Adaptation of the flexibility tool-box for commercial micro-grids

Deliverable 5.1

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About ERA-Net Smart Grids Plus

ERA-Net Smart Grids Plus is an initiative of 21 European countries and regions. The vision for Smart Grids in Europe is to create an electric power system that integrates renewable energies and enables flexible consumer and production technologies. This can help to shape an electricity grid with a high security of supply, coupled with low greenhouse gas emissions, at an affordable price. Our aim is to support the development of the technologies, market designs and customer adoptions that are necessary to reach this goal. The initiative is providing a hub for the collaboration of European member-states. It supports the coordination of funding partners, enabling joint funding of RDD projects. Beyond that ERA-Net SG+ builds up a knowledge community, involving key demo projects and experts from all over Europe, to organise the learning between projects and programs from the local level up to the European level.

www.eranet-smartgridsplus.eu

List of acronyms

AS	Ancillary Services
BRP	Balance Responsible Party
CHP	Combined Heat and Power
CM	Commercial Microgrid
DAFP	Day-Ahead Flexibility Procurement
DER	Distributed Energy Resources
DSM	Demand Side Management
DSO	Distribution System Operator
EU	European Union
EV	Electric Vehicle
FCR	Frequency Containment Reserve
FRR	Frequency Restoration Reserve
GHG	Greenhouse Gases
ICT	Information and Communication Technology
LFM	Local Flexibility Market
MTU	Market Time Unit
RED	Renewable Energy Directive
RES	Renewable Energy Sources
RR	Replacement Reserve
TSO	Transmission System Operator
VPP	Virtual Power Plant

1. Introduction

This report is part of the project m2M-Grid (from micro to Mega Grid: Interactions of micro-grids in active distribution networks), founded by the ERA-Net Smart Grid Plus initiative.

The adoption of bottom-up technologies such as micro-grids in distribution grids is facing challenges from the coexistence of top-down grid control systems and market models. Distribution networks are expected to be the core of the energy transition, hosting renewable production and storage devices, thus transforming from a mere passive asset for delivering energy to the end-users, to an active grid providing system services up to the transmission network, and allowing bidirectional flows due to distributed generation. Traditional top-down control systems and market models are not fully suitable for handling this technological evolution.

The scarce observability of the distribution networks is likely to be overcome in the future years due to the digitalization of the energy sector, bringing to the development of an ICT framework and realizing the interoperability and coordination of distributed energy resources. The development of micro-grid technologies can lead to innovative coordination schemes and control algorithms that can handle the new way of managing and producing energy at the distribution level.

The project aims to stimulate the adoption of the micro-grid technologies by:

- enhancing the distribution grid planning process to consider technical and market impacts of micro-grid integration;
- developing control functions for effective coordination with distribution grids;
- developing a commercial interface for the market interaction of physical and commercial micro-grids.

Specifically, Work Package 5 of the m2M-GRID project regards the interaction of so called commercial micro-grids with the upper market framework. A primary concern of microgrids is the how these can interact with the upper market layer for e.g. providing different system services to DSOs and the TSO. This comprises both the interaction at the local level (local markets and local communities) and at the wholesale level (intra-day and ancillary services markets).

The work of task 5.1 has concerned the adaption of the flexibility tool-box previously developed by TU/e. The tool-box includes two different procedures: one market-based and one contractual-based, for the procurement of flexibility services from microgrids. Furthermore, this report will provide an overview of the possible interactions of commercial microgrids, in the context of the rapidly evolving European legislation. The tool-box will pave the way for the upcoming research in the work package. In task 5.2, a peer transactive energy between commercial micro-grids will be developed. Task 5.3 will finally define a local market for energy and flexibility trading within micro-grids as well as between micro-grids and with overlaying markets. The local market should be aligned with the wholesale markets, but it will not necessarily have the same market time granularity, time horizon, or structure.

1.1 Aim and scope of the report

The aim of the report is to give an overview of the flexibility tool-box developed by TU/e in a previous project, describing how a local flexibility market framework can be used for trading flexibility between micro-grids and the interested market parties (energy suppliers, distribution network operator, Balance Responsible Parties).

The scope of the deliverable is:

- Introducing key-concepts (flexibility and commercial microgrids) and relevant stakeholders;
- Defining commercial microgrids' uses and characterising their market interaction in the actual European regulatory context: market access at the wholesale level and development of local markets at the distribution level;
- Presenting the content of the flexibility tool-box: a market-mechanism for providing flexibility locally to DSOs and BRPs; and a clustering algorithm for assessing the effectiveness of DERs in solving different problems (congestions and voltage issues)

1.2 Outline of the report

This chapter continues by giving an overview of global and European policies for tackling the environmental issue and moving towards a low-carbon power system. In Chapter 2 the concept of commercial microgrid is introduced. Chapter 3 elaborates on the change in the way of procuring flexibility, describing the flexibility potential coming from the Distributed Energy Resources and individuating the key interested stakeholders. In Chapter 4 the Commercial Microgrids' interactions at the wholesale and local level are described, highlighting regulatory barriers and providing existing business cases in some European Countries. Chapter 5 describes the Flexibility tool-box: the first part concerns the local flexibility market for providing services to Balance Responsible Parties and Distribution System Operators; the second part regards a clustering algorithm for selecting DERs in the distribution that can effectively solve more grid problems at the same time, such as voltage problems and transformer congestions.

1.3 Background and driving forces

The power sector is undergoing a radical transformation. From fossil fuels to renewable energies, from big scale to small scale, from asset-centric to consumer-centric. Due to the dramatic rise in levels of atmospheric CO_2 (403.3 ppm on average in 2016), social awareness is growing over the environmental issue. The most recent response at the institutional level is the Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC) developed during the 21st Conference of Parties (COP21). The central aim is to counteract the threat of climate change by keeping a global temperature rise this century below 2 degrees Celsius above pre-industrial levels and to limit the temperature increase even further to 1.5 degrees Celsius. To reach these ambitious goals, appropriate financial flows, a new technology framework and an enhanced capacity building framework will be put in place, thus supporting action by developing countries and the most vulnerable countries, in line with their own national objectives.

1.3.1 Global Situation

Phasing out of fossil fuel technologies is slowly proceeding: globally, renewable power generation capacity had the largest increase ever in 2016, accounting for around 161 gigawatts (GW) of newly installed capacity. Solar PV represented nearly half of the added capacity, followed by onshore wind and hydropower. As depicted in Figure 1.1, at the end of 2016, 24,5% of the electricity was produced by renewable energy with hydropower having a predominant role in the share [1].

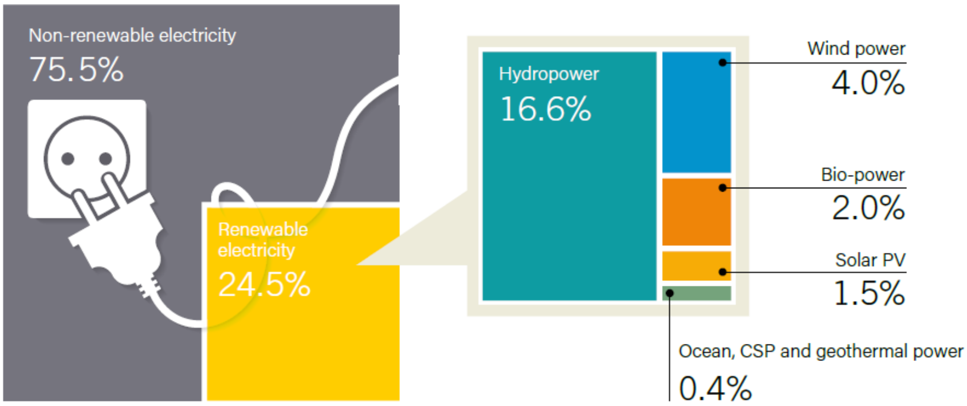

Figure 1.1 – Electricity production from renewable sources in 2016 – (Source: REN21).

The power sector is not the only one involved in the energy transition: Heating and Cooling sector, as well as the transport sector, are also involved in the energy transition. Certainly, the power sector is the driving force of the process. The following Figure 1.2 clearly represents where the institutions are putting most efforts in realizing the paradigm shift to a new sustainable world. All over the world, the number of countries where a policy concerning the power sector is established is nearly double of the number of countries where a transport policy is established and at least five times the number of countries with a heating and cooling policy.

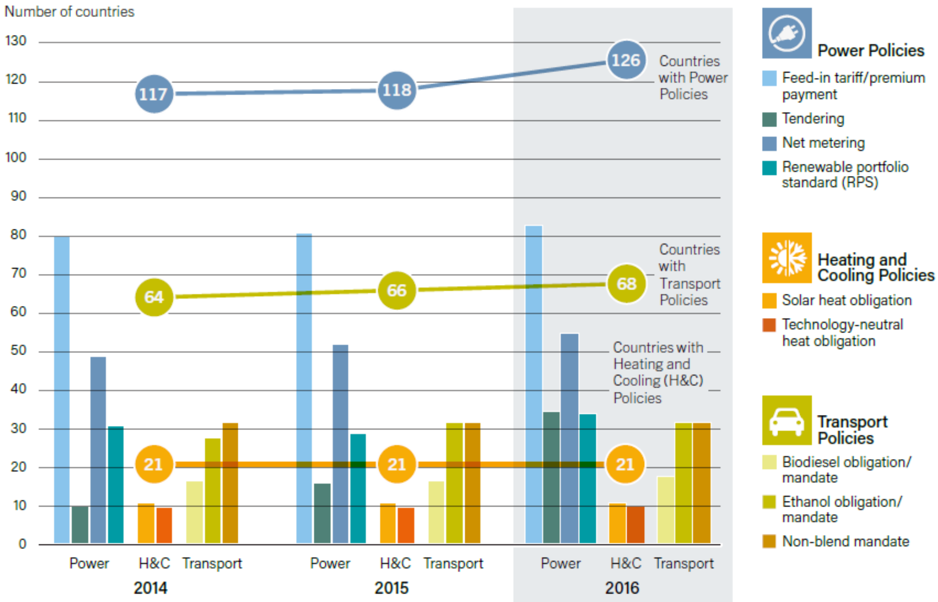

Figure 1.2 – Renewable or environmental policies per sector (Source: REN21).

This can be acknowledged as one of the reasons why other sectors are looking into the electrification as one of the solutions to face the energy transition: e.g. electric vehicles from the transport sector, and heat pumps (air-source or ground-source) from the heating and cooling sector.

1.3.2 European Situation

Today, the European Union (EU) faces a huge energy challenge: decrease of available reserves, growth of the energy demand and dependence on fossil-fuel imports. EU countries must build a long-term strategy to ensure the energy demand satisfaction, thus preserving the security of its supply. The rising of energy prices involves significant costs consequently decreasing competitiveness of the European economy. In addition to, the climate change imposes the reduction of greenhouse gas emissions leading to the improvement of energy efficiency and increasing the renewable energy penetration in the energy mix.

Since the 90s, the EU has taken a leading role in sustainable, low-carbon policies. The EU renewable energy policies for 2020 and 2030 combine targets regarding three major pillars: Greenhouse Gases (GHG) emission reduction, energy saving, and renewable energy consumptions. The global target of 20% RES for 2020 is split into national targets, set at a different level to reflect the national status at the time of the agreement. For 2030, the binding commitment of at least 27% of renewable energy in its gross final energy consumption, was agreed among the member states. Figure 1.3 summarizes the situation of the power sector, where the share of renewable energy (RES-E) is generally greater than the average renewable share in the overall energy consumption.

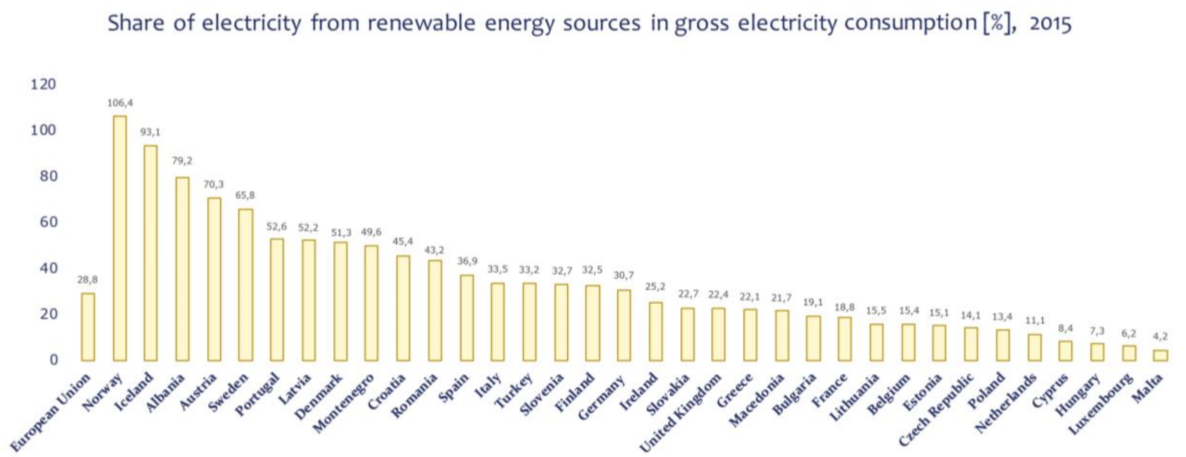

Figure 1.3 - Share of electricity from RES in gross electricity consumption [%] – 2015 – Eurostat.

The peaks are represented by Norway and Iceland where the climate conditions and the geographical position played a favorable role in RES deployment. EU-wide the renewable share is **28,8%** at the end of the year 2016.

In the last 25 years, a lot of efforts were spent in Europe to conduct policies regarding sustainability, energy efficiency and renewable energy, giving EU leading role in the process towards the decarbonization of the energy sector. This led to renewable energy to play a consistent role in the energy market. The next challenge is to enable rapid growth in renewable energy and energy efficiency investments so that they can become the backbones of our future energy system, while at the same time cutting our reliance on fossil fuels. This transition will induce a paradigm shift in the way of producing and managing electricity. The power system should adapt its framework in such a way to put at its center the renewable energies: from technology development to mass production and deployment, from small scale to larger scale, integrating local and more remote sources, and from subsidized to competitive [2].

The European Commission's "Clean Energy for all" package, of November 2016, includes a recast of the Renewable Energy Directive (RED) that reconfirms this minimum EU-binding RES target. It includes measures to promote the better integration of electricity from renewable sources into the market and it updates the sustainability policy for bioenergy. The next step it is not to push the renewable energies at the center of the power system by subsidizing them but rather to shape the new power system around the new technologies, Distributed Energy Resources, by adapting the energy market framework.

The technical infrastructure and energy market framework were based on a system operated in a top-down manner, with big generating units at the top and passive energy consumers at the bottom. The energy system will have more likely a horizontal structure, where big points of generation will be limited to a few, essential, key-node while most of the generation will coexist in a smaller-scale, with the energy consuming-units.

The transmission networks, traditionally the backbone of the network, will not only have the function of connecting generation points and distribution networks but will also allow bi-directional flow from the medium voltage where distributed generation will have a fundamental role.

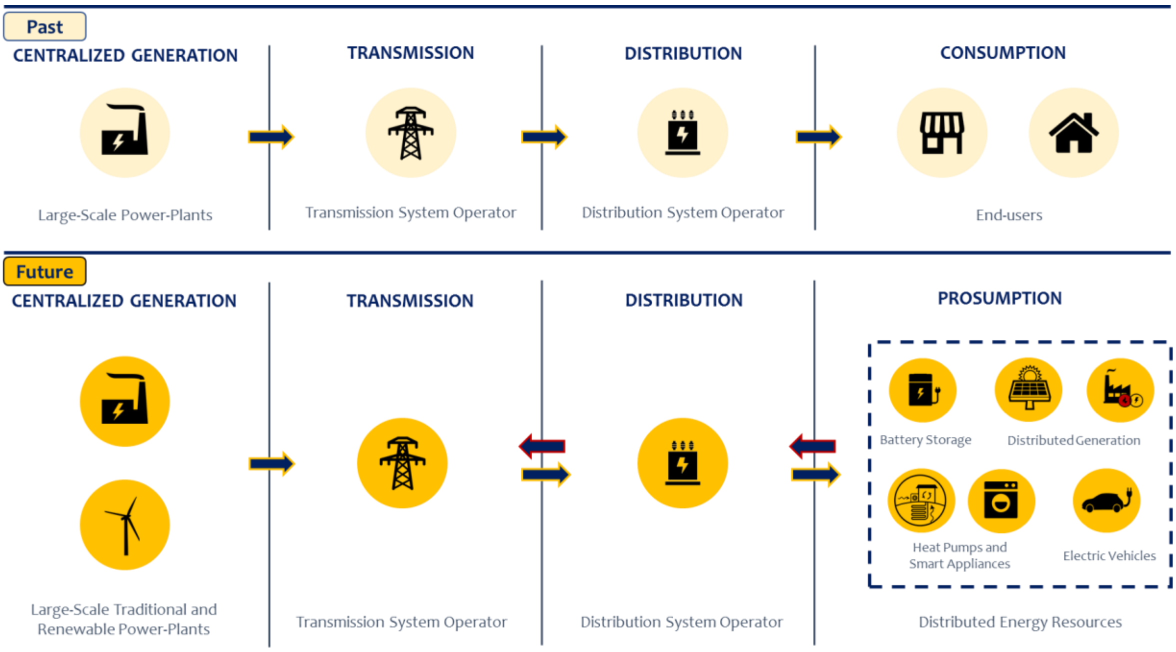

Figure 1.4 – Past/future electricity streams in the power system.

As Figure 1.4 depicts, the distribution network is the element of the grid where most of the changes will occur. Traditionally managed with a 'fit and forget' approach, distribution networks will not be operated as a passive asset anymore. DSOs will be involved as active manager of a new distribution grid, where generation and consumption can happen even in the same place. The technical infrastructure needed, should allow more control at the local level, bi-directional flows and grid reconfiguration. Renewable energy resources are only a small piece of the puzzle. The need for coordination and interoperability among small actors, growing in number and importance, will be vital. Finally, the rise of the Distributed Energy Resources will bring more challenges as well as more opportunities.

Since 2002, with the project Microgrid [3], the EU recognized the development and integration of micrograds at the distribution level, as a solution for promote DER investment, while improving the quality of supply in a cost-efficient way.

Some key-benefits of the development of micro-grids are [4]:

- Improvement of the active management of the network facilitating the integration of DER, (DG in particular) otherwise limited by limited network capacity or lack strategies for handle distributed generation and bidirectional flows;
- Deferral of transmission/distribution investment due to the improved coordination and management of active loads and decentralized

generation, effectively addressing network congestions and improving control over power quality; in particular, in rural or isolated areas (e.g. islands), microgrid's technologies and control strategies can defer/limit the investment in the connection to the main grid;

- Development of an operative interface between the small DERs and the electricity market, improving competition by enabling the trading from small generation and consumption;
- Increase in the resiliency of the distribution network, since more microgrids will mean less dependency from the centralized generation and bottom-up ancillary service provision to support the active distribution network.

2. The commercial microgrid concept

The **physical microgrid (PM)** [5] concept is recognized as the building block of the smart grid: a cluster of producing and consuming units (DG, flexible loads, and storage) geographically located in a specific part of the distribution network (e.g. under the same MV/LV transformer) which most of the time operate in grid-connected mode but can occasionally operate autonomously [6]. The key characteristic of a microgrid is a hierarchical control structure and coordination among different levels: this is what distinguishes the physical microgrid from a feeder with Distributed Energy Resources.

Figure 2.1 represents a potential subdivision in microgrids at an MV busbar with two different MV/LV transformers. Here the location is a fundamental feature, so all the resources are in a confined area, physically part of the same feeder.

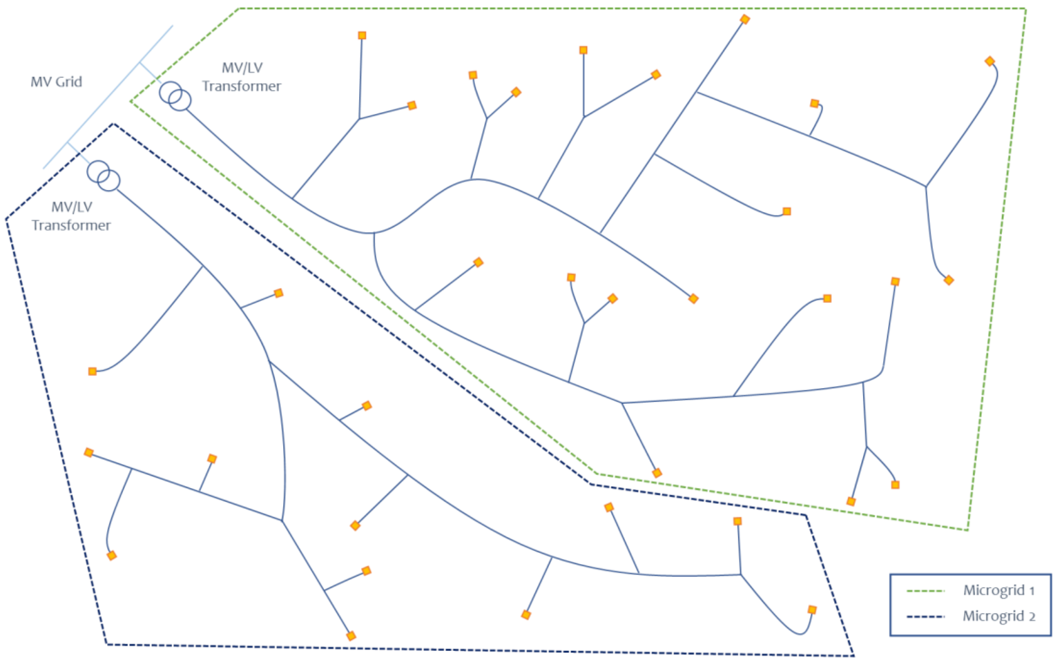

Figure 2.1 - Clustering of energy resources according to the physical microgrid concept.

An energy management strategy is achieved through interoperability between different control levels, from the device till the central microgrid control. The microgrid can be operated with different objectives:

- the minimization of the operational energy cost;
- the minimization of the exchange with the external grid, so prioritizing the supply of the local demand;
- the maximization of the profit made by providing services to the main distribution grid or to interested market participants.

The choice of the operational objective can be influenced by economic, technical and social factors:

- Economic factors can be prevalent when there is a high market value for grid services or balancing services that can be provided from the microgrid.
- Technical factors influence the strategy if the area is sensitive (rural area, or weakly connected to the main grid): in this case the minimization of the energy dependency from the energy grid and local

supply of the internal demand is a safer operation mode to guarantee the security of supply.

- Social factors can also play a significant role. E.g. considering the newly introduced term of local energy community as a "value rather than profit-driven" organization whose aim is to provide local community benefits by acting as a DSO, supplier or aggregator. A community can own the microgrid valuing on the locally produced energy, or in the energy-independence, with the purpose of being recognized as a sustainable community.

A clarification is needed when introducing the concept of **commercial microgrid (CM)**: this refers to a coordinated cluster of flexible resources, able to modify their consumption/production in reaction to an external signal. This cluster of resources is not necessarily located along the same feeder or under the same secondary substation. A central coordinator is needed to manage the resources and deploying them when needed. The driver of the resources' aggregation is the commercial aim: the potential flexibility coming from DERs can be offered to different marketplaces and to different stakeholders. Figure 2.2 depicts the possible aggregation of dispatchable generation and loads belonging from different parts of the distribution network.

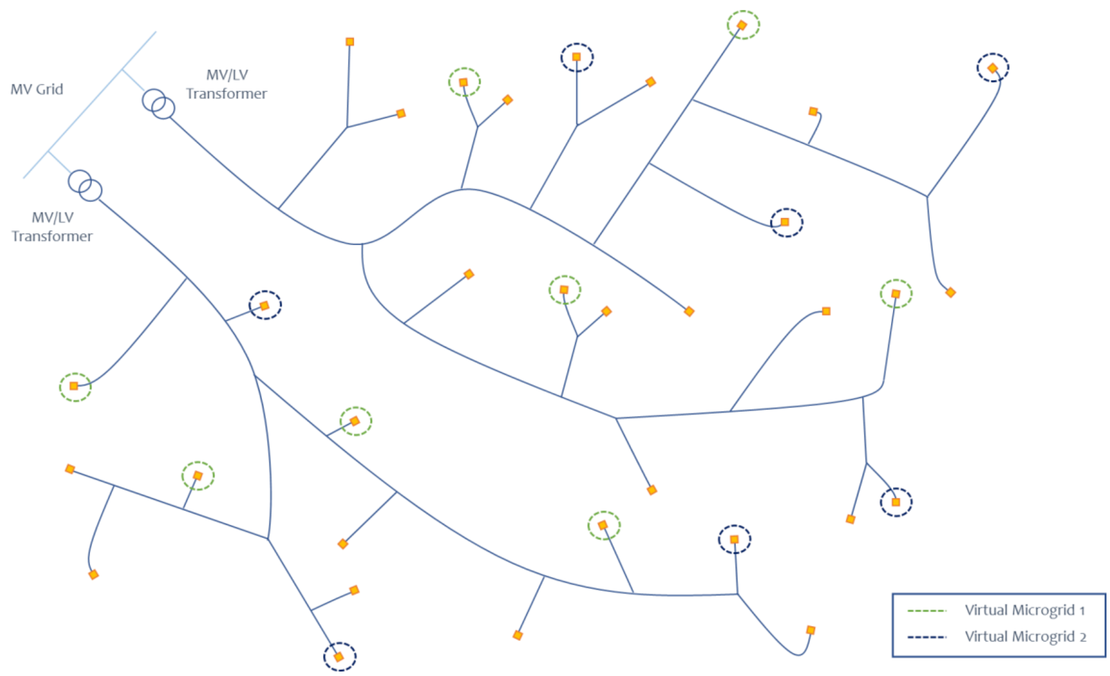

Figure 2.2 – Clustering of energy resources according to the commercial microgrid concept.

A new emerging market-agent, the aggregator will manage the flexible assets by establishing contracts with the prosumers, having direct or indirect control over the flexibility and using it for gaining profit through new business cases, sharing the benefits with the prosumers. This role can be taken by an energy supplier, an Energy Service Company (ESCO), or a DSO. Anyway, legislation that can define role and responsibilities regarding this new actor in the energy sector still need to be defined in most of the European Member States.

A Virtual Power Plant (VPP) constitutes an aggregation of different producing units owned by the same generation company geographically distributed, deployed in order to reduce portfolio imbalances or to gain profit by bidding in the electricity markets. There are some key differences between our definition of CM and a VPP [7]:

- the size of the managed flexible resources is quite small, from smart appliances at the household level, to municipality-owned small Combined Heat and Power (CHP), from electric vehicles to rooftop-PV with the associated energy storage; this makes a clear distinction with respect to medium-to-big generating units being part of a VPP;
- the assets are not owned by the aggregator, but a contractual relationship will exist between aggregator and prosumer/DER owner/end-users to define the type of control that the aggregator will have over the flexible part of his/her consumption/production.
- The aggregation of this resources is certainly beneficial, but it is above all needed for pursuing the commercial aim (e.g. bidding in the electricity market). Without being aggregated, these small-scale flexible resources would not be able to participate in any organized energy markets, since their characteristics are not suitable for meeting the minimum requirements for entering the markets.

3. Flexibility provision: from big generation to small-scale units

3.1 Flexibility definition

The particularity of the power system is the well-known concept of real-time balance between supply and demand. Electric energy cannot be stored in large quantities, so Transmission System Operators used to dispatch the necessary generation for satisfying the exact amount of requested demand. Traditionally, TSO has been in charge of keeping the security of supply in consequence of some problems, due to erroneous forecasting, technical contingencies or power quality issue. In other words, they are in charge for procuring flexibility where the word flexibility expresses the extent to which a power system can modify electricity production or consumption in response to variability, rapid and large imbalance, expected or otherwise. [8]

The TSO procures flexibility in forms of ancillary services: for handling nearly real-time imbalances with primary and secondary reserve (frequency control), for handling grid constraints such as voltage limit violations, for system restoration after a failure. The providers of such type of flexibility have been the big, dispatchable generating units. With the energy transition approaching, there are two main key-aspects that will affect this *status quo* in the near future:

- Besides the balancing problems at the transmission level, other network issues will emerge in the future at the distribution level: increasing the need for flexibility;
- The conventional generating units, are gradually losing their market share because of the growing production from renewable energy sources; having priority of dispatch they are shifting the traditional fossil fuel-powered plants to move from baseload units to peak-load units. These plants are not adequately remunerated to recover their capital costs and they are being mothballed or shut down.

On a more individual level, flexibility can be recognized 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 to the power system [6][7]. This will change completely the way of managing the power system because the flexibility will be available not only at the transmission level but also at the distribution level: the Distribution System Operator (DSO) is called to have a more active role in procuring flexibility for managing the distribution network. The use of technologies such as electric vehicles and heat pumps will likely increase the coincidence factors in the distribution networks determining network congestions, voltage issues at the end of long feeders or increased imbalances between phases compared to the past.

DERs will introduce more challenges in the coming years but also a new flexibility potential. How to adapt the regulatory framework in such a way that this new flexibility potential can be unleashed is a significant challenge. The difficult task for policy makers is to provide a market framework, tariff schemes, incentives to promote the involvement of small-scale actors and small-scale resources to actively participate in the market, to provide services for the grid operator and for the energy companies.

3.2 Different uses of flexibility

Flexibility is a multi-dimensional commodity that requires more than one metric. There are several attributes to consider when it comes to the technical perspective of controlling, managing the flexible resources and integrating them into the power grid. Figure 3.1 gives a good overview of the relevant metrics.

We can summarize the following attributes [11]:

- Capacity
- Energy content
- Duration
- Response time
- Direction
- Ramp rate or rate of change
- Location (Transmission or Distribution System)

Depending on the specific DER, more importance is given to one attribute with respect to another: for a Combined Heat and Power (CHP) plant the rate of change could be an issue rather than for an EV which starts charging/discharging when it is plugged; on the other hand, the duration time is significant for an EV because depends on the capacity of the battery and on the state of charge; unlikely this attribute will be significant for a CHP plant. Furthermore, each flexible resource introduces new additional parameters such as the time availability, the predictability, and so on [12]. Standardization of different flexibility products should take into account this granularity, providing sufficient alternatives that create value for all the flexible resources. Currently, this flexibility does not have any market value because it is impossible to bid in any organized marketplace.

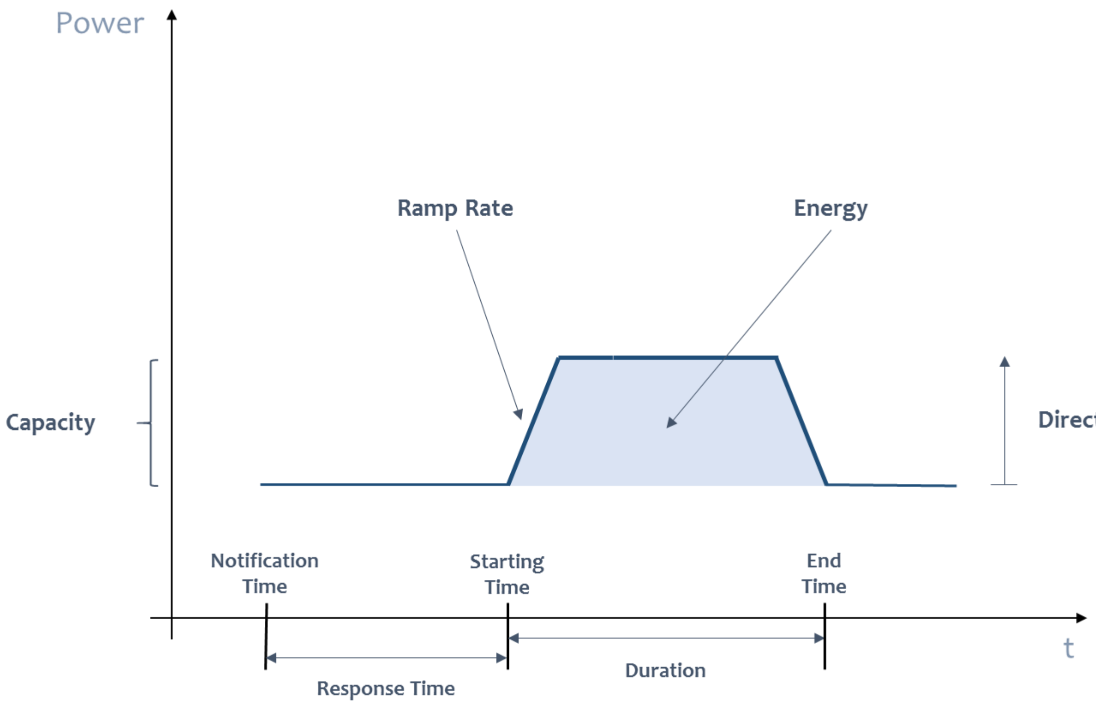

Figure 3.1 – Flexibility attributes.

One significant categorization for the flexible resources is between residential and industrial type.

The management of industrial flexibility for interacting with the market (day-ahead or ancillary services) can be easier due to main reasons:

- Due to the bigger size of the flexible loads and generation, a lower number of resources is needed to reach a critical size for participating in the market;
- The ICT framework is often already installed in the industry sector, optimizing the energy consumption through an energy management system; lower investments are then needed to install the communication technology.

Residential flexibility introduces more complications [15]:

- a layer of uncertainty is added when coming to predict and procure the available flexibility from residential customers because these loads have direct relation to users' behaviour and comfort; E.g., controlling the set-point of residential heat pumps for space heating, thus changing the power consumption, will sooner or later (depending on the thermal inertia of the heated space) affect the internal temperature of the building;
- inter-temporal constraints of some resources, such as smart appliances, come into play. The flexibility available at time t depends on the flexibility offered and possibly activated at time t-1; this makes more challenging the scheduling and forecasting processes of the flexibility available for a longer time (such as one day-ahead scheduling);
- size of the loads and costs to be incurred make unfeasible the opportunity of participating in the market for a single household.

Moreover, electric flexibility can be procured for different purposes. Three main different uses can be highlighted [10][11]:

- **Market-oriented use**: the flexibility can be used for solving portfolio imbalances of BRPs if offered in a common marketplace, or can be used internally for solving imbalances if the aggregator is the same entity of the BRP;

- **Grid-oriented use**: the locational value of the distribution-level flexibility can be deployed for mitigating local problems, such as congestions, voltage issues, or local net-load variations. Ancillary services products coming from the transmission level does not have the same effectiveness because they are located in a different place.

- **System-oriented use**: distribution-level flexibility can be sold back to the TSO for solving balancing purposes or for limiting the activation of the reserve. The gap in terms of size is significant and the contribution is very small but in the future, with the increase of the flexibility potential existing at the local level, these resources can have the same potential of the standard reserve that used to be deployed in the past.

3.3 Flexibility providers

The growth of the Distributed Energy Resources in the distributed sites can potentially materialize in flexibility by injecting the surplus energy into the distribution grid. On the other hand, renewable power generation can be considered as a tool of flexibility through curtailment and downward regulation. In this section, renewable as well as non-renewable resources listed below are considered as flexibility providers.

3.3.1 Non-renewable sources

The historical source of flexibility is the fossil-fuel and nuclear production, and hydraulic plants. The flexibility of the production is based on the possibility to reserve part of the production to support the system if needed; power-plants under normal operation can reserve part of their capacity to provide either downward or upward power regulation, namely spinning-reserve; a more expensive solution, is constituted by the starting-up of non-spinning reserve, namely fast generators, such as gas turbines or diesel generators.

3.3.2 PV and Wind systems

The common practice for reserve procurement is to adjust the fossil power generation to prioritize the power production from renewable sources, leading to increased share of renewables in the energy mix and decreasing the GHG emissions. On the other hand, the RES can provide downward regulation, through power curtailment to provide flexibility services needed for technical or economic reasons. The figure 3.2 shows that wind and PV systems constitute an important flexibility source for the grid.

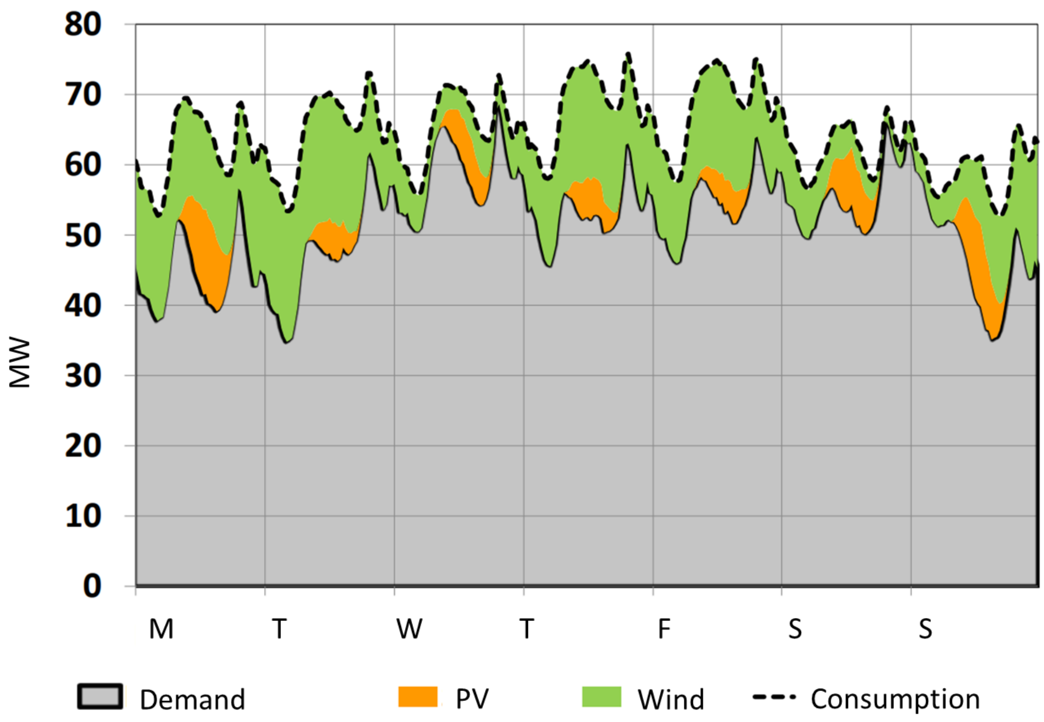

Figure 3.2 – Flexibility potentially available from renewable energy sources – (Source: RTE [15]).

E.g. in the North, Northeast, and Northwest of China, the curtailed renewable power generation from Wind amounted to 12.3 billion kWh in 2011. In Spain, it was 0.315 billion kWh in 2010. Concerning the solar power generation, the worldwide-curtailed energy was valued to be around 130 billion kWh in 2013 [16].

3.3.3 Energy storage systems

Pumped-storage hydroelectricity consists in pumping water from a lower elevation reservoir to a higher elevation, usually using off-peak electric power, for producing electricity (through hydro-turbines) in periods of high electrical demand. Italy is first in Europe with

7.5 GW of installed capacity, followed by France (6.9 GW) and Germany (6.8 GW); 2.5 GW of pumped-storage are planned or under construction until 2020 [17]. Storage gives to the network an additional degree of freedom, per consequent increases the flexibility highly requested by the DSOs.

The development of battery storage systems, both at the industrial and residential level, is now limited by the big investment and cycling costs. The development of technology will make the resource accessible to more people, that can make an investment for ensuring its security of supply, or for optimizing their consumption through the storage, making profit by providing support to the utility grid.

3.3.4 Smart Appliances

Smart appliances are expected to grow at the residential level (washing machines, tumble dryers, dishwashers), making possible the scheduling of programmable processes at a later or sooner stage with respect to the usual time-of-use. The flexibility potential of this category, both upward and downward, is conditioned by the degree of involvement of the end-user. Right incentives and social awareness need to be developed in order to increase the participation of the future prosumers, stimulating an effective consumption pattern.

3.3.5 Thermostatically Controlled Loads (TCLs)

Residential or industrial loads that supply space heating or cooling such as heat pumps, chillers, and refrigerators can be used to provide flexibility services by adjusting their consumption upwards or downwards. The limit to their flexibility is constituted by the violation of the comfort limits of the space where they are operating. Nevertheless, they can exploit the thermal inertia of the environment (which depends on the surface, occupancy, insulation) for providing short-term services to the grid.

3.4 Key stakeholders

This section will give an overview of all the actors in the power system that will be interested in the flexibility provided at the distribution level.

- Consumer (Prosumer)
- BRP
- Aggregator (Independent Aggregator)
- Energy Suppliers
- Distribution System Operator
- Transmission System Operator

3.4.1 Consumer (Prosumer)

The figure of the end-user is changing with the possibility of being more active in the energy sector. Its active role derives from the growing interest in Demand-Response programs, aiming to stimulate a 'consumer behaviour' that can support the grid in keeping the real-time balance. Moreover, distributed generation and storage can also be present at the consumer' premises, giving him the possibility of exchanging power with the grid in a bi-directional way. Enabled by the use of smart controls and communication technologies, consumers will transform from paying passive agents to active providers of energy services (prosumers), or may even compete with the traditional energy utilities [18].

Prosumers involvement is one of the key enablers of the future power system. Nowadays, single prosumers cannot participate in the energy markets. Policy makers need to come up with good incentive schemes or tariff structures which can give a level-playing field to system operators and energy suppliers to stimulate the participation of the end-users.

The prosumers can establish different flexibility contract with the aggregators: depending on the level of freedom they want over their consumption. Two extreme alternatives are the direct control, and the voluntary participation. Direct control implies that the aggregator can directly overrule the normal control of the appliances when needed from the flexibility buyer. Voluntary participation means that the prosumer can decide day-by-day or hour-by-hour if he wants to give availability to the aggregator. Alternatives to the middle concern more complex contracts in which the two-parties may agree on modalities and time of the day over the use of flexibility.

3.4.2 Balance Responsible Party

Any consumer connected to the grid is a Balance Responsible Party, it means that is responsible for keeping its balance. Small-to-mid size consumers outsource this responsibility to a third party (for residential consumers is a matter of the energy supplier). Any participant in the day-ahead market, or having bilateral agreements but using the public grid, will send its Energy Programme to the market operator (which is the Transmission System Operator) and after the gate closure, this programme will become financially binding. In Fig. 3.3, a general temporal line for the energy and ancillary services market is depicted. Time horizons of some market, such as the ancillary service markets, can differ from country to country within the European Union. In any case, any imbalance in the real withdrawals and injection of energy from/into the grid with respect to the day-ahead programme will be settled by the TSO depending on the national regulations.

Balance Responsible Parties have different possibilities to compensate for their imbalances via the intra-day markets but also through various ancillary services markets. The imbalance settlement which will occur after the delivery time will take into account the energy programme and all the following adjustments up to the delivery time, due to participation in different energy markets. BRPs are interested in the aggregated flexibility coming from the distribution system because it can be another hedging tool for mitigating imbalances in their portfolio. On another side, activated flexibility by a third party (e.g. independent aggregators) on their clients can be a problem if they are not aware of this.

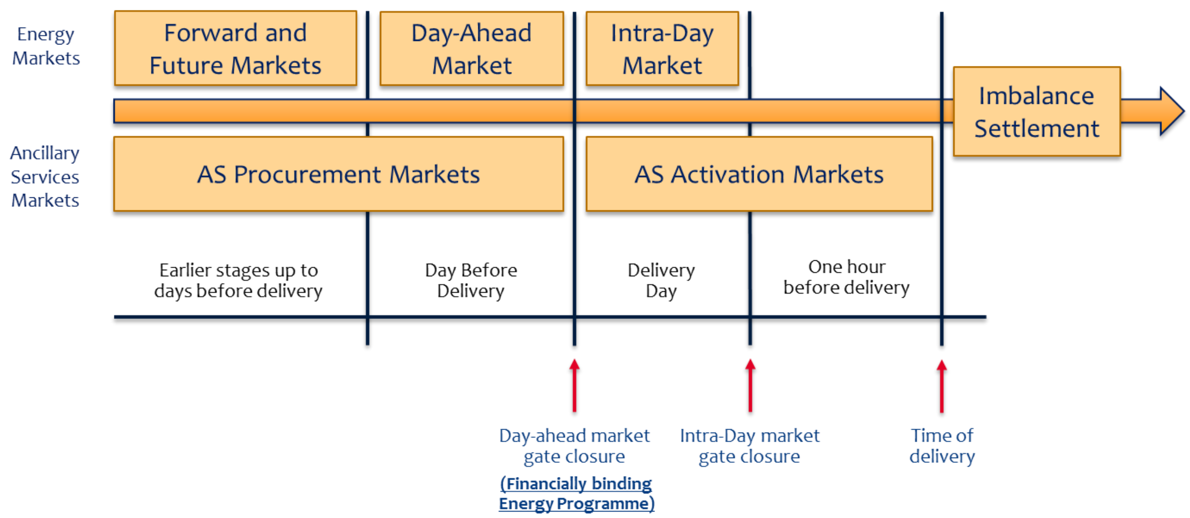

Figure 3.3 – Temporal line of energy and ancillary services market.

3.4.3 Aggregator

In the European Directive on Energy Efficiency of 2012, the aggregator was essentially defined as a demand-response provider, so as a mean to gather short-term duration load, otherwise unable to participate in any organized energy market. The focus was on demand-response as a tool to empower customers and promote energy efficiency. In the recent legislative proposal for a European directive on common rules for the internal market in electricity, the definition of aggregator changed to the following statement:

> *"aggregator means a market participant that combines multiple customer loads or generated electricity for sale, for purchase or auction in any organised energy market";*

The definition changed for embracing both consuming and producing units, thus considering all DERs' flexibility.

Furthermore, the concept of "independent aggregator" is also introduced in [19], meaning an aggregator that does not need to be associated with a Balance Responsible Party to participate in the energy markets. This put at risk the portfolio of the BRP associated with the end-users. Figure 3.4 explains the mutual relations between prosumers, aggregators and Energy Supplier (BRP).

If a downward flexibility regulation is deployed from an independent aggregator, after the delivery time, the BRP will face an imbalance due to the flexibility activation of the end-users. This highlights a gap in the regulation that should define a kind of agreement or compensation payment between independent aggregator and BRP in order to ensure that balancing and energy costs induced by aggregators are fairly allocated among the market participants.

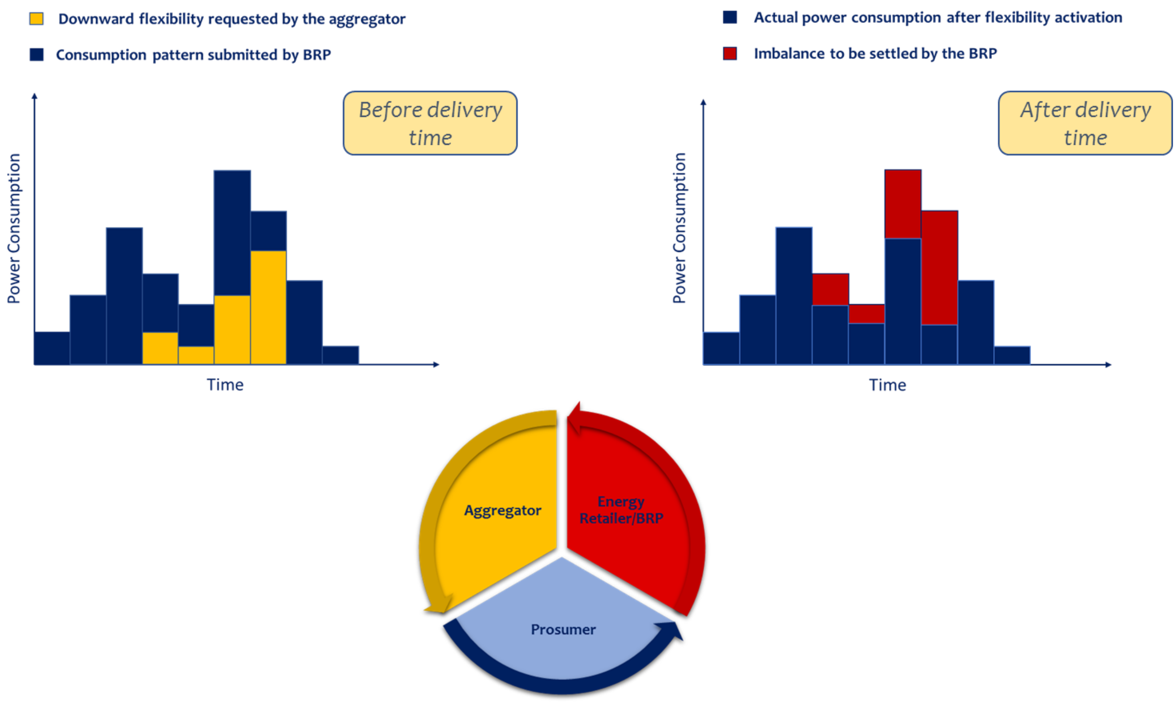

Figure 3.4 – BRP-independent aggregator implications with flexibility activation.

The European Union within the recently released 'Clean Energy for All' package (also known as Winter Package) clearly identifies the enablement of the independent aggregators as a milestone for the market integration of DERs. A regulation should be proposed for embedding the aggregators in the actual framework, allowing them to establish contract directly with the end-users, acting as an intermediary between the small-scale flexible resources and the energy markets.

Currently, in Europe only two countries have defined a complete regulation on independent aggregators. In France, three different options are given [20]:

- *contractual regime*, agreed directly between aggregator and energy supplier;
- *regulated regime*, where aggregator pays to the BRP a fixed tariff decided by the TSO;
- *corrected regime*, where the aggregator is invoiced for the energy component of the energy that would have been consumed by the end-user without flexibility activation.

In Switzerland, the aggregator contracts directly with SwissGrid (the swiss TSO); the day after the operation the TSO corrects the parameter of each BRP considering all the operations that have occurred in the specific area [21]. So, in this case there is no agreement needed between BRP and aggregator.

3.4.4 Energy Supplier

The situation regarding the Energy Supplier is similar to the one described for the BRPs. Energy suppliers can have their Balance Responsible Party for their portfolio or they can be themselves a BRP. In any case, the influence of flexibility aggregation and activation by a third party is influencing his financial settlement with the TSO. Another aspect to mention is that if the Energy Supplier is acting as BRP itself it can have an interest in having also the function of aggregator. In this case the energy supplier and the aggregator can coexist in the same utility (AggSup) and manage both the supply of the electricity and the flexible consumption/production of the customers. They can use flexibility at the distribution level for solving internally the imbalance, thus minimizing the penalty cost.

3.4.5 Distribution System Operator

As previously mentioned, the DSO will face a paradigm change in their duties in the coming years. The distribution network will change significantly, hosting generation and consumption, allowing bidirectional flow, becoming more dynamic. The DSO will act as active manager of the grid because the growing number of DERs will introduce challenges such as congestions, voltage issues, further imbalances. The 'fit and forget' approach is no longer suitable, and DSOs will change their planning procedure by procuring flexibility services as an alternative to grid reinforcement. One option is to establish contractual agreements directly with the flexibility provider (e.g. the aggregator). Another option is the implementation of market-based mechanisms for procuring flexibility. Within the Proposal for a Directive on common rules on internal electricity market, is interesting to highlight the following article in which the EU Commission states that:

> *"Distribution system operators to procure services from resources such as distributed generation, demand response or storage and consider energy efficiency measures, which may supplant the need to upgrade or replace electricity capacity and which support the efficient and secure operation of the distribution system. Distribution system operators shall procure these services according to transparent, non- discriminatory and market-based procedures.*
>
> *Distribution system operators shall define standardised market products for the services procured ensuring effective participation of all market participants including renewable energy sources, demand response, and aggregators."*

Market-based procedures are expected to be established in the future for supporting the DSO in the management of the grid, for avoiding or deferring grid investment costs. A preliminary condition for the implementation of such changes is an adjustment of the remuneration scheme of the DSO considering new strategies of grid managements. This involves also the possibility of offering Time-of-Use or power-based network tariff, which can stimulate effective use of flexible resources.

3.4.6 Transmission System Operator

The TSO is usually procuring services for balancing the grid via contracting and activating primary, secondary and tertiary reserve which have different requirements in terms of activation time, response time and communication infrastructure. Mechanisms (long-term auctions, bilateral agreement, mandatory commitment for big units) for procurement the necessary resources (capacity or energy products) differ in each country, and the timeframe ranges from months to days before the actual delivery.

The changing structure of the distribution network will lead to increased power exchange between the transmission and the distribution level. Enhanced coordination between TSO and DSO will be needed to have the necessary data exchange to optimally manage the grid. The possibility of procuring balancing services also from the Distribution Level need to be regulated in such a way that the power exchange does not violate constraints in the domain of the DSO. The regulators are working in the direction of increasing the granularity of the wholesale energy markets to allow participation of aggregators and DERs (e.g. reducing the minimum bid size), while increasing the responsibility of the DSO in managing the distribution grid.

4. Interaction of commercial microgrids

CMs can provide their services to different stakeholders in the short-term markets. They have two main ways to value their services:

- At the wholesale level, by providing transmission-level ancillary services or by participating in the intra-day market.
- At the local level, by distribution-level flexibility services that can be used for market-purposes or grid-purposes.

The procurement of ancillary services from the distribution level will increase in the future, thus DERs market integration is a key-issue to overcome the management problems that the system operators (both at the transmission and at the distribution level) will face in the future. The increase in the flexibility requirements on one side and the exit of traditional flexible resources on the other side are leading to the research for alternative sources of flexibility. DERs can provide flexibility on different time-scales, dependently on the technology.

The European Union have recognized the interesting potential of small-scale DERs in providing flexibility, so in the coming years, the energy markets will undertake a regulatory change for valuing this new flexibility potential. There are two different trends:

- On one side there is the trend of re-adjusting the short-term markets, for allowing the participation of small-scale actors.
- On the other side, the penetration of DERs concurrently with the shifting of the operational problems to the distribution network is increasing the interest in local markets.

4.1 Interaction at the wholesale level

At the wholesale level, different markets are operated with different aims. As previously depicted in Figure 3.3, after the closure of the day-ahead market, the BRPs tries to repair for their imbalances, exploiting the shorter horizon of the forecasting techniques. There are two main options for the interaction at the wholesale level:

- The intra-day market, operating from the closure of the day-ahead market up to one hour prior to delivery;
- Ancillary Services markets: market-procedure operated by the DSO for procuring the services needed for keeping the quality and security of supply.

The intra-day market is favourable for correcting the erroneous positions. BRPs try to repair by selling energy which is forecasted to be no longer used, or by purchasing energy which was not forecasted to be used before. For the reserve markets, the TSO managed the balancing operation of the grid by contracting resources at the transmission level. The reservation phase (year to months prior to delivery) can also be realized via auctions. The activation phase, in real-time, can also occur via calling for tenders. Mechanisms and time windows for procuring ancillary services, both frequency AS (balancing) or non-frequency AS (voltage control, black start) depends on the specific national regulation.

A focus, is given here, to the balancing services that can be provided. A uniform definition is present for the balancing reserve, needed for keeping the balance between supply and demand. We can usually distinguish three different layers [17][18]:

- Primary frequency control: fast activation devices, usually primary control of the turbine speed governor in big generating units are deployed for limiting the deviation from the frequency setpoint after the occurring of an imbalance in the control area. Frequency Containment Reserve (FCR) is used for the primary frequency control, involving operating reserves with an activation time up to 30 seconds;

- Secondary frequency control: a central controller for each control area automatically activate the secondary control power of the contracted power stations in order to keep the desired energy interchange between the different control areas. As a condition these power plants must be in operation keeping an amount of power for reserve provision, in order to meet the requirements of the central controller whenever requested. It is also used for restoring the frequency within the control area after a contingency. The reserve used is the Frequency Restoration Reserve (FRR) which is an operating reserve necessary for restoring the frequency and relieving the FCR if the deviation lasts more than 30 seconds. Activation time should be between 30 seconds and 15 minutes.
- Tertiary frequency control: it is mainly used for relieving the FRR and restoring the desired amount of FRR for future actions. It is realized by manually changing the set-point of the generators (re-scheduling) due to major, persistent control deviations. The reserve used is the Replacement Reserve (RR). Activation time is from several minutes up to hours.

Non-frequency ancillary services (such as reactive power provision, black start) are also an opportunity but their structure is less uniform among the European Countries with different regulations and type of products depending on the specific grid and its weak points.

4.1.1 Barriers to market access

Traditionally, the short-term markets were designed around the capabilities of big generating units, since they were the providers of balancing services. The requirement for accessing the market is being a Balance Responsible Party. The independent aggregator cannot directly bid into the market because the regulation does not clarify how the compensation payment will be realized with respect to the BRP in charge for the baseload consumption. So, a contract with a BRP has to be established to allow him the market participation. Thus, market-use of flexibility (providing flexibility for repairing BRP's imbalances) is limited from the fact the market access is not allowed. The flexibility can be offered only to the BRP with which the aggregator has a direct contract, basically conducting the aggregation function for another commercial party. A fairer approach would be reached by giving to the independent aggregator the possibility to sell its flexibility on the intra-day market to best buyer.

Recently, the interest in Demand Side Management (DSM) as flexible resource led to the re-adjustment of the markets in order to allow for aggregator's participation. Aggregation is recognized as an unavoidable step to integrate small-scale resources in the market framework.

Table 4.1 gives an overview of most European countries, defining where the aggregator as a manager of flexible resources (loads or generation) can have access to the market. The intent is to give a general overview by taking into account the main markets: day-ahead, intra-day and reserve markets. Reserve markets are divided into the three categories described above. In each specific country, market or contractual mechanisms for procuring reserve are more than one and occur with different modalities, obligations, and time windows. Here, *Yes* means that the aggregator (BRP-associated) can participate in at least one market mechanism.

Country	Day-Ahead Market	Intra-Day Market	FCR	FRR	RR
Austria	Only generation	Only Generation	No	Yes	Yes
Belgium	No	No	Yes	No	Yes
Denmark	Yes	Yes	Yes	Yes	Yes
Estonia	No	No	No	Yes	No
Finland	Yes	Yes	Yes	Yes	Yes
France	Yes	Yes	Yes	Yes	Yes
Germany	Yes	Yes	Yes	Yes	Yes
Great Britain	No	No	Yes	Yes	Yes
Greece	No	No	No	No	No
Ireland	Yes	Yes	Yes	Yes	Yes
Italy	No	No	No	No	No
Netherlands	Yes	Yes	No	Yes	No
Norway	Yes	Yes	Yes	Yes	No
Poland	Yes	Yes	No	No	No
Portugal	No	No	No	No	No
Slovenia	No	No	No	No	Yes
Spain	No	No	No	No	No
Sweden	Yes	Yes	Yes	Yes	Yes
Switzerland	Yes	Yes	Yes	Yes	Yes

Table 4.1 – Aggregator access to the energy markets in most of the European countries (Source: [16]-[19]).

Theoretically, in the recent years, there has been a trend to open short-term markets to the participation of Demand Response Providers. Practically, a re-adjustment of the short-term markets is needed for allowing aggregator of small-scale flexible resources to bid in the organized marketplaces. Some key points are:

- Minimum bid size: an overestimated bid size for entering the market could be a significant barrier for aggregators of flexible resources, that may have to engage a significant number of customers to reach a critical size for entering the market; recent trend in the regulators is to lower the minimum bid size to 1 MW, which can be considered reasonable for flexibility access;

- Symmetric bidding requirements: in some reserve markets the bids are required to be symmetric in both upward and downward regulation; since aggregators can have unidirectional flexibility providers (residential or industrial loads) in his portfolio, this may not be available in both directions for each period time unit;

- Activation time: this is typically designed for big generation units, so contracted reserve may be required to be online up to 10 hours, which is not compatible with small consumers-flexibility, even if aggregated

4.1.2 Aggregators: significant examples from European Countries

Business cases for aggregators are already existing in some countries. The countries that are ahead in defining alternative ways of procuring reserve or ancillary services, such as France, Belgium, United Kingdom constituted the optimal level playing field for aggregators (originally only as demand response providers) to start their activity. Several examples are reported in Table 4.2.

Name (Country)	Clients/Flexible resources	Purpose	Remarks
Energy Pool (France) [25]	Industrial and Commercial DSM	Participation in balancing markets, security reserve and capacity markets	Now, the company operates also in UK and Belgium, having contracts with the TSOs in those countries.
Flextricity (UK) [25]	Large industrial and commercial customers (>500 kW)	Short-term operating reserve (STOR), frequency reserve and capacity markets	Active since 2004, provides both generation and load aggregation
KiWi Power (UK) [26]	Industrial customers	Frequency response, reserve market services and network constraints management	Provides different Demand Reduction Strategies depending on the specific type of customer
Next Kraftwerke (Belgium) [27]	Distributed Renewable Generation and flexible demand	Own portfolio balancing; reserve and capacity markets; wholesale and retail markets	It is active in different countries providing different services depending on the national context (own balancing in Germany)
Ngenic (Sweden) [9]	Cloud-based control for residential heating system	Focus on energy consumption optimization and energy efficiency	Start-up phase
REstore (Belgium)	Industrial and commercial DSM	Participation in Ancillary Services Market and Capacity Markets	Managing more than 1,5 GW of Industrial capacity in 4 different countries
SEAM (Finland) [9]	Industrial clients / DSM	Optimize energy consumption; FCR provision to TSO	Founded in 2011
Voltalis (France) [28]	Domestic Electric heating systems and Industrial DSM	Short-term shedding for residential household	Directly control appliances when the TSO sends signals

Table 4.2 – Aggregators in the energy sector in Europe.

Two main aspects group these business-cases:

- Exploitation of flexibility from industrial assets is already in place, as demonstrated by many business-cases. A smaller number or resources is needed to have the necessary size for bidding in the short-term markets.
- The use of residential assets is now limited to specific cases in rural areas or sensitive spots in the grid. Otherwise, the use and aggregation of residential loads are made with the purpose of energy efficiency or bills reductions.

The upcoming regulatory change is expected to enable profitable business cases for small-scale aggregators managing CMs to access the energy market.

4.2 Interaction at the local level

In addition to offering flexibility-services to transmission-level wholesale markets, CMs may also be able to offer valuable flexibility services locally. At the local level, the main buyer of flexibility services is the local Distribution System Operator (DSO).

The DSO is responsible for maintaining and operating the electric grid at the distribution level. As discussed in Section 3, the roles and responsibilities of DSOs are evolving because of, for example, increasing amounts of distributed generation, storage, and demand response. These developments result in power flow patterns that differ from the demand-driven flows that distribution grids are typically dimensioned for. Because the existing distribution networks are not designed for these new requirements, issues related to local congestion or voltage violations may arise.

To cope with these new challenges, some investments in new equipment at the distribution level are likely to be necessary. However, as an alternative to expensive investments, DSOs could choose to more actively manage congestion and voltage in their networks. This creates a demand for local flexibility services, such as from CMs.

As opposed to transmission-level ancillary service markets operated by TSOs, DSOs are typically not concerned with frequency-related ancillary services since they are not responsible for balancing supply and demand in every moment. Instead, local flexibility services are limited to ancillary services with a locational aspect. Congestion management and voltage control are examples of such services since they are only effective if delivered at the right location.

Another potential buyer of flexibility is the Balance Responsible Party, which may be interested in procuring flexibility at the local level as another hedging tool against its long or short position in the market, which may cause penalty costs.

However, from the perspective of the service supplier, such as a consumer participating in a CM, it may be irrelevant what the service is sold as. For example, both congestion management and frequency control require an increase or decrease in active power withdrawals from the consumer. The result for the consumer could, therefore, be the same if the service is sold locally for congestion management or if it is sold to the TSO for frequency control.

4.2.1 Local flexibility market design: key aspects

As we discussed, the growing demand for local-flexibility services and the potential offer coming from the emerging DERs are leading to the interest in local flexibility market. A platform where flexibility can be traded at the local level. With the exemption of research projects and demonstration sites (a few of which are discussed below), there are typically no organized markets where CMs can offer flexibility-services to local entities. The idea of a market for local flexibility services is still relatively new, and the need for such services has not yet fully materialized in many places. Moreover, conditions for the establishment of a market include a sufficient level of competitiveness and sufficient liquidity in the commodity to be traded. Both conditions are not satisfied, since aggregators and flexibility sellers still are an emerging figure in the energy sector, developing the technology and the business cases for profitably entering the market; furthermore, the amount of available flexibility will increase in the future due to the penetration of DERs but at this moment, might be not enough to ensure the right functioning of the market.

A key issue in the market design is the relation between grid-oriented and market-oriented use of flexibility. The DSO is seeking flexibility for mitigating technical problems that might encounter in the near future and BRPs or Energy Suppliers are seeking flexibility for repairing market imbalances. A market design principle is that it should provide market access to all interested parties, so limiting the market-based procurement to only one use (market or grid-oriented) would violate this principle. Rather, the challenge is twofold: one on side ensuring the priority of grid-use which is oriented to ensure the quality and security of supply in the distribution network; on the other side ensuring the afore-mentioned principle by allowing market-oriented use.

One interesting concept on the coordination of different flexibility use is the traffic light concept [29] that differentiate between the network state being adequate (green light) or congested (amber and red phase). When technical problems are not expected, the market can run with full competitiveness because the DSO is not interested in flexibility. In the slightly threatening situation, the DSO (amber phase) might start to interact with the market for procuring flexibility. In the red phase the DSO take over the control of the network for avoiding imminent risk or failures.

The time window, and time unit, as well as the flexibility product standardization, are also relevant design aspects. The collocation in time of the local market should be aligned with the already existing wholesale market for allowing market actors to bid both at the local and the wholesale level. Product standardization should take into account the characteristics of small-scale flexibility and the variety of DERs that can provide this kind of service.

A market-based procedure is not the only option for procuring local flexibility services. Although transmission-level ancillary service markets typically operate (at least in the activation phase) as short-run, bid-based, and centralized markets for standardized services, this is not necessarily the best way to operate ancillary service markets at the local level. As previously discussed, since local flexibility services are highly location-specific, there may only be a small number (or perhaps only one) flexibility service provider capable of delivering the required service. There may therefore not be sufficient local competition among service provides for a short-run bid-based market to work effectively. In such an environment, it is likely to be more efficient to base transactions between CMs and DSOs on negotiated long-term contracts. In the flexibility tool-box, we will present two mechanisms: one based on a market-based procedure, and another one based on bilateral contract between the DSO and a CM.

DSO will more likely take the role of more proactive manager of the distribution grid in the future. A regulatory change, encouraged by the European Union, is expected to change the business model of the DSO. DSOs can be characterized as natural monopolies, so they are often highly regulated. The remuneration scheme of the DSO will be based on different evaluation factors and allow it to recover the cost of the establishment of a market-based procedure for flexibility services.

4.2.2 Examples of local flexibility markets

This section highlights a few European research projects related to local flexibility service markets.

The EMPOWER project [1], with pilot demonstration sites in Norway, Germany and Malta, includes a local market design and trading concept, leading to a platform-based business model. The local market can operate both in islanded mode or connected with the central market. The connected mode brings more commercial opportunities while the island mode increases the technical challenge of autonomously keeping the power balance. This market model is based on forward contracts and futures between the Smart Energy Service Provider (SESP) and the members of the community (prosumers, consumers, storage owners and so on). The available flexibility agreed upon contractual terms can be used to correct local deviations from the Energy Plan, for participating in the Tertiary Reserve market or for solving a DSO request (whose relationship with the SESP, acting as an aggregator, is established on a contractual agreement) [30].

The iPower Platform in Denmark [3] has developed a clearinghouse concept for flexibility services at the distribution level, called FLECH [4]. The concept is based on a centralized clearinghouse where DSO is acting as the sole buyer of flexibility offered by different distribution level aggregators. The market is intended to become a tool to embed in the DSO's planning and management of the distribution network, to provide economically-efficient alternatives to grid reinforcement. There are two different phases: the reservation phase where medium-term (1 or 2 years) contracts are established between the DSO and aggregators: this ensures that the DSO will always have flexibility sellers when there is a call for auction. When there is a need for flexibility, starts the activation phase that consists of a market clearing of flexibility offers, in form of standardized products, from contracted and non-contracted aggregators [31].

In Sweden, the Fossil Free Energy District project (FED) [32] is demonstrating a local energy market, where market participants within the energy district trade energy among themselves, while also offering flexibility services to the local DSO. With this market structure, individual market participants can offer flexibility services to the DSO through the FED market interface.

5. The flexibility tool-box

In this chapter, we will elaborate on the flexibility tool-box: a market-based procedure and a clustering algorithm developed with the purpose of exploiting the flexibility from distribution level-resources. The flexibility tool-box concerns the exploitation of the flexibility within the local distribution system, without considering the interaction with the transmission grid or the TSO. Distribution network will evolve in the future due to the rapidly changing nature distribution-level customers towards the prosumer role [18]. Becoming prosumers, they will own production or storage facilities at their premises, eventually providing energy or flexibility services to the interested parties: DSOs, TSOs, Aggregators and BRPs. While end-users are more directly involved in the energy market, the Distribution System Operator will evolve from a passive operator, who takes care of the maintenance and the long-term planning of the distribution network. Rather, he will evolve as an active manager of the distribution grid, being involved in the short-term management induced by the dynamics of renewable energy production and enabled by the enhanced observability on the distribution grid, due to the improvement of the Information and Communication Technology (ICT) framework.

In the first part, a local market framework for trading flexibility is introduced, giving an overview of its structure, market participants, clearing mechanisms, and mathematical formulation.

Despite the local market is the widely adopted solution by the European Union, which is pushing the Member States to establish rules for allowing a more active role of DSOs in procuring flexibility services via market-procedures from small-scale actors, there could be some exceptions. For lack of liquidity or competition the market could not be established, so a bilateral contract between the DSO and a Commercial Microgrid (CM) can help solving technical problems via the deployment of flexibility. We propose a day-ahead flexibility procurement, based on a clustering algorithm, which aims to group the available flexible resources according to on their capability of solving different technical problems at the same time. If the algorithm finds a solution, the selected cluster can help solving partially or totally the grid-problems.

5.1 Local Flexibility Market: previous experience from DISPATCH project

As reported in [33], a market is an environment designed to help potential buyers and sellers of a given economic product to interact and reach an agreement on transactions. The following framework is intended to provide a basis for commercial actors to invoke and procure flexibility available from potential providers, such as prosumers, aggregators, DER and/or RES owners. For discussing the proposed market mechanism, four different points need to be highlighted:

1. Market participants
2. Commodity or service to trade
3. Market operator and market clearing mechanism
4. Structure and time windows

5.1.1 Market participants

A local flexibility market (LFM) is assumed to consist of at least one market platform, a number of aggregators/suppliers, one Distribution System Operator and a number of Balance Responsible Parties all competing for the flexibility available at the distribution level. [34]

a. **Aggregator/Supplier (AggSup)**: as mentioned in the section 3.2.4, if a supplier has itself balance responsibility for their portfolio it can have interest in managing the flexible share of the energy of their consumers to repair for the imbalance and continuously adjusting the energy programme to minimize the penalty cost due to the Transmission System Operator. In this case, AggSups are considered because are in contraposition with BRPs. In short, AggSups have a twofold role: supplier role, buying from the wholesale market the energy needed from the end-users, and the aggregator role, collecting information on the available flexibility from different prosumers and making this flexibility available for the LFM. Working in a microgrid environment, an AggSup can be representative of consumers that are widespread in a distribution network: meaning that the aggregator role is performed by managing Commercial Microgrid (CM). If the AggSup is responsible for a physical microgrid, for a specific part of the network below the MV/LV transformer: it performs the supply of the baseload to the physical microgrid but also collects the available flexibility for each Market Time Unit (MTU) and makes it available for the LFM.

b. **Balance Responsible Parties**: entities responsible for keeping the supply and demand balance for a portfolio of producers and consumers (net sum of injections, withdrawals, and trades) over a given time frame (the imbalance settlement period). For avoiding short or long energy positions in real-time the BRPs can bid in different markets, including the LFM;

c. **Distribution System Operator**: the DSO is responsible for quality and security of supply in a specific network area, specifically medium and low voltage. The interest for procuring flexibility comes from the need for reducing congestion problems (here only congestions are considered as the sole technical problem that the DSO is trying to solve with flexibility services).

5.1.2 Commodity or service to trade:

In this work, flexibility is the services to be traded in the market-mechanism in response to a market need. A deviation from a predefined consumption or production pattern that commercial parties are able to provide for each MTU, in response to a command or a price signal.

An important attribute is the direction of flexibility: flexibility offers can be in two different directions since the suppliers can act as energy sink or energy source. Flexibility directions are defined with respect to the suppliers of flexibility:

a. Positive, when flexibility-supplier acts as an energy sink. They are required to increase their energy consumption (curtailment of roof-PV self-consumption, turning on smart appliances, charging storage devices)

b. Negative, when the flexibility-supplier acts as an energy source. Thus, they are required to decrease their energy consumption at that specific time (curtailment of rooftop-PV production injected into the grid, shift or adjust smart appliances consumption)

The same definition is adopted for a flexibility request so, if a BRP or the DSO as a need for the sellers to decrease their consumption they will send a request for a negative flexibility.

5.1.3 Market operator and market clearing mechanism

An LFM is a trading platform where participants can provide or monetize flexibility services. The assumption here is that the market operator is an independent entity that takes care of managing the bidding platform and clearing the market. The main reason is that the market operator should ensure the neutrality of the market, in which both regulated entities as DSOs and market-agents as BRPs are participating. The market clearing is the process where all flexibility offers, and requests are collected, determining the market equilibrium in terms of traded volume and equilibrium price.

Market participants send their flexibility offers and requests in the form of bid pairs. Different possibilities are considered to form the bid:

a. Bid pairs for MTU, where market participants submit their bid pairs (quantity/price/direction) to the market. The market operator then clears the market for every MTU independently from the other MTUs.
b. Bid profiles for a whole market horizon, so when the market operator clears the market, the profile is either wholly accepted or rejected.
c. Bid profiles for multiple MTU can be allowed due to intertemporal-constraints of flexible resources. The activation of flexibility at time t, can be conditional to the increase of the energy consumption in the following MTUs, so the bid profile is a unique block that after the market clearing is either accepted or rejected.

The MTU can range from 15 mins to 1 hour and depends on the specific energy resources, running in that geographical areas, as well as the regulation and alignment with the short-term wholesale markets. For the sake of simplicity, we consider the LFM operating in a geographical area where one DSO is operating, requiring flexibility to solve technical problems. The interaction with neighbouring local markets and the coexistence of multiple DSOs in the framework are not considered in this work.

5.1.4 Market structure and time-windows

The proposed framework is structured in two different scheduling sub-mechanisms to deploy the prosumer's flexibility in an economically-efficient way from the planning process to the real-time operation:

1) Ahead market-based scheduling
2) Real-time dispatching

The framework includes a market-based procedure (operated by the local market operator) that runs from the day before delivery until the closure of the wholesale intra-day market. If the ahead market mechanism fails to resolve technical problems and further adjustments are needed, the DSO will apply a set of control actions (direct or indirect, negotiating with aggregators), taking over the role of the market operator, applying a set of control actions for keeping the security of supply for its end-users. The ahead market-based mechanism includes two different phases: day-ahead and intra-day market. They will run in parallel with the correspondent wholesale energy market, clearing before, so that the market participants can update and send their new energy programme to the wholesale energy market, after the trading in the LFM. The assumption here is that the DSO has sufficient data to perform a power flow analysis of its own network for the next day, individuating critical moments and requesting flexibility for relieving network problems.

In this report, we will not discuss the real-time dispatching, but we will discuss in detail the two phases of the ahead market mechanism:

a) Day-ahead scheduling (DA)
b) Intra-day scheduling (ID)

The difference between the two mechanisms lies in the objective, the time horizon, the market participants, and the time elapsed between the closure of the decision-making process and the actual energy delivery.

Figure 5.1 gather together Figure 3.2 and the time-windows of the proposed Local Flexibility Market. The DA runs in parallel with the day-ahead market and it is cleared before the gate closure so that after the trading in the LFM, the market participants can send their latest updated energy programme to the day-ahead market operator. After that, in the intra-day planning, market participants can repair their imbalanced position and modify their situation right before the closure of the intra-day market by bidding in the ID scheduling of the LFM. After the closure of the intra-day market, nevertheless, it can happen that the DSO was not able to procure the amount of needed flexibility thus the real-time dispatching is meant to repair for unexpected deviation that may cause technical problems in the distribution network.

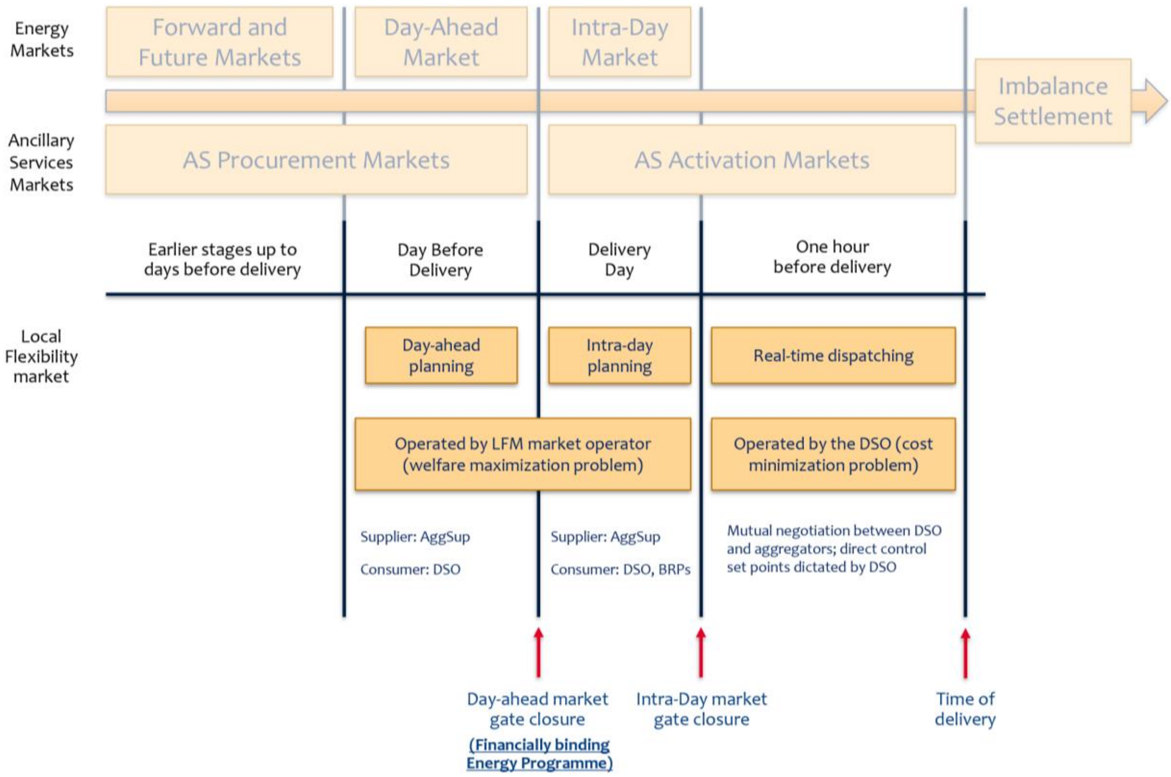

Figure 5.1 – Temporal line of the Local Flexibility market (DA and ID scheduling).

5.1.5 Day-ahead scheduling

In the day-ahead market clearing, the DSO defines the direction in which the flexibility should be cleared since it is the only buyer in this time windows; BRPs are excluded because they can adjust their positions in the day-ahead wholesale market. Figure 5.2 represents the steps necessary to clear the DA scheduling. In step 1, the AggSups collect the data of the energy baseload and flexibility offers received from the customers. The interactions could be on a daily basis or can be predefined by a contractual agreement in which the end-users decided modalities and time of the day where the AggSups can make use of his flexible devices. In step 2, if there is a contractual agreement in place between the DSO and AggSups, the AggSups transmit the aggregated energy profile to the DSO that performs a power flow analysis to assess any possible technical problem. If there is any contract in place, the DSO performs the risk analysis based on its load model. Grid information related to the technical problems are given back in step 4 to AggSups that submit the flexibility bid profiles to the LFM (step 5). LFM clears market taking into account the DSO requests and the AggSups offers and gives back the DA market results in step 7. After flexibility offers have been accepted or rejected, the AggSups can submit the optimal energy programme to the wholesale energy market.

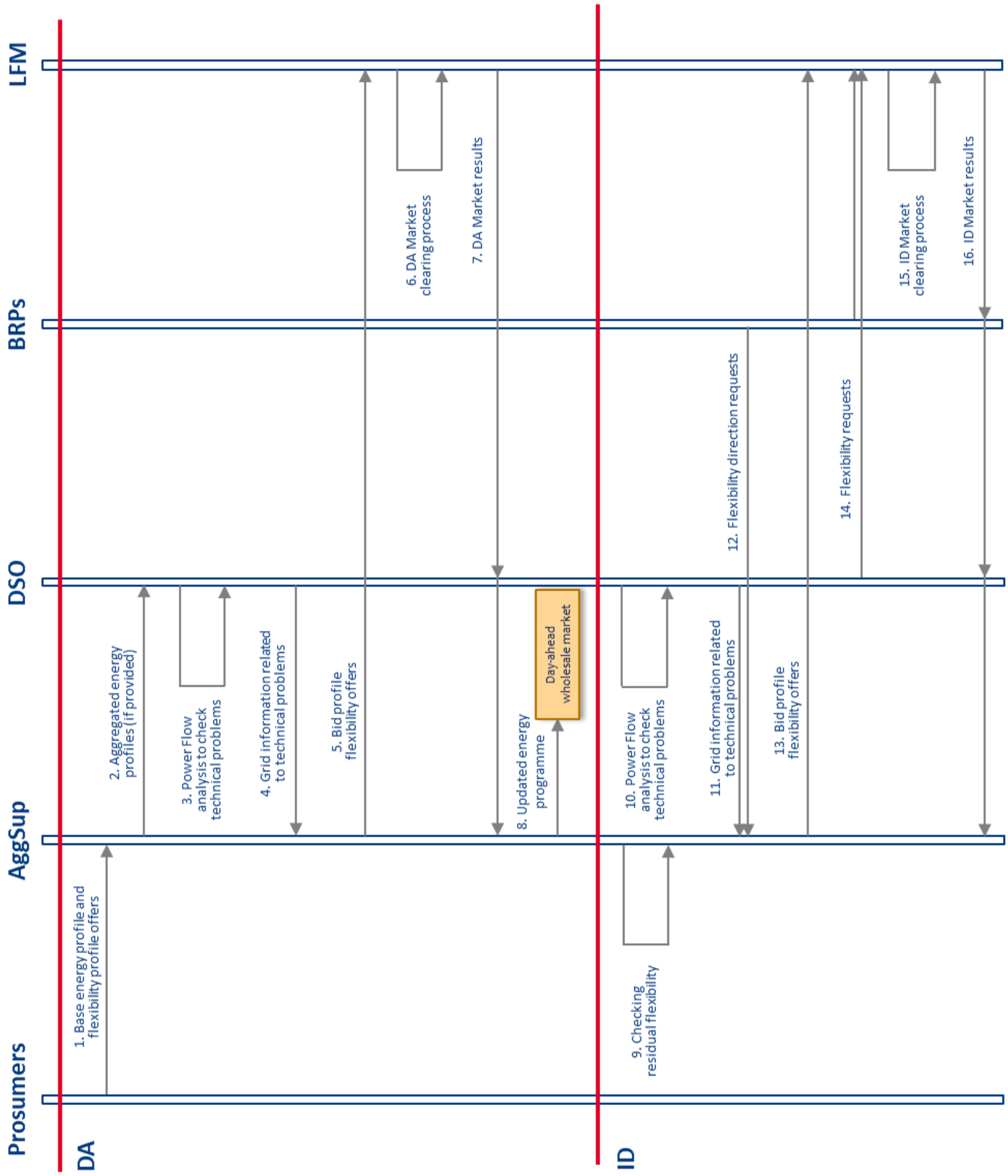

Figure 5.2 – Diagram of market agents' interactions in the LFM.

In this phase, the market clearing depends on DSO's requests since it is the only buyer of the flexibility. The DA scheduling clears before the closure of the wholesale day-ahead market, so that market participants can provide the updated energy programme, modified the flexibility transactions. The AggSup also has balance responsibility in the local flexibility market, for the flexibility that has been cleared in the DA scheduling. He will face penalty costs if he does not deliver the flexibility that has contracted in the clearing. It was outside the scope of this work the definition of a baseline, although it is of crucial importance for settling properly the imbalances and to verify if the traded flexibility in the day-ahead market procedure was correctly activated from the end-users.

5.1.6 Intra-day scheduling

The intra-day scheduling (ID) starts after the closure of the day-ahead market and runs in parallel with the intra-day wholesale market. Due to the uncertain nature of the market, the DSO might not be able to procure all the flexibility needed for solving the encountered technical problems. After the closure of the DA scheduling, the DSO runs another risk analysis (step 10) while the AggSups check whether all the flexibility have been deployed and what is the remaining availability. In this stage, the flexibility offers comes from two different parties: the DSO which requests flexibility for grid-purposes and BRPs that requires flexibility for market-purposes, so for repairing the imbalance of their portfolio. The LFM can be seen as another market-place that the BRP can use to adjust their imbalances, apart from the short-term wholesale markets. BRPs also send flexibility direction requests to the AggSup in step 12. The sellers send the bid profiles to the LFM that clears the ID market after receiving the flexibility requests from the DSO and from the BRPs (steps 14-15). Market results are finally communicated to all interested parties.

Here, flexibility is invoked for different purposes, and the market clearing of the ID scheduling takes into account the different direction requests of flexibility. Theoretically, the purposes of DSO and BRPs are different but that may indirectly affect each other's position. For example, a BRP may request flexibility in a direction opposite to the one requested by the DSO; if the flexibility request is accepted then the technical problems encountered by the DSO may become worse because of the activated flexibility. It may also be the opposite so that a flexibility request from a BRPs is relieving the technical constraints for which the DSO was asking flexibility to the AggSup. To consider this situation, the market clearing of the ID scheduling is defined as follows.

The schematic reported in Fig. 5.3 represents the market clearing process in the ID scheduling.

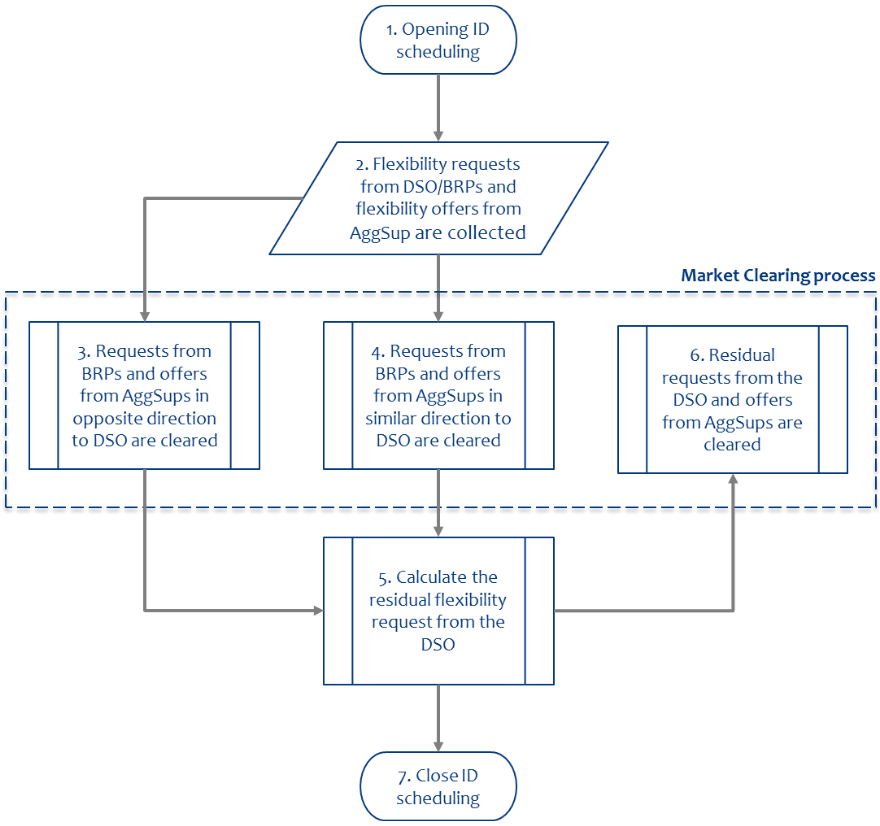

Figure 5.3 – Clearing mechanism for the ID scheduling.

After receiving all offers and requests, the market operator matches together the request from BRPs and the offer from AggSups, which are in the opposite direction of the request of the DSO (step 3). Step 4 consists in the assignment of a request from BRPs in a similar direction to the DSO to offers from AggSups. Finally, the residual flexibility needed from the DSO is requested by summing up to the original request, the flexibility cleared for the BRPs in the opposite direction (which tends to increase the need of the DSO) and subtracting to them the cleared flexibility for BRPs in the similar direction (which tends to improve the situation of the DSO). Step 6, consists in the nomination of the offers from AggSup that will solve the DSO's requests.

5.1.7 Mathematical formulation

This subsection presents the mathematical formulation of the market clearing for the DA and ID scheduling platforms. One DSO is procuring flexibility from $n(\Omega_a)$ AggSups. Ω_a is the set of indexes of all AggSups. Index a is used to refer to AggSups, Index d is used to refer to the DSO. The clearing mechanism is modelled as a social welfare maximization problem, over the scheduling horizon $n(\Omega_t)$ and Ω_t is the set of indexes of all the operating hours included in the scheduling horizon. The DA scheduling problem is formulated as follows:

$$\max\ S_{da} = \sum_{t\in\Omega_t}\left[B_{da}^{t} - G_{da}^{t}\right] \quad (1)$$

subject to

$$B_{da}^{t} = \beta_d \cdot \left|\rho_{d,da} \cdot q_{d,da}^{t}\right|,\ \ \forall t \in \Omega_t \quad (2)$$

$$G_{da}^{t} = \sum_{a\in\Omega_A}\sum_{p_a\in\Omega_a^P} \beta_a^{p_a} \cdot \left|\rho_{a,da}^{p_a} \cdot q_{a,da}^{p_a,t}\right|,\ \ \forall t \in \Omega_t \quad (3)$$

$$\left|q_{d,da}^{t}\right| \le \sum_{a\in\Omega_a}\sum_{p_a\in\Omega_a^P} \left|\beta_a^{p_a} \cdot q_{a,da}^{p_a,t}\right|,\ \ \forall t \in \Omega_t \quad (4)$$

The term S_{da} in the objective function (1) represents the aggregated social welfare over the scheduling horizon in DA-scheduling. It is defined as the benefit of consumption B_{da}^t minus the cost of providing flexibility G_{da}^t. In (2), B_{da}^t is defined as the cost of buying $q_{d,da}^t$ flexibility by the DSO at the price of $\rho_{d,da}$. In (3) G_{da}^t is defined as the benefit of selling $q_{a,da}^{p_a,t}$ flexibility provided by the a^{th} aggregator in its p_a^{th} profile during the t^{th} MTU, at the price of $\rho_{a,da}^{p_a}$. Ω_a^P is the set of indexes of all flexibility profiles p_a offered by AggSups. Eq. (4) enforces the net flexibility procured from the AggSups to be larger than or equal to the flexibility requested by the DSO for each MTU. The optimization objective is to determine linear combination of all flexibility profiles provided by the flexibility sellers in such a way to achieve the maximization of the social welfare. β_d is the binary variable associated with the DSO's request being accepted or rejected. $\beta_a^{p_a}$ is the binary variable associated with the p_a^{th} profile of the a^{th} aggregator being accepted or rejected. The DA scheduling is straightforward since the only flexibility buyer is the DSO and the clearing mechanism is based on the social welfare maximization problem based on the sole DSO's request.

The ID scheduling mechanism is way more complex since in this case BRPs are involved in the process of buying flexibility. The index a_r is used to refer to AggSups while the index b_r is used to refer to BRPs; they can have respectively flexibility requests and offers in direction $r\epsilon\{o,s\}$, opposite or similar to the DSO's request as explained in the previous subsection 5.1.6. Therefore, $\Omega_{A_{id}} = \Omega_{A_{id}^o} \cup \Omega_{A_{id}^s}$ (or $\Omega_{B_{id}} = \Omega_{B_{id}^o} \cup \Omega_{B_{id}^s}$) are the set of indexes for AggSups (or BRPs), made by the union of aggregators $\Omega_{A_{id}^s}$ (or BRPs $\Omega_{B_{id}^s}$) having offers (or requests) in a similar direction to the DSO, and aggregators $\Omega_{A_{id}^o}$ (or BRPs $\Omega_{B_{id}^o}$) having offers (or requests) in an opposite direction to the ones of the DSO. $\left\{\Omega_{k_r}^{p} | \, k \in \{a,b\}, r \in \{o,s\}\right\}$ is the set of indexes of all profiles offered by AggSups and BRPs, in opposite *o* and similar *s* directions. $\beta_k^{p_k}, k \in \{a,b,d\}, r \in \{o,s\}$ is the binary variable associated with the p_k^{th} profile of market participant *k* being accepted or rejected.

The ID-scheduling problem is formulated as follows:

$$\max \; S_{id} = S_{id,o} + S_{id,s} \tag{5}$$

subject to

$$S_{id,r} = \sum_{t\in\Omega_t} \left[B_{id,r}^{t} - G_{id,r}^{t} \right], \quad r \in \{o,s\} \tag{6}$$

$$B_{id,o}^{t} = \sum_{\substack{b_o \in \Omega_{B_{id}^{o}} \\ p_{b_o} \in \Omega_{b_o}^{P}}} \beta_{b_o}^{p_{b_o}} \cdot \left| C_{b_o}^{p_{b_o},t} \right|, \quad \forall t \tag{7}$$

$$B_{id,s}^{t} = \sum_{\substack{b_s \in \Omega_{B_{id}^{s}} \\ p_{b_s} \in \Omega_{b_s}^{P}}} \beta_{b_s}^{p_{b_s}} \cdot \left| C_{b_s}^{p_{b_s},t} \right| + \beta_{d,s} \cdot \left| C_{d,id}^{t} \right|, \quad \forall t \tag{8}$$

$$G_{id,r}^{t} = \sum_{\substack{a_r \in \Omega_{A_{id}^{r}} \\ p_{a_r} \in \Omega_{a_r}^{P}}} \beta_{a_r}^{p_{a_r}} \cdot \left| C_{a_r}^{p_{a_r},t} \right|, \quad \forall t, r \in \{o,s\} \tag{9}$$

$$C_{k_r}^{p_{k_r},t} = \rho_{k_r}^{p_{k_r}} \cdot q_{k_r}^{p_{k_r},t}, \quad \forall t, r \in \{o,s\}, k \in \{a,b,d\} \tag{10}$$

$$\sum_{\substack{b_r \in \Omega_{B_{id}^{r}} \\ p_{b_r} \in \Omega_{b_r}^{P}}} \beta_{b_r}^{p_{b_r}} \cdot \left| q_{b_r}^{p_{b_r},t} \right| \le \sum_{\substack{a_r \in \Omega_{A_{id}^{r}} \\ p_{a_r} \in \Omega_{a_r}^{P}}} \beta_{a_r}^{p_{a_r}} \cdot \left| q_{a_r}^{p_{a_r},t} \right|, \quad \forall t, r \in \{o,s\} \tag{11}$$

$$\left| q_{d,id}^{t} \right| + \sum_{\substack{a_o \in \Omega_{A_{id}^{o}} \\ p_{a_o} \in \Omega_{a_o}^{P}}} \beta_{a_o}^{p_{a_o}} \cdot \left| q_{a_o}^{p_{a_o},t} \right| \le \sum_{\substack{a_s \in \Omega_{A_{id}^{s}} \\ p_{a_s} \in \Omega_{a_s}^{P}}} \beta_{a_s}^{p_{a_s}} \cdot \left| q_{a_s}^{p_{a_s},t} \right|, \quad \forall t, r \in \{o,s\} \tag{12}$$

In Eq. (5), the social welfare maximization problem is differentiated according to the flexibility direction. In both directions, the social welfare $S_{id,r}$ is defined (6) as the sum of benefit of consumption $B_{id,r}^{t}$ minus the cost of providing flexibility $G_{id,r}^{t}$ over the scheduling horizon $n(\Omega_t)$. In (7), $B_{id,o}^{t}$ is defined as the cost of buying $q_{b_o}^{p_{b_o},t}$ amount of flexibility requested in the $p_{b_o}^{th}$ profile of BRP at the price of $\rho_{b_o}^{p_{b_o}}$ in opposite direction with respect to the DSO's request. In (8) the benefit of consumption $B_{id,s}^{t}$ of flexibility in s direction is the sum of the cost incurred by BRPS and by the DSO. Constraint (9) shows that the benefit of providing flexibility $G_{id,r}^{t}$ is the sum of the cost of providing flexibility for each direction. Constraint (10) defines the cost of buying/selling flexibility by each agent. In (11), is ensured that, if there are requests or offers in the opposite direction of the DSO, then the total flexibility amount procured through the flexibility sellers has to be larger or equal to the total flexibility request by the BRPs. After clearing in the opposite direction, the situation for DSO could be further aggravated, so constraint (12) enforces the flexibility procured by the AggSups in the direction needed by the DSO to be larger or equal to the original request of the DSO plus the accepted amount of flexibility requests in the opposite direction. The optimization problem consists in determining the linear combination of AggSups profiles that maximize the social welfare by satisfying the requests of the BRPs and of the DSO.

5.2 Day-ahead planning of DSO: grid-flexibility services through clustering of flexible resources

As explained in the previous chapters, the role of the DSO will change significantly in the future years, being it called to a more active role both in the planning process and in real-time operations [35]. The distribution network used to be operated as a "fit and forget" asset, but in the future, the pace of change of the network will speed up due to distributed generation and increased demand (and increased coincidence factors due to heat pumps and electric vehicles). Renovation of assets for the DSO is an expensive investment if compared to the DSO's revenue: substituting a transformer with a bigger-size one or laying down more cables are expensive solutions that might be not necessary if the technical constraints are violated a few times per month or per year. Another solution is the procurement of flexibility from a flexibility seller. Flexibility sellers can be aggregators, prosumers, Balance Responsible Parties. The electric flexibility can be used for avoiding or mitigating congestions, voltage limit violations or unbalancing.

In the "Clean Energy for all" package, the European Commission underlines the need for a regulatory change that enables the DSO to procure flexibility from market parties in a non-discriminatory market-based procedure. From the perspective of a liberalized energy market, the flexibility should be procured in a market environment where all the interested commercial parties should be enabled to participate. When reducing the size of the geographical area in which this procedure takes place, by considering only a part of the distribution network there are some problematics that may emerge. The DSO may operate in an area which is not big enough to establish the sufficient competition to run a competitive market, or e.g. there could not be enough liquidity (in terms of commodity to be traded, so enough flexibility) for guaranteeing the well-functioning of the market mechanism. Under certain circumstances, a viable alternative is the establishment of bilateral contracts between the DSO and a flexibility seller, an aggregator managing a commercial microgrid. By deploying the resources of the CM, the aggregator can help solving the technical problems encountered by the system operator on a daily basis.

This procedure for procuring flexibility for grid-purposes can be incorporated in the day-ahead planning of the DSO, which can request for flexibility after running a risk analysis and individuating imminent technical problems. The clustering algorithm is needed for characterizing the resources based on their flexibility attributes, so determining their attitude in solving one or more technical problems at the same time.

5.2.1 Day-ahead flexibility procurement

The day-ahead flexibility procurement (DAFP) can be used to mitigate technical problems encountered in the day-ahead planning process. The DAFP will be terminated before the closure of the day-ahead wholesale market: in this way, the aggregator and the affected BRPs can adjust their energy programs considering the agreed activation of the flexibility of the CM. This guarantees that at least in the day-ahead process there will be not direct influence on other BRPs that may be responsible for the customers included in the CM. Anyway, this not guarantees the absence of imbalances that can be caused by deviation occurring after the closure of the day-ahead market, closer to real-time operations.

The mechanism is depicted in Fig. 5.4. The DSO runs a probabilistic power flow (PPF) analysis for the day after and individuate emerging technical problems at specific time intervals (5-minutes time interval). The preliminary PPF is performed based on the historical data of the baseload, plus the flexible resources in their usual time of use. The information regarding technical data is then transferred to the aggregator.

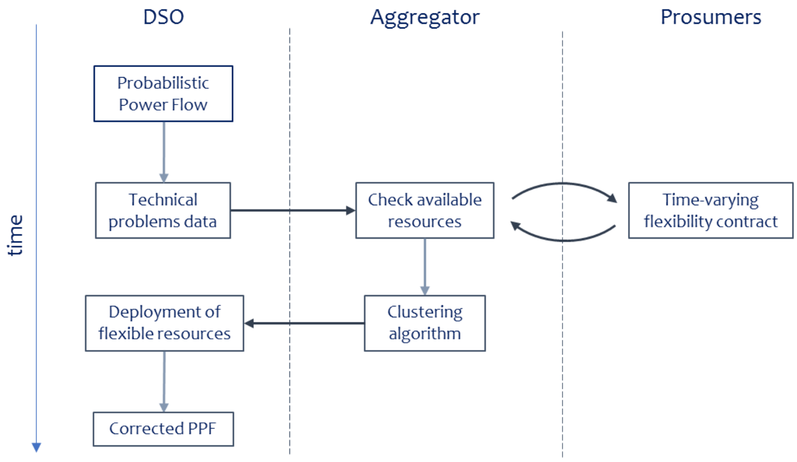

Figure 5.4 – Schematic of the day-ahead flexibility procurement.

The aggregator manages a CM, made of different DERs, including smart appliances, PV systems and electric vehicles. DERs that are part of the Commercial Microgrid cannot be activated at any time. The relation between the aggregator and the customers is assumed to be based on a time-varying flexibility contract. This contract defines which resources can be used, in which hours of the day and for how long. The level of complexity of this contract may increase by differentiating between week-day and weekends, distinguish levels of priority and so on. This contract is the reason why, when receiving a request for activating flexibility due to technical problems, the aggregator has to check the available resources based on the flexibility contract stipulated with each customer. The contract ensures that the comfort constraints of the customer is not violated, and the resources are controlled by the aggregator when are not needed; on the other side the aggregator incur in penalty cost if it does not deliver the flexibility agreed in the day-ahead procurement mechanism; the contract ensures that penalty costs are forwarded to the prosumers if the flexibility is not activated. This possibility is not considered in the current work, because we are still in the day-ahead planning phase. Based on this assumption, the flexible resources are modelled as deterministic resources, meaning that the aggregator has direct control over the energy resources for the agreed time of the day.

After checking the available resources based on the flexibility contracts, the aggregator performs a clustering algorithm to characterize the resources. Taking into account different attributes of flexibility each resource is characterized by different indexes, reflecting its availability, priority, location, capacity and so on. Furthermore, each technical problem for which the aggregator is giving data, generate one additional index for each resource, defining the ability of the resource in solving the issue. E.g., if there is a voltage limit violation at a specific bus, each resource will have an index which defines its capability of solving the voltage issue: closer resources to the interested node will have a higher score with respect to further ones. The same with a load balancing issue, so resources that have are on the unbalanced phase and have a bigger capacity will get a higher score. The clustering algorithm will group together resources that have similar indexes, so resources that have a similar capability of solving the problems encountered by the DSO. In this way, by taking into account different problems, the clustering can be validated in a case when there are multiple technical problems at the same time, defining the best cluster of resources for tackling several problems at the same time. Lastly, the aggregator passes back the data regarding the best deployable cluster(s) of resources to the DSO that consider the new scheduling of the resources and performs once again a PPF to evaluate the mitigation of the problem.

6. Conclusions and future works

In this report, developed after the work conducted in Task 5.1 of the m2M-Grid project, an overview of the possible market interactions of commercial microgrids is given. The electric flexibility is a multi-dimensional commodity that has different attributes, and the energy transition is posing challenges on the flexibility provision since traditional sources (conventional fossil-fuel or nuclear power plants) of flexibility are being mothballed for their impossibility to recover capital costs. This is due to the increasing share of renewable energy production in our energy sector. On the other hand, the same RES development is increasing the need for flexibility, that has to be procured from alternative sources. Microgrid technologies, both physical and commercial, can provide flexibility-services to the main utility grid, keeping the security and quality of power supply.

The market integration of CMs is of vital importance to determine the profitability of business cases, and for valuing the flexibility available at the microgrid level. An overview of potential stakeholders interested in the microgrid flexibility is presented in the report, highlighting that the flexibility can be used for different purposes: market-use, grid-use, and system-use. The interface can be realized at the wholesale level by interacting with the short-term markets, including balancing markets, and at the local level by interacting with local markets or with the DSO.

At the wholesale level the interaction is feasible due to some recent adjustments to the energy markets, but still, many barriers are in place for aggregators managing small-scale flexible resources to bid and value their services to the market parties, and to the Transmission System Operator. Nevertheless, aggregators are already providing services to the TSO in countries where the legislation is more advanced, (such as France, Belgium, UK). In their portfolio, there are industrial loads and customers which are easier to manage and require less coordination and investments. At the local level, the interaction is almost absent, because the DSO is still a regulated entity, which cannot establish any relation with commercial parties, and the energy suppliers/BRPs have also other marketplaces to repair for the imbalances. Local flexibility markets are still in the research or pilot phase.

The core of the deliverable is the flexibility tool-box developed at TU/e: constituted by a market-based and a contractual-based procedure for exploiting flexibility from commercial (CM) and physical microgrids (PM).

The Local Flexibility Market (LFM) aims to enable trading of flexibility between commercial and physical microgrids and external actors (such as Balance Responsible Parties or Distribution System Operators). The mechanism is divided in two phases: Day-ahead (DA) and Intraday (ID) scheduling which differ one from each other for the market participants, the clearing mechanism and the time elapsed between the scheduling and the actual time of delivery. In a DA scheduling, the DSO is the only buyer of flexibility, and the flexibility requests are matched to flexibility offers coming from AggSups (CM or PM operators). In a later phase, during the ID-scheduling, the BRPs can send their requests to the market operator, increasing the complexity of the clearing mechanism since the flexibility is requested for different purposes: market-use and grid-use.

The second part of the tool-box is a contractual-based procedure for procuring flexibility on a day-ahead basis. The DSO after running a risk analysis, provides the information regarding possibly emerging technical problems to the aggregator. The aggregator, managing a CM, applies a clustering algorithm based on the flexibility attributes of the resources reflecting their ability to solve one or more problems at the same time (congestions, voltage limit violations, imbalances). Giving back the best cluster of DERs, the aggregator provides a grid-flexibility service, agreeing on the requested schedule of their resources. The DSO can check again if the flexibility activated, is enough for solving the forecasted problems, eventually passing to further control actions. A flexibility contract is established between the aggregator and the DER's owners in the commercial microgrid, defining availability, duration, priority and capacity of each resource, to be directly controlled within the CM.

The work of task 5.1, particularly the content of the flexibility tool-box will be the starting point of the future tasks in the same working package. The main aim of the m2M-project is to enable microgrid technologies, by improving the level of coordination and interoperability at the distribution level. The development of the distribution network as a set of grid-connected microgrids can beneficiate from a marketplace to exchange services, commodities such as energy and flexibility, with the aim of supporting the microgrid itself, the exchange between the microgrid, and the services provided back to the utility-grid, managed by the DSO. Working package 5, tries to explore the connection between the microgrid development and the market interaction at a local and wholesale level, to highlights reciprocal benefits and common ground. Task 5.2 will develop peer transactive energy between commercial microgrids by revealing optimal demand side management solutions in multi-time stages, exploring the flexibility value for multiple clusters of the active end-users based on proactivity and predictability of local energy resources and energy storages. Task 5.3 will analyse market interactions between different types of micro-grids and local energy communities, as well as the interactions between such markets and the overlaying wholesale markets. The LFM, part of the flexibility tool-box, can be used as an example of a micro-grid market design. The flexibility tool-box represents the first phase of the working package, and certain aspects are voluntarily neglected for lack of time. Interesting points to be tackled in the future work are:

- Exploring the real-time phase: both the mechanisms are running in the day-ahead phase (and intra-day for the market-based procedure); after the realization of the day-ahead phase, it may happen that the DSO does not procure from the procedures all the needed flexibility to ensure the security of supply, so a consecutive phase, should address this possibility by implementing further direct or indirect control on the flexible resources;
- The definition of the baseline is a crucial aspect for the establishment of a flexibility-mechanism (market-based or contractual-based). A clear methodology should determine the baseline, according to historical data and usual habit of the end-users. This is the preliminary requirement to adequately remunerate the activation of flexibility or to penalize the deviation from the agreed trading.
- Pricing structure and penalty costs for not-delivering: the energy component of our electricity component is fixed by the contract between end-users and energy supplier, based on the expected day-ahead price of the electricity for period on which the contract is established. In the same way, the flexibility price will be defined on some metric that value the modification of the end-users habits to offer flexibility services. Another point of interest is the definition of the penalty costs for not-delivering, for violating the term of the contracts.
- Prioritization of the DSO's requests: in the intra-day market procedure, the BRPs seem to have priority on DSO requests. It can occur a situation where the BRPs requests are first cleared and the market imbalances are solved, but then the DSO is not able to procure all the needed flexibility. This procedure is suitable for a situation when the network is safe or rarely congested. When several problems are expected in the day of delivery, the procedure should be modified in such a way that the DSO requests are cleared first and the network is secured; afterward the trading can continue involving flexibility services for market-purposes.

7. References

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