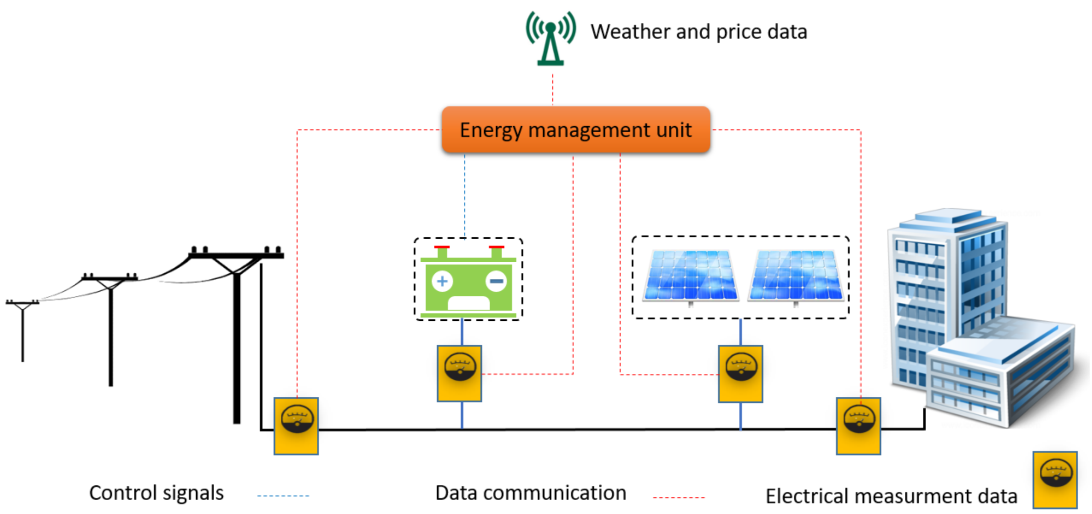

Figure 21. A simple illustration of standalone battery applications in the grids [58]

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Demo sites at University of Malaga and Catholic Institute of Lille are equipped with some EV charging stations. The charging stations in University of Malaga have also the V2G infrastructures.

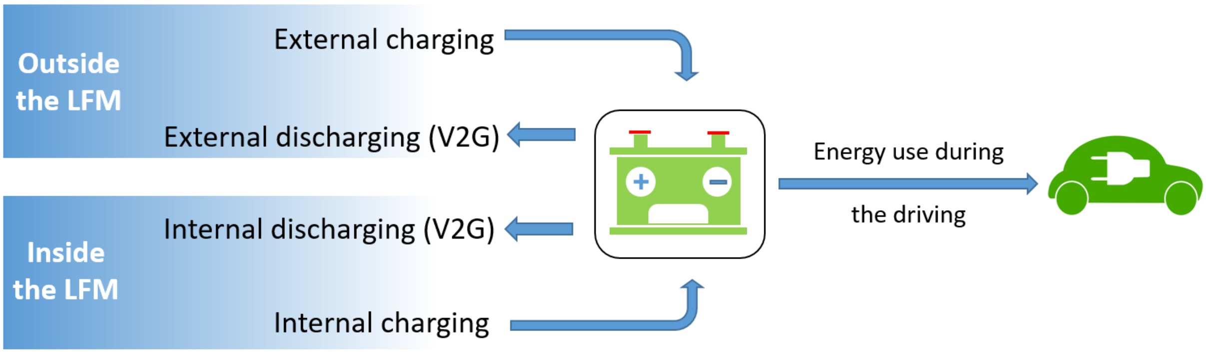

Figure 22. Energy flow of the embedded batteries in electric vehicles

3.2.2 Electricity production assets

Distributed generation has experienced a period of continuous growth over the last decades, boosted by policies supporting the decarbonization of the energy sector on the one hand, and by decreasing investment costs on the other. Some of the DERs technologies are presented in Figure 23. Solar panels and, in some countries, small wind turbines are the most widespread solutions for producing electric energy in buildings. These types of DERs are not flexible by themselves because the output power of solar panels and wind turbines depends only on solar radiation and wind speed, respectively, and cannot be controlled.

In some residential, commercial, and industrial buildings, in addition to solar panels and small wind turbines, other types of DERs like diesel power generators, combined heat and power (CHP) units, combined cooling, heating, and power (CCHP) units, and small gas turbine generators are also used for producing electric energy. There are limitations to procure flexibility from these resources, too. The volume of available fuel for supplying diesel power generators is limited and these generators are usually used as backup for supplying the loads. Plus, they cannot work at part load for a long time, since it would reduce their efficiency. For instance, some CHP power plants should not work under 50% percent of their power generation capacity for more than 30 minutes and working under 30% of the power generation capacity is not recommended. Another point is that the purpose of designing CHP and CCHP power plants is to produce electric energy and provide heat or both heat and cold water for the buildings. So, the thermal restrictions of input and output water of these units should also be taken into account in the operation which limits their ability in providing flexibility to the grid.

Some other DER technologies like fuel cells, biomass, and mini hydro electricity generators can also be used for producing energy at the distribution level and providing flexibility, however, these technologies are not commonly used in buildings.

In the ebalance-plus project, PV is the most common DER and is available at the University of Malaga, Catholic Institute of Lille and University of Calabria (Italy) demo sites. There are also a heat concentrator photovoltaic plant generator and a geothermal plant at the University of Calabria demo site.

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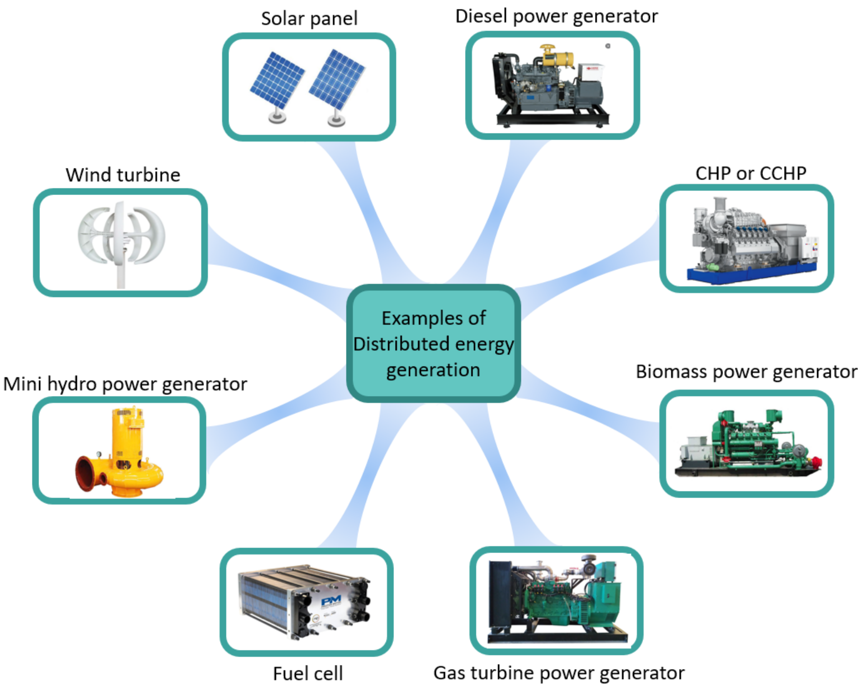

Figure 23. Some distributed energy generation technologies

3.2.3 Heating and cooling systems

Heating, ventilation, and air conditioning (HVAC) systems are recognized as effective sources of demand-side flexibility. HVAC refers to different systems used for moving air between indoor and outdoor areas, along with heating and cooling in both residential and commercial buildings. HVAC systems also filter and clean indoor air to keep residents healthy and maintain humidity levels at optimal comfort levels [59]. Implementation of HVAC systems is different in different buildings. In some buildings, there might be only heating or cooling systems based on the geographical location of the building. Modern residential and commercial buildings are usually equipped with central HVAC management systems that optimally control and adjust the building ventilation and temperature [59]. Three of the most commonly used systems for commercial buildings are:

- Chiller, cooling tower, and boiler systems;
- Variable-air-volume systems with a packaged rooftop unit;
- Water-source heat pump systems with a cooling tower and boiler [55].

Figure 24 shows the basics of the HVAC system with chiller, cooling tower, and boiler system. These systems use water as a medium to deliver or extract heat. The cold and hot water is provided by chillers and boilers, respectively [60]. HVAC systems can be used to provide flexibility to the grid. Indeed, if the thermal load is met through power-to-heat technologies like heat pumps or electric boilers, building thermal inertia can be exploited to implement flexibility measures (e.g. load-shifting strategies). The higher the thermal capacity of a building, the greater the ability to provide flexibility without jeopardizing occupants' comfort.

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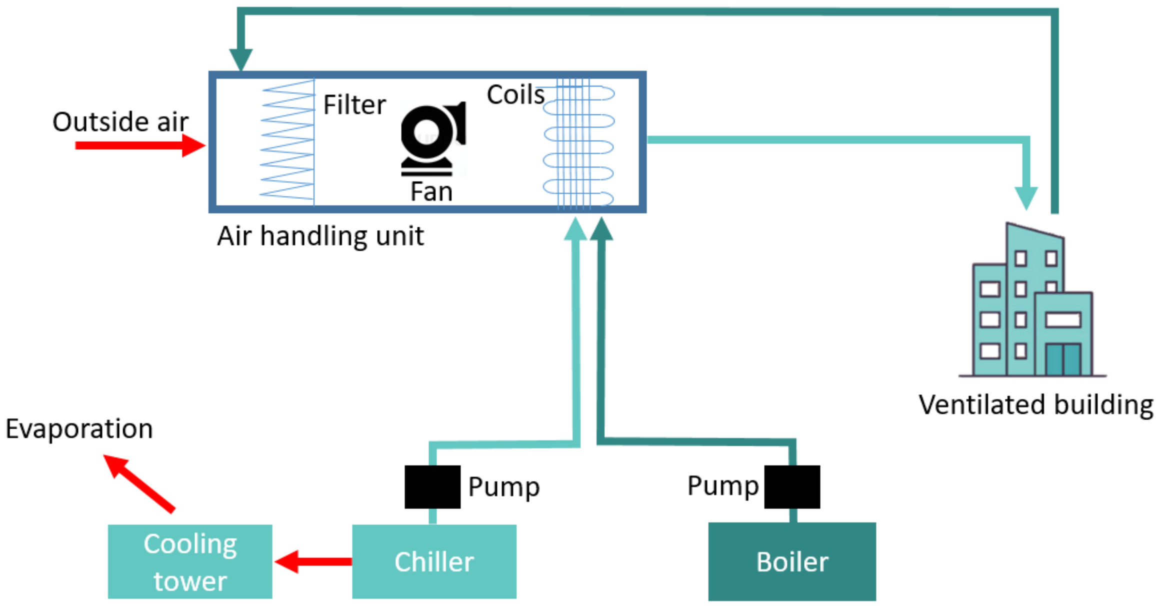

Figure 24. Basics of the HVAC system with chiller, cooling tower, and boiler system [61]

The HVAC system flexibility can also be affected by occupation status of the buildings. In inactive hours, i.e., when the building is not used by the residents, the HVAC system may provide more flexibility than the hours that it is used by the residents [42].
Another type of heating and cooling system is the heat pumps that are used to control the water temperature for instance in swimming pools and other applications. Figure 25 shows the schematic of a heating system of a swimming pool that uses a heat pump as a heat generator.

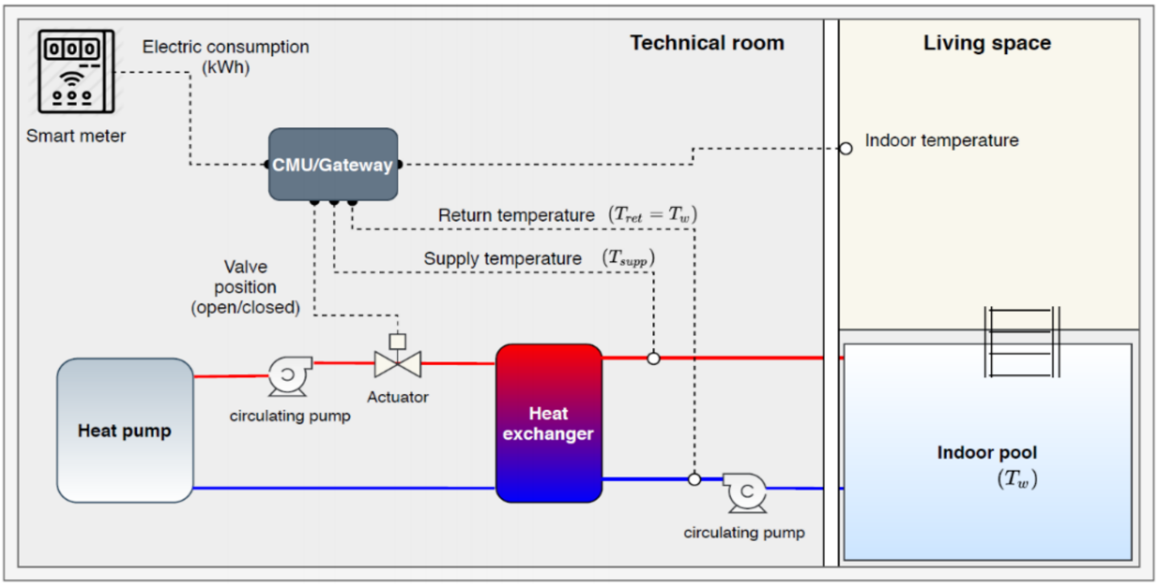

Figure 25. Structure of a heat pump set up for managing the swimming pool temperature

Control management units are used to optimally schedule the operation of the heat pump while satisfying occupant comfort requirements.

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Catholic Institute of Lille demo site is equipped with an air and heat unit (AHU) and boilers. Jutland summer houses demo site in Denmark is equipped with heat pumps.

3.2.4 Thermal energy storage (TES)

TES is another form of energy storage. Energy is stored as sensible or latent heat by increasing the storage medium temperature or changing its phase, respectively. Water is the most common storage medium. Like building thermal inertia, thermal storage can be used to provide load shifting and peak shaving to the power system. For instance, the TES can be pre-heated by electric heat pumps and electric boilers during off-peak hours and then heat used in peak hours. Similarly, if the end-users should provide upward flexibility, the resulting extra electricity consumption can be converted into thermal energy and stored in the TES. If downward flexibility is requested, the heat pump and/or electric boiler can be turned off and the thermal demand met by discharging the TES. Therefore, TES can be used as auxiliary components for providing demand-side flexibility. TES is much cheaper than electricity storage and it has a high potential of integrating intermittent renewable energy sources such as wind and solar into the heating sector [62].

3.2.5 Appliances

The term “appliance” refers to different assets like electrical devices that are commonly found in residential and commercial buildings. Not all appliances have the ability to provide flexibility. Some of the appliances like TV or coffee makers cannot be scheduled for operation or scheduling them affects the comfort of the residents significantly. So, we cannot use these devices for providing flexibility from buildings. However, there are some appliances like washing machines or dishwashers that can be scheduled to run and consume electricity at specific hours [42].
It should be noted that in order to use the appliance for procuring flexibility in the power system, these devices should be equipped with communication devices or IoT hardware. This enables energy management units to monitor and control these devices.

3.3 Hardware requirements

In order to implement the flexibility market, some physical instruments should be added to the system. In this section, the main necessary hardware for operation of the flexibility market is reviewed.

3.3.1 Control management units

All end-user and DERs expect to benefit from the flexibility market to minimize their operation costs or maximize their profit. Making optimal decisions in the aggregation of energy and ancillary services considering different operational constraints of buildings or the distributed energy generation sector is not an easy task for market players. Moreover, flexibility markets run periodically over short time intervals, and making optimal decisions for each time interval is almost impossible especially for end-users. Another point is that in case the end-user has a flexibility contract with an aggregator, the aggregator should be able to control the demand of end-users or send flexibility orders to the end-users that should be applied to the building or DERs immediately. To overcome these problems, control management units can be installed for end-users and DERs which in ebalance-plus are referred to as customer management units (CMUs) and distributed energy resources management units (DERMUs), respectively. Each CMU or DERMU should be able to receive information like weather, market prices, building occupation, and requested flexibility from the aggregator and measured data from metering

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devices and sensors, and send orders to different devices that provide flexibility for consumers or DERs. Decisions in the control management units are made by energy management software that will be described in more detail in Section 3.4.

3.3.2 Distribution grid management units

One of the main goals of implementing flexibility markets and especially LFMs is solving the congestion and voltage regulation issues in the distribution grid. To this end, a management unit is needed to collect the measurement data and information from the grid, estimate the required flexibility in each area of the grid for removing congestion and voltage regulation issues, and send information to the DSO or flexibility market operator. In the ebalance-plus project, this management unit is called a low voltage grid management unit (LVGMU).

3.3.3 Metering devices

Metering devices are essential elements for the proper operation of management units and consequently, the flexibility market. As mentioned in Sections 3.3.1 and 3.3.2 all CMUs, DERMUs, and LVGMUs need metering data of buildings, DERs, and distribution grids to perform their duties correctly. These metering devices could be instruments for measuring electrical parameters like voltage of nodes, consumption power, power factor, or loading of the distribution grid lines or non-electrical data like rooms' temperature in the buildings.
Moreover, the metering devices are necessary to check and record the response of end-users after they received a flexibility request. This information is used for evaluating the performance of consumers and DERs in following their flexibility commitments and hence to evaluate the corresponding incentives/penalty payments.

3.3.4 Data communication devices

Communication devices are required for transferring data between devices in the flexibility market. Different types of data communication can be used in the system. Wired data communication is mostly used in buildings between CMU and controllable loads. Wireless communication is also widely used in the system especially over long distances in the forms of TCP/IP and web services.
Figure 26 shows an example of implementing hardware devices in end-users' buildings, DERs, and distribution grids.

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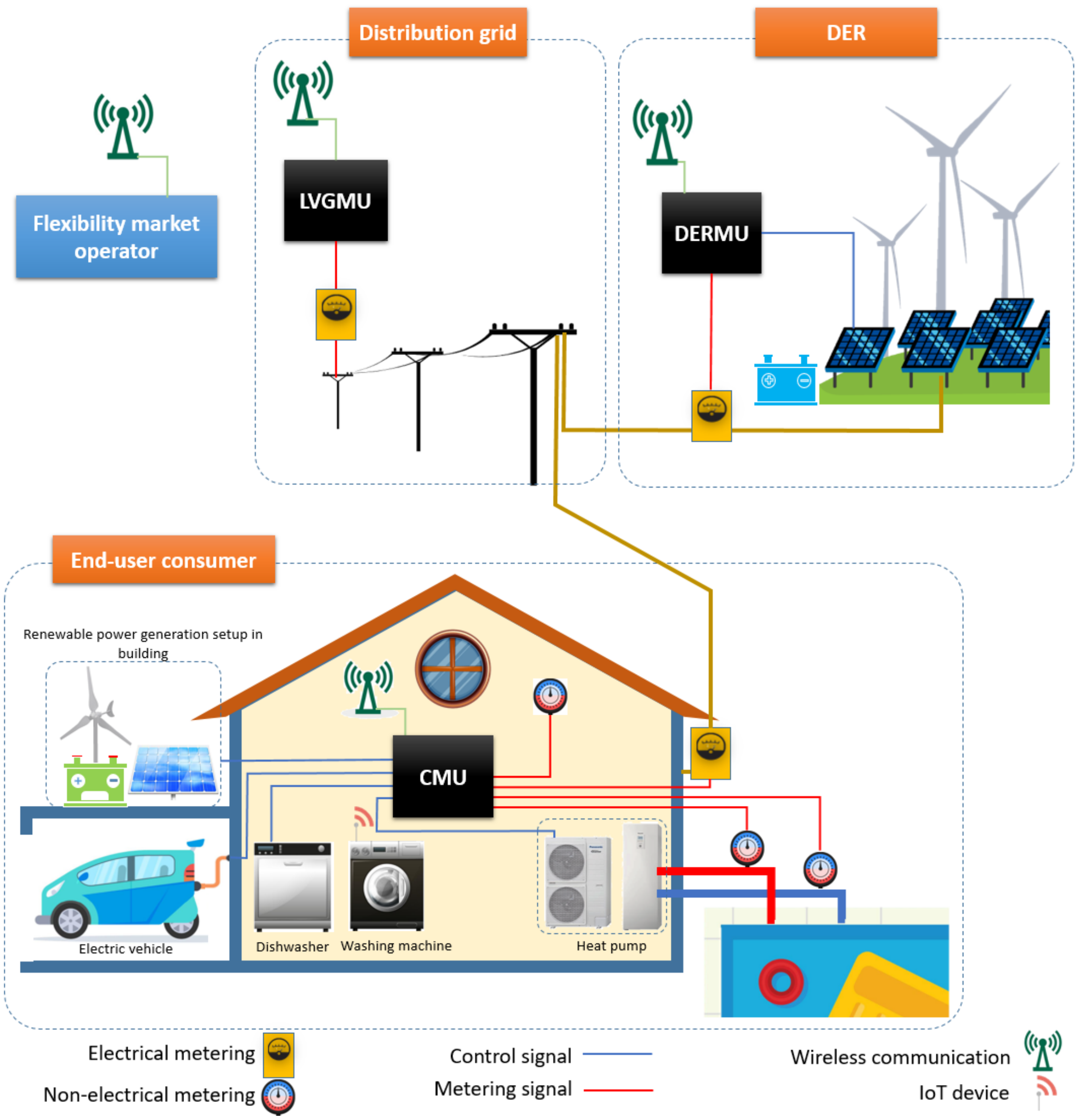

Figure 26. Example of implementing different hardware devices in end-user consumers, DERs, and distribution grid

3.4 Software requirements

Implementing the flexibility market needs development of new software or updating existing software to consider the requirements of the new designed market. In this section, some of the main software requirements in the flexibility markets are discussed.

3.4.1 Energy management algorithms

Energy management programs that are used in the CMUs and DERMUs should be developed or updated such that the impacts of spot market prices, CO_2 emission data, weather forecast data, building occupation status, and flexibility requests of the aggregators on the optimal operation of the buildings and DERs are included in the models. Inputs, outputs, and objectives of general energy management software are illustrated in Figure 27.

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Other software like mobile applications could also be designed to let the users monitor buildings' energy consumption or DERs through mobile phones. By showing the achieved cost and emission saving, mobile apps can increase end-users' willingness to implement energy management and flexibility measures. End-users can also use such mobile apps to set their comfort preferences and the availability to flexible operation of their home devices.

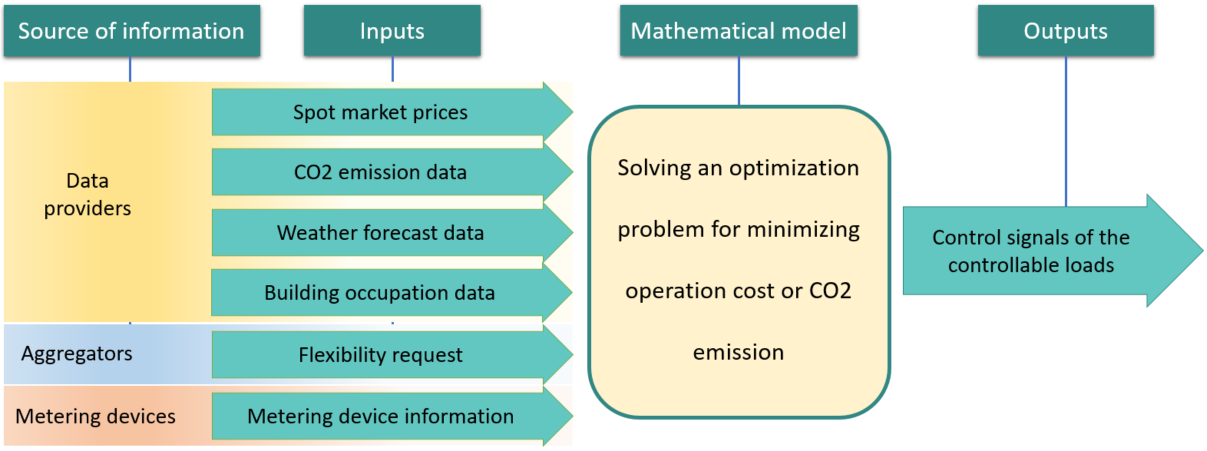

Figure 27. Inputs, outputs, and objectives of energy management software

3.4.2 Software development for LVGMU

LVGMUs are instruments installed in the distribution grid to estimate the required flexibility of the grid for flexibility market operators. General structure of the software implemented in the LVGMU is illustrated in Figure 28. This software receives grid information via metering devices, performs a power flow analysis, identifies congestion and voltage regulation issues in the grid, evaluates the flexibility requirements for solving these issues, and send the results to the flexibility market operator.

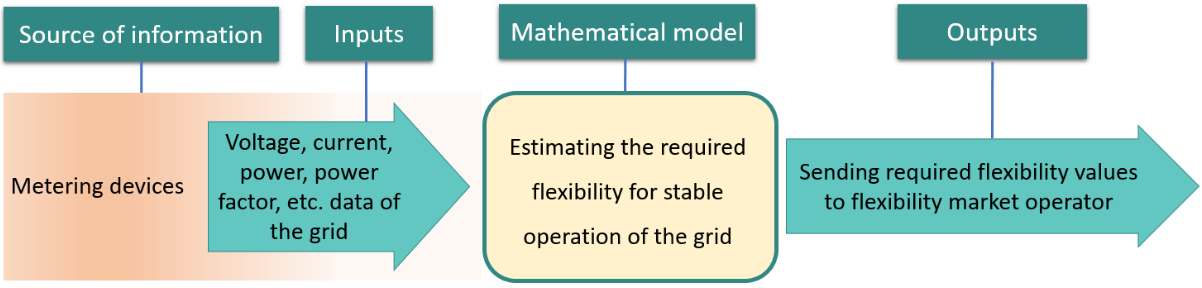

Figure 28. General structure of LVGMU software

3.4.3 Flexibility market platform

The introduced flexibility market needs a software platform for implementation. Design properties of this software are directly dependent on the defined structure for the flexibility market. A general structure of this software is depicted in Figure 29. Like all markets, the platform implementing the flexibility market receives bids from all market players. According to the market rule, the bids can be formulated in different forms: price bids, power bids, price-power block bids, etc. Once the market is closed, the market operator solves the market considering the distribution grid limitations and issues like congestion and voltage regulation and communicate the flexibility commitments to the market players. It should be noted that

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based on the structure of the flexibility market, the DSO could be one of the market players or the market operator of the system.

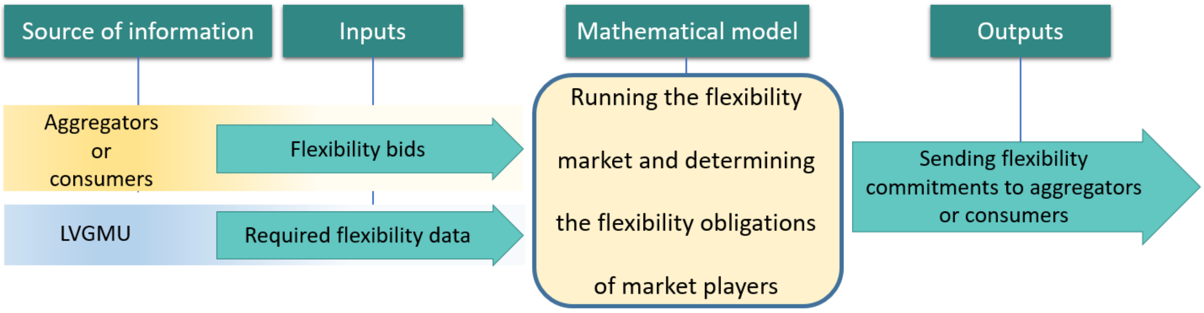

Figure 29. General structure of flexibility market software

3.4.4 Cloud platforms

Cloud platforms are useful tools for collecting and sharing information among market players. In a flexibility market, aggregators, end-users, and DERs need information like electricity prices, CO2 emission, weather forecast data, and in some cases building occupation data to increase their performance in the market. As shown in Figure 30, cloud platforms provide an environment where data provider companies can send their information to an online platform. This information can then be retrieved and used by flexibility market players.

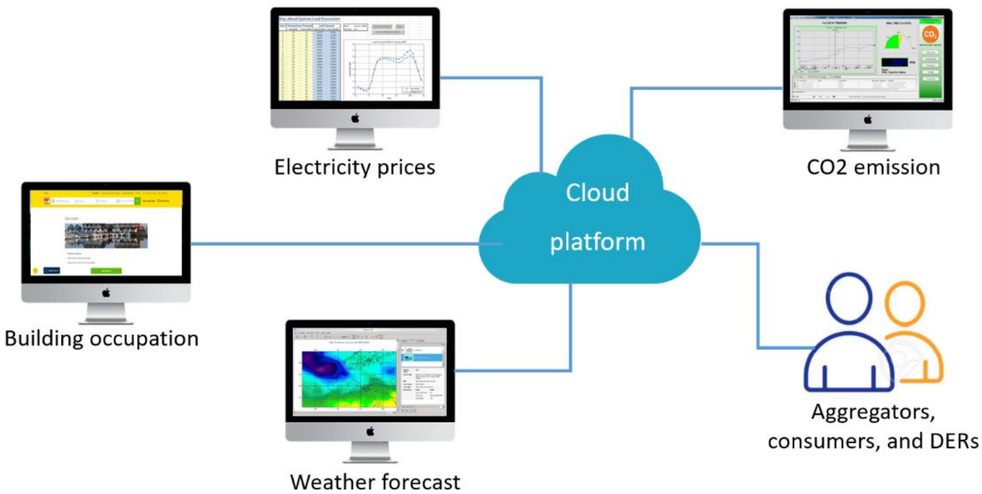

Figure 30. Cloud platform and related entities

3.4.5 Prediction models

Prediction models are useful tools to increase the efficiency of the flexibility markets' operation. Based on the defined structure for the flexibility market the required prediction tools and parties that need these tools can be different. In this section, some of the possible prediction models for end-users, DERs, and aggregators are discussed.

3.4.5.1 Prediction tools for end-user consumers and DERSs

As discussed in Section 2.5.5.2 end-users and DERs participate in the flexibility market through aggregators. Aggregators can procure flexibility from consumers and DERs either directly, by

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controlling consumers' loads and DERs' set points, or indirectly, by using price-based incentives. In both cases, predicting the volume and time period of requesting flexibility by aggregators can help the consumers and DERs to schedule their energy resources such that required flexibility is provided and the operational cost is optimized. In fact, a prediction tool for flexibility requests will benefit end-users, DERs, and the flexibility market.
In terms of the DERs with uncertain output power as discussed in Section 3.1.2, these units are not flexible by themselves but if they are coupled with energy storage systems then flexibility can be expected from these units too. In this case, output power prediction tools and flexibility request prediction tools will help these resources to provide flexibility and optimize their profit.

3.4.5.2 Prediction tools for aggregators

Estimating the available flexibility of consumers and DERs is very important for aggregators. Underestimating the available flexibility reduces the revenue of aggregators in ancillary service markets and overestimating the available flexibility may impose expensive charges due to their inability to meet their flexibility obligation. Aggregators should use prediction methods that help them to estimate the available flexibility of all consumers and DERs.
Moreover, aggregators should bid into the flexibility market. Anticipating the behaviour of other market players in the flexibility market and amount of the flexibility that is going to be requested by the market at different hours of the day will help them submit a more accurate bid to the market and increase their profit.

3.5 Market players' engagement and behaviour

As mentioned end-users' and DERs' behaviour impacts the efficiency of the flexibility market, significantly. In order to activate the consumers and DERs in this market, the first step is increasing the market players' knowledge about the flexibility market concept, their role in this market, and the benefits they and society can earn by participating in the market. The consumers should be assured that participating in the flexibility market will not threaten their privacy and affect their comfort. End-users and DERs should also be able to determine the level of their engagement in the flexibility market.
On the other hand, flexibility market regulators should provide a structure that makes it easy for any kind of consumer to become a flexibility provider for the market. The contracts should be organized clearly and the interfaces for engaging with the market should be easy to understand and apply personal adjustments.
In the case of implementation, it is mostly recommended that end-user consumers and DERs should have a contract with aggregators. According to this contract, the aggregator participates in the flexibility market and confronts the complexities of optimal participation in the flexibility market on behalf of these market players. Grouping the market players also reduces the risk of unfulfilling flexibility obligations and losing money in the flexibility market. So, from the viewpoint of consumers and DERs, they have a contract with an aggregator based on which some of their controllable loads are used for procuring flexibility and they receive money for providing this service.
The point is that the aggregators should anticipate the available flexibility of market players before participating in the market. As discussed in Section 3.6.4.2, accurate prediction models can be very useful tools for aggregators to estimate the available flexibility of consumers and DERs precisely.
Once the aggregator's bids are accepted, the aggregator needs to deliver the flexibility traded into the market, by driving its customers' consumption. Two methods could be used to solve this issue:

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1. The aggregators can have direct control over the controllable loads of the end-user consumers or power resources of the DERs.
2. The aggregators can use price base controls to procure flexibility from consumers and DERs indirectly via price signals.

The first method guarantees procuring the requested flexibility from consumers and DERs directly, however, there are some concerns about invading the privacy of the market players. The second method respects the privacy of the end-users but there is uncertainty about the end-users' or DERs' answer to the flexibility request as it is expected by the aggregator. Price signals should be determined such that incentivize the consumers and DERs for providing flexibility and also keep the aggregators' portfolio profitable.

In addition to interacting with consumers and DERs, aggregators can also participate in the markets for selling the available flexibility in their portfolio. Based on the system regulations, the aggregators can participate in different markets like the day-ahead, intraday, regulating power market, and also flexibility market. So, in case that they can participate in several markets at the same time, they should manage their gaming strategy in all markets. In case the aggregators participate only in the flexibility market, then their goal will be providing optimal bids in the market considering forecasted available flexibility and flexibility requests in the market.

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4 Conclusion

This document reviews the principles of electricity markets and requirements for implementing flexibility markets. The goal is to identify market places among existing markets and practical new markets to exploit flexibility of end-users and DER such that there will be enough incentives for all parties to be a part of the plan. The electricity market review includes introducing all market players and market operators, their roles and responsibilities, and market places for trading energy and flexibility. Based on the flexibility markets definition we identified that all the existing frequency related ancillary service markets can be known as flexibility markets and the flexibility of DERs and end-users can be traded in these markets through aggregators. The latter could only be feasible if the regulation in each electricity market allows the participation of aggregators with small bid sizes and in some cases asymmetric bids into the market. Another important subject is the social acceptance of flexibility programs from the end users' perspective. The risk of losing money or comfort will discourage end-users from being a part of flexibility programs in the long-term, and hence, should be included in the proposed structures.

The analysis showed that in case of requiring flexibility at the distribution grid level for solving problems like congestion at this level, new local flexibility markets can be defined. These local flexibility markets should be operated by DSO or local market operators. At the moment, several projects are working on designing LFM. To implement a local flexibility market successfully different issues like financial incentives of participants, complexities of market operation, evolution in the roles of DSO, coordination between the DSO and TSO, conflict of interests among market players, etc., should be solved. Plus, a local flexibility market has requirements such as identifying the flexible resources in the grid, providing hardware and software infrastructures, and determining the user engagement method. All these requirements have been addressed in detail in this deliverable.

In this framework, the ebalance-plus platform, with its novel technical solutions, will support the transition towards a more active role of the DSO in the management and operation of the grid. More specifically, the innovative automation and control solutions developed and tested through the ebalance-plus platform will enable the DSO to exploit resources located in the distribution grid to procure flexibility in a market-based approach. At the same time, these solutions will allow DER assets and end users to support the grid by offering their flexibility to the DSO, thus supporting the development of local flexibility markets.

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