Politecnico di Torino

Master's Degree in Electrical Engineering

Thesis

Vehicle-to-Grid as secondary frequency reserve support asset

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List of Acronyms

AEEG Autorità per l'energia Elettrica e il Gas

AC Alternating Current

ARERA Autorità di Regolazione per Energia Reti e Ambiente

AEEGSI Autorità L'Autorità per l'energia Elettrica il GAS e il Sistema Idrico

BRP Balance Responsible Parties

BSP Balance Service Provider

CCS Combined Charge System

DC Direct Current

DSO Distribution System Operator

ENTSO-E European Association for the Cooperation of Transmission System Operators for Electricity

FAT Full Time Activation

GME Gestore dei Mercati Energetici

HV High Voltage

IPEX Italian Power Exchange

LV Low Voltage

MSD Mercato dei Servizi di Dispacciamento

MV Medium Voltage

NPRES Not Programmable Renewable Sources

POD Point of Delivery

RES Renewable Energy Sources

SOC State of Charge

TSO Transmission System Operator

UC Unità di Consumo

UP Unità di Produzione

UVA Unità Virtuali Abilitate

UVAM Unità Virtuali Miste

V2G Vehicle-to-Grid

WAP Weighted Average Price

Chapter 1

Introduction

Nowadays electricity has become a part of modern life and it is difficult to think about a world without it.
The relevance of electricity is also growing in the last years because it is the main player of the energy transition in action. In fact,the greenhouse effect are already visible and it is a real race against time to change the direction.

There are many ways in which the change is on, starting from the production of electricity in fact thermoelectric plants powered by fossil fuels are slowly giving way to photovoltaic and wind turbines.
A similar process is taking place in means of transportation. As reported in [1], with 6.5 millions of electric vehicles sold worldwide, 2021 can be considered a starting point for an automotive industry new era. The annual increment of new registrations is equal to 98 %: 68 % of full electric vehicles and 31 % of plug-in vehicles.
China is at the moment a leader in this sector, Europe is in second place with the 30 % of the market. It is estimated that by 2025, European vehicles manufacturers will sell 14 millions of electric cars.

Hence, sustainable mobility is an optimal solution for reducing the carbon fossils use, especially if electricity used for charging vehicles is obtained from renewable sources. As the diffusion of electric vehicles grows, it is developed the attention on Vehicle-to-Grid (V2G) technology that enables plug-in vehicles to supply ancillary services to the grid. This technology has the potential to give benefits both to the grid operators and car's owners.

Politecnico di Torino and Edison S.p.A, an Italian company specialized in the production and distribution of electricity, have joined forces in a research focused on the potential of V2G technology as power supply given the current market conditions.
In detail, the aim of this thesis is to show that economic convenience exists if V2G takes part to ancillary services, in particular this thesis focuses on the Secondary Frequency Regulation.

At first it was done an excursus on the structure of Italian National Electrical System and its management. In detail, it was analyzed the frequency control, its regulation and the phases for restoring the rated frequency of the grid after a variation of the load.

Then it was introduced the Italian Electricity Market with its historical background and the structure. It was done a focus on MSD market because it is the one used by the Italian TSO (Terna S.p.A) for acquiring sources for ancillary services.
Later, the V2G technology was introduced with the pilot project held by Terna that enables V2G as UVAM (unità virtuali abilitate miste) to the supply of Secondary Frequency Reserve.

Then it was explained the simulation part of the thesis that consists of two sections. The first one is about the analysis done on Italian Electricity Market public data of the year 2019 available on GME site. This survey was realized using Matlab software and its aim was to find the probability that an offer for aFRR has to be accepted on the market.

The data acquired from this analysis was then used in a second Matlab script in which it was simulated the participation to the market of a parking lot for 300 plug-in cars and then the calculation of remuneration for accepted offers following the rules provided by Terna.

All the results provided by the Matlab simulations and conclusions deduced from them were then reported in the last part of this thesis.

Chapter 2

Italian Electrical System

The National electrical system is composed by four sections as shown in Figure 2.1.

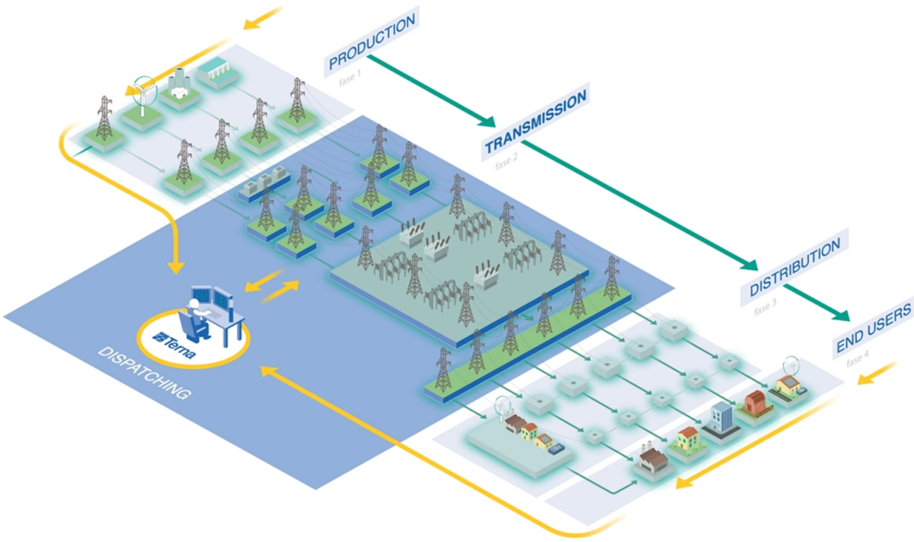


Figure 2.1: Italian National Electricity System Phases[2].

These sectors, when a competitive market exists, are well distinguished and operated by different actors.

- **Production**: Electricity is an energy carrier and not a source. Hence it does not exist in nature: it must be produced by converting primary sources.
  Traditional sources are the non-renewable ones as oil, coal and natural gas. In the last decades, as a consequence of a growing warning for the greenhouse effect and its consequences on Earth as climate change, it has been an increasing interest on implementing new production systems exploiting renewable sources: hydroelectric, solar, wind energy and geothermal.
  The electricity production market is completely liberalized.

- **Transmission**: The transmission system allows the transportation across the country of electricity that is produced:

  - in national production sites;
  - in foreign countries and then imported.

  Transmission is operated at high voltage (**HV**) $> 30kV$. The National Transmission System Operator (**TSO**) (in Italy it is Terna S.p.A) is responsible for the management, maintenance and development of the transmission grid and for the dispatching. The latter one consists in managing of the power flow of the grid every instant.
  Transmission is a natural monopoly system (this is the optimal configuration for Italian territory).
  In order to ensure competition within the market, the TSO cannot take part to the electricity production, distribution and sales to customers.

- **Distribution**: It refers to the infrastructure which makes the electricity available to users. It's composed by both medium voltage (**MV**) and low voltage (**LV**) networks. The electricity is taken from HV system and, thanks to HV/MV transformers, it is distributed through the MV system. A further transformation from MV to LV allows also to reach LV costumers.
  Distribution a local monopoly system. Distribution system operators (**DSOs**) take care of the management of MV-LV grids.

- **Utilities** The last segment of electric chain is the market with sales companies.

2.1 Network Management

Electricity cannot be easily stored. Hence, there is the need of instantaneous and continuous balance between the quantity of power injected in the grid and the one withdrawn from it net of transport and distribution losses.
In the meantime, service's constraints that refers to values of **voltage** and **frequency** and thermal constraints must be respected.

2.2 Frequency Control

Frequency is one of the most important quality parameters of the power system [3]:

- it sets the speed of motors (synchronous and asynchronous) powered by the grid;
- it defines the 'asynchronous time';
- it takes part, though in a small part, to the magnetic fluxes of the motors

$$\lambda \propto \frac{V}{f} \tag{2.1}$$

Frequency must lie in a range close to the rated frequency in order to avoid the separation of generators for over or under frequency (this condition can lead to a blackout).

$$f_{min} \leq f \leq f_{max} \qquad f \sim f_{rated} \tag{2.2}$$

The value of the rated frequency f_{rated} is not the same everywhere, Figure 2.2 shows a map of the world coloured depending on the value of f_{rated}.

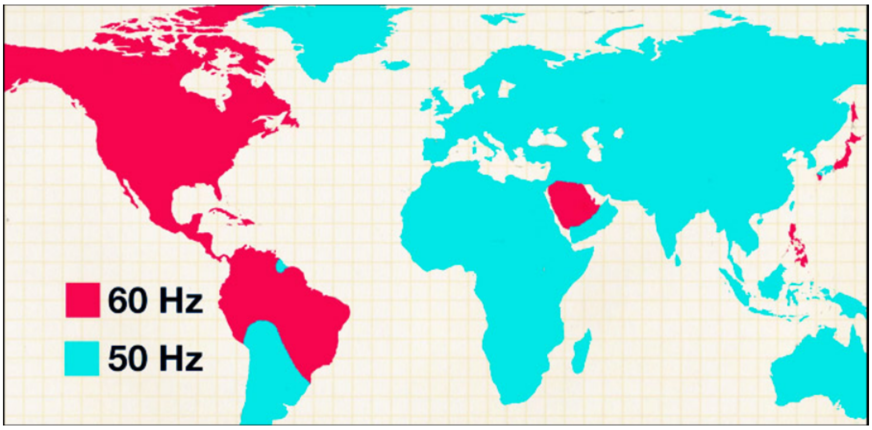


Figure 2.2: Values of f_{rated} in the world [4].

For what concerns Europe, the **EU 12/08/2017 Regulation** [5] established the frequency quality parameters of synchronous areas as in Figure 2.3:

Frequency quality defining parameters of the synchronous areas

	CE	GB	IE/NI	Nordic
standard frequency range	± 50 mHz	± 200 mHz	± 200 mHz	± 100 mHz
maximum instantaneous frequency deviation	800 mHz	800 mHz	1 000 mHz	1 000 mHz
maximum steady-state frequency deviation	200 mHz	500 mHz	500 mHz	500 mHz
time to recover frequency	not used	1 minute	1 minute	not used
frequency recovery range	not used	± 500 mHz	± 500 mHz	not used
time to restore frequency	15 minutes	15 minutes	15 minutes	15 minutes
frequency restoration range	not used	± 200 mHz	± 200 mHz	± 100 mHz
alert state trigger time	5 minutes	10 minutes	10 minutes	5 minutes

Figure 2.3: Frequency Quality Parameters of Synchronous areas[5].

where:

- **CE** = Continental Europe;
- **GB** = Great Britain;
- **IE/NI** = Ireland/North Ireland;
- **Nordic** = Finland, Norway, Sweden, a part of Denmark.

2.2.1 Frequency Control Regulation

Frequency variations in power systems can occur because of an imbalance between generation and load.
The load-frequency control structure is composed of four steps defined in [5]:

- Frequency Containment Reserve (**FCR**) also called *Primary Frequency Control*;
- automatic Frequency Restoration Reserve (**aFRR**) also called *Secondary Frequency Control*;
- manual Frequency Restoration Reserve (**mFRR**) also called *Tertiary rotating reserve* [6];
- Reserve Replacement (**RR**) also called *Tertiary replacement reserve*[6].

Variation of the Load

Let's examine the case in which there is an increase of load powered by a group of n generators.
The generated power does not change immediately, so the energy for compensating the change in load comes from generators' inertia. The *inertial response* consists in the fact that, at first, the required energy comes from the kinetic energy of rotating generators that start decreasing their speed and so the system's frequency.
At this point the power system has two main tasks:

- Update the mechanical power produced by the generators to the power needed by the load;
- Keep constant the frequency.

In order to achieve these goals, each generator must have a speed controller that, after the inertial response, acts to increase the generation power. In this way, it is possible to recover the speed (that is linked to a frequency recovery) and to clear the unbalance.

This is the *Frequency Containment Reserve* (**FCR**), the fastest among the three levels and it is automatic. In Italy, Terna requires that in 30 seconds (**FAT**[1]), each generation unit must be able to generate the required additional power and to keep it constant for at least 15 minutes. This service is not remunerated due to the fact that it is mandatory for all the production units with power higher or equal to 10 MW except for the renewable energy source (**RES**) that cannot be scheduled (for example: wind, solar, hydroelectric . . .). So each unit shall have a dedicated reserve power in order to accomplish this regulation when active.

Once the primary regulation achieve its goals, it must be noticed that:

- In steady state conditions, the system's frequency value is not the rated one but there is a residual error;
- the reserve margins of generators have been just used.

Hence, there is the need of restoring the nominal value of frequency and the generators' reserve. These are the objectives of the *automatic Frequency Restoration Reserve* (**aFRR**) that is operated by m of the n generators (with $m < n$) that are fully activated in 5 minutes and perform the secondary regulation for at least 15 minutes providing a total reserve that is the sum of primary and secondary one.
The secondary reserve margins depend on TSO requirements, in Italy:

- For thermoelectric UP : the reserve margin is equal to the maximum between ±10MW and ±6% of the maximum power;
- For hydroelectric UP: ±15% of the maximum power.

[1] it is the time period between the activation request and the fully delivery of the request.

The secondary control is automatic but, unlike primary regulations, there is a central controller and it is much more slower because they must not work together. The secondary regulation is on the market and entities who take part to it get remuneration.

After 5 minutes from the perturbation, the *manual Frequency Restoration Reserve* (**mFRR**) starts and it replaces **aFRR** at 12.5 minutes with the purpose of restoring the reserve margins just used. For this service the TSO calls single producers (even if they do not take part to secondary control) according to the need.
This control level is not automatic but it is executed on TSO request.

Finally, the Replacement Reserve **RR** is useful for restoring **mFRR** margins that are subjected to change of demand or long-lasting faults of power plants [9].
According to European Regulation **2017/2195**, **RR** is optional depending on each TSO dispatching approach, so **ENTSO-E**[2] defined some strategies for its supply [10].

The Figure 2.4 is made up of two graphs, both in depends of time: the first one shows frequency trend after the perturbation while the second one displays the activation of **FCR**, **aFRR** and **mFRR**.

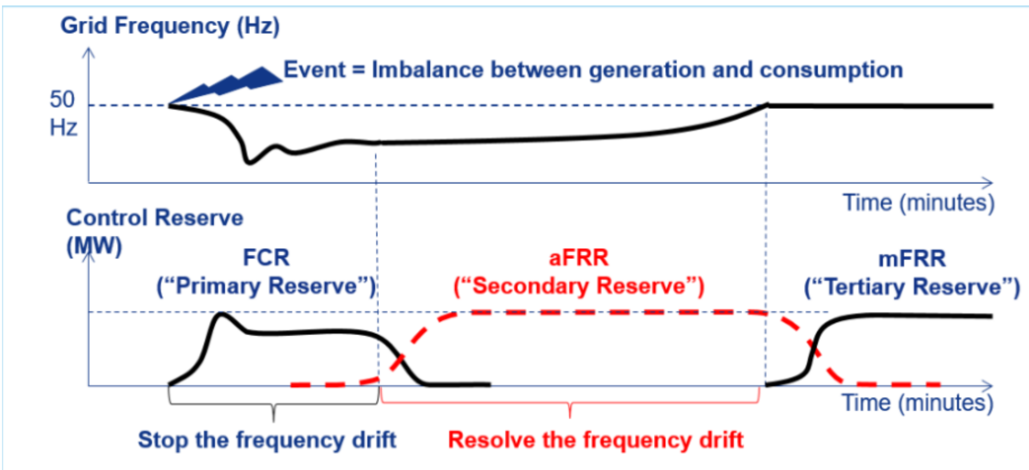


Figure 2.4: Phases of reserve services activation and effects on Grid frequency with time [7].

In Table 2.1 a brief summary of the four Regulations.

Table 2.1: The four phases of frequency regulation

	FAT	Duration	Italian Definition
FCR	< 30 s	15 min	Primary frequency control
aFRR	5 min	15 min	Secondary frequency control
mFRR	12.5 min	15 min	Tertiary rotating reserve
RR	30 min	15-60 min	Tertiary replacement reserve

[2]ENTSO-E: European association for the cooperation of transmission system operators (TSOs) for electricity

2.2.2 *Balancing* Regulation

On 18 December 2017, the European Regulation **2017/2195** [8] become law. This resolution is also called *Balancing Regulation* because it pursued the establishment of a guideline on electricity balancing.
The main purpose of this law is supporting the integration of EU states' balancing market in order to have much more efficiency in the supply of ancillary services.
The instrument that allows the achievement of resolution's goals is the development by TSOs of platforms for the exchange of balancing products. From an economic point of view, each platform is based on a multilateral model **TSO-TSO** with the activation of offers by *merit order*.

The platforms are developed within the framework of European projects:

- Project *TERRE* → Platform **RR**;
- Project *MARI* → Platform **mFRR**;
- Project *PICASSO* → Platform **aFRR**;

Project TERRE TERRE is the acronym of *Trans European Replacement Reserve Exchange*. This project is aimed at the creation of an European platform called **LIBRA** for the exchange, in an harmonized playing field for Market Participants, of the balancing sources useful for the activation of supplied RR.
As shown in Figure 2.5, at the moment eleven TSOs takes part into the project TERRE including operational members (Terna is one of them), non-operational members and observers (3 TSOs + ENTSO-E) [11].

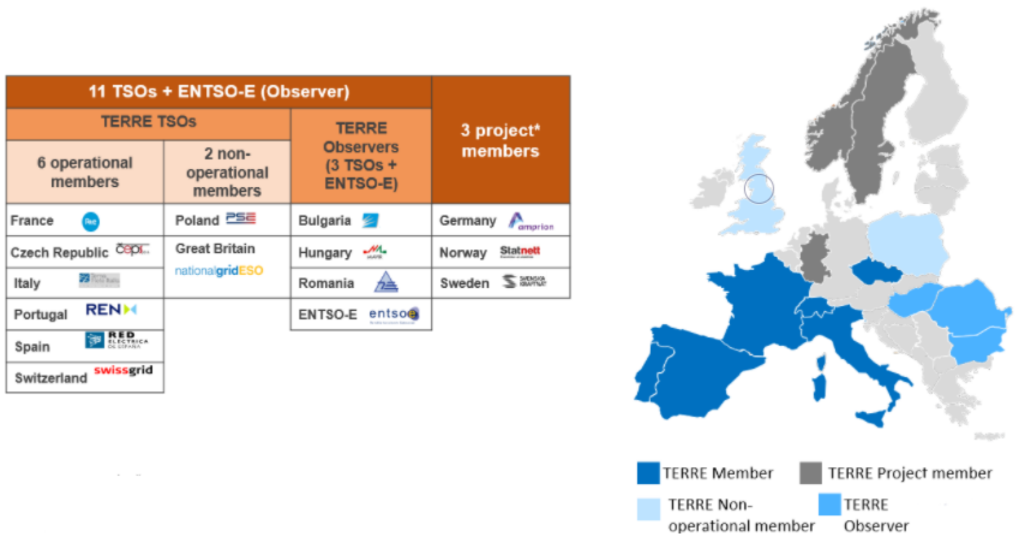
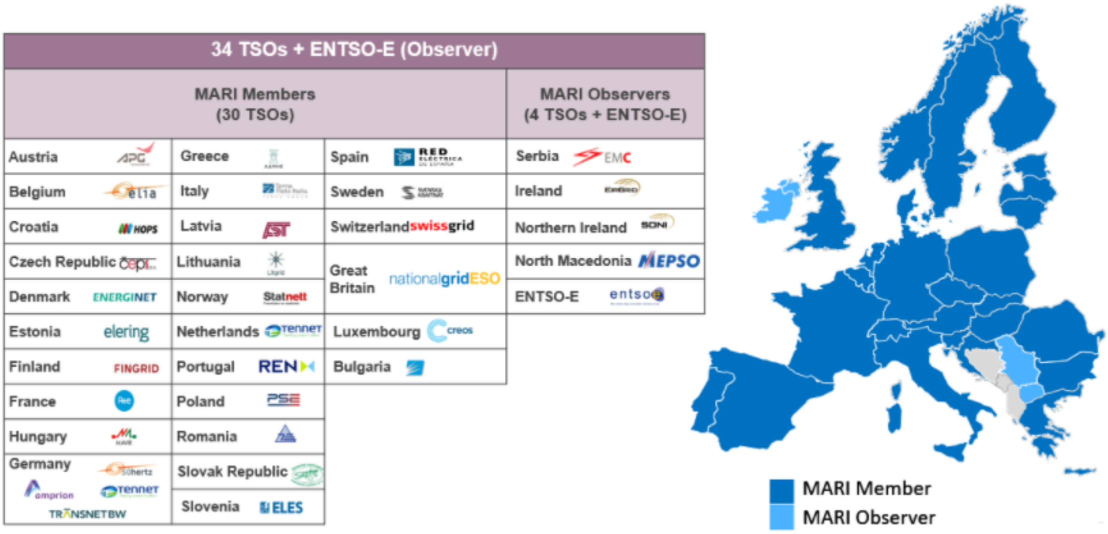


Figure 2.5: TERRE members as April 2021 [11].

Project MARI MARI is the acronym of *Manually Activated Reserves Initiative*. This is the project for the implementation of an European **mFRR** platform.
Unlike project TERRE, the project MARI is not still activated: in fact, at the

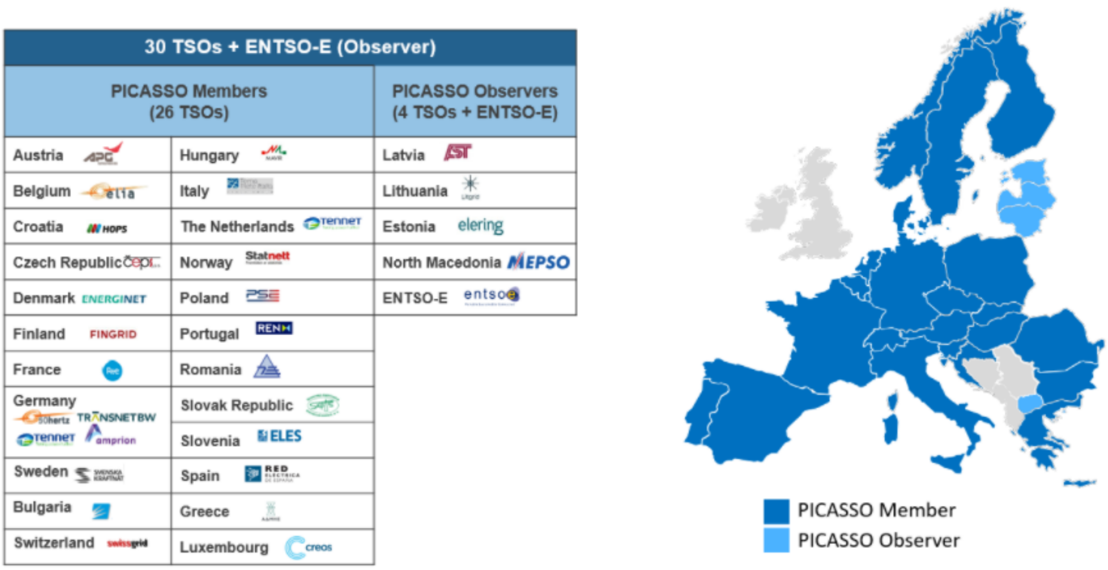
moment European TSOs are working on development of the platform. The project will be operative in EU by the 24/07/2022 [6].



34 TSOs + ENTSO-E (Observer)			
MARI Members (30 TSOs)			MARI Observers (4 TSOs + ENTSO-E)
Austria	Greece	Spain	Serbia
Belgium	Italy	Sweden	Ireland
Croatia	Latvia	Switzerland	Northern Ireland
Czech Republic	Lithuania	Great Britain	North Macedonia
Denmark	Norway		ENTSO-E
Estonia	Netherlands	Luxembourg	
Finland	Portugal	Bulgaria	
France	Poland		
Hungary	Romania		
Germany	Slovak Republic		
	Slovenia		

Figure 2.6: MARI members[12].

PICASSO PICASSO is the acronym of *Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation*. All the TSOs through the ENTSO-E Market Committee take part to this project, which aims to establish the European platform for the exchange of balancing sources from **aFRR** platform [13].
As for MARI project, PICASSO is still not activated because the platform is not ready yet; the project will be operative by the 24/07/2022 [6].



30 TSOs + ENTSO-E (Observer)		
PICASSO Members (26 TSOs)		PICASSO Observers (4 TSOs + ENTSO-E)
Austria	Hungary	Latvia
Belgium	Italy	Lithuania
Croatia	The Netherlands	Estonia
Czech Republic	Norway	North Macedonia
Denmark	Poland	ENTSO-E
Finland	Portugal	
France	Romania	
Germany	Slovak Republic	
	Slovenia	
Sweden	Spain	
Bulgaria	Greece	
Switzerland	Luxembourg	

Figure 2.7: PICASSO members[13].

Chapter 3

Italian Electricity Market

3.1 Historical Background

The energy market has a very recent history in Italy. It was introduced by **Legislative Decree No 79/99** [14], known as **Bersani Decree** in reference to the minister in charge.
This decree was issued as an adaptation of the European Directive 96/92/EC [15] which established the creation of common rules for the EU single energy market.
This document set up a step-by-step liberalization of all the activities composing the 'Electrical Chain' in order to promote the free competition as a benefit to consumers.
In 1995, it was established an independent autority for the regulation at the market called **AEEG**. Its duties were:

- Guarantee the promotion of competition;
- Public services efficiency;
- Safeguarding users interests.

In 2011, it were conferred to this Autority also functions related to water services and there was a change in the acronym, it became **AEEGSI**. In 2018, functions linked to the waste management were added to the Autority, this leaded to a change of the name in **ARERA**.
The Bersani bis Decree in 2007 [16] established the total liberalization of Italian energy market opening it to new suppliers and allowing consumers to choose their supplier.
It was settled a period of coexistence between the **free market** and the **regulated** one known as *maggior tutela* in order to provide to consumers enough time to change from the latter to the former.
The end of the regulated service has been postponed many times, the latest change sets it on:

- 1/01/2022 for private consumers;
- 1/01/2021 for Micro Enterprises, SMEs and Large Enterprises.

3.2 Main Characteristics of Italian Market

The establishment of the Electrical Market is due to two main reasons:

- Promoting the competition among wholesale production and selling, with the creation of a *stock exchange*;
- Facilitating the maximum transparency and efficiency of the economic management of dispatching services.

The electricity market is a *virtual marketplace* for the wholesale trading of electricity where schedules of injection/withdrawal are defined. On the market, the price of energy is equal to the MCP obtained by the meeting of demand and supply. The partecipation at the Power Exchange (**IPEX**) is not mandatory, sellers and buyers can independently define contracts outside the power market known as Bilateral Contracts.
Operators can submit on the market offers to sell or bids to buy only if they have been admitted by the **GME**. Its mission is organising and managing the Electricity Market under guidelines of transparency, neutrality and competition between producers.

3.2.1 Market's zones

In order to verify and remove congestions, **GME** uses a simplified map of the Italian network in which are highlighted only the transit's constraints between national zones, foreign zones and poles of limited production.

Figure 3.1: Italian regional markets and foreign virtual zones [17].

As shown in Figure 3.1, the National transmission network is divided into:

- Six geographical zones:
  - Central-Northern Italy **(CNOR)**: Toscana, Marche;

- Central-Southern Italy(**CSUD**): Lazio, Abruzzo, Campania, Umbria;
- Northern Italy (**NORD**): Valle D'Aosta, Piemonte, Liguria, Lombardia, Trentino, Veneto, Friuli Venezia Giulia, Emilia Romagna;
- Sardinia (**SARD**);
- Sicily (**SICI**);
- Southern Italy (**SUD**): Molise, Puglia, Basilicata;
- Calabria (**CALA**).

- Nine foreign virtual zones:
  - Austria (**AUST**);
  - Corsica (**CORS**);
  - Corsica AC (**COAC**);
  - France (**FRAN**);
  - Greece (**GREC**);
  - Slovenia (**SLOV**);
  - Switzerland (**SVIZ**);
  - Malta (**MALT**);
  - Montenegro (**MONT**).
- Four National virtual zones that are poles of limited production.
  These are zones composed of a single unit of production whose capability of connection with the network is even smaller than the unit's power.

Offer Points Each geographical or virtual zone is a group of offer points.
These are the smallest units of electrical energy and injection/withdrawal hourly schedules must be defined in relation to them.
Offer Points are distinguished into:

- Injection Points;
- Withdrawal Points;
- Mixed Points (for both injection and withdrawal).

3.2.2 Market's structure

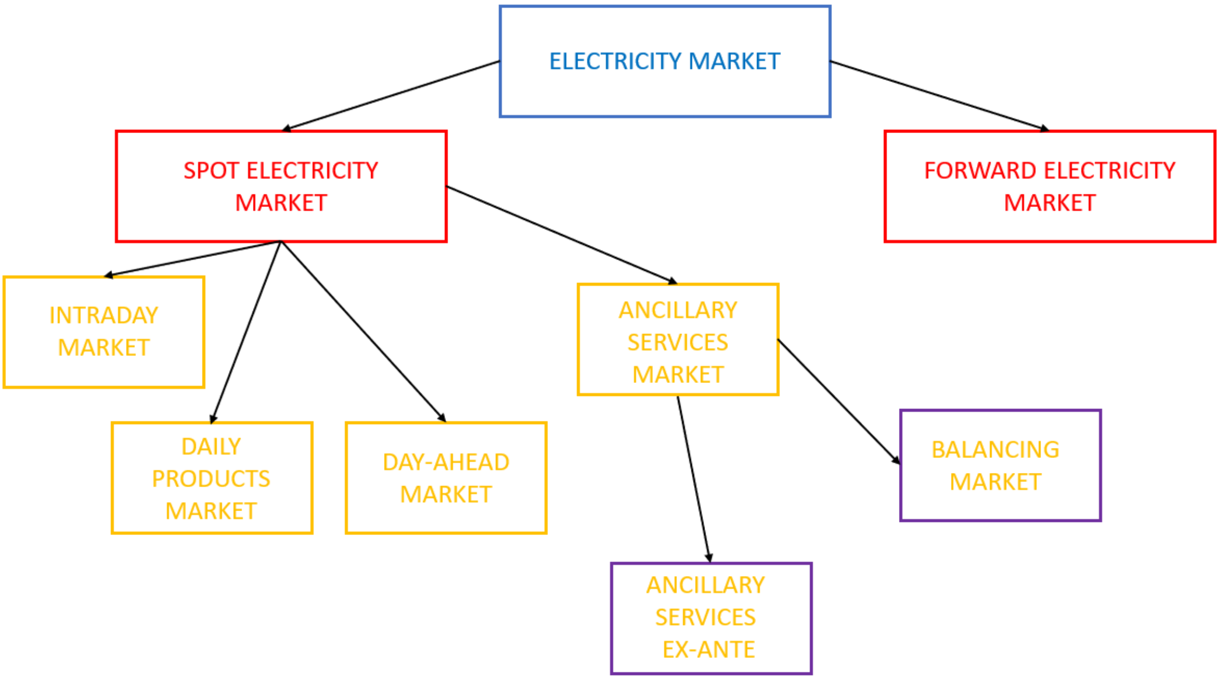


Figure 3.2: Electricity Market Structure.

As shown in Figure 3.2 the electric market can be divided into:

- **Forward Electricity Market (Mercato Elettrico a Termine MTE)**: Venue for trading electricity long term contracts.
- **Spot Electricity Market (Mercato Elettrico a Pronti MPE)**: It can be splitted up in four smaller markets:
  - **Day-Ahead Market (Mercato del Giorno Prima MGP)**;
  - **Intraday Market (Mercato Infragionaliero MI)**;
  - **Daily products Market (Mercato dei Prodotti Giornalieri MPEG)**;
  - **Ancillary Services Market (Mercato dei Servizi di Dispacciamento MSD)**.

3.3 Spot Electricity Market

3.3.1 Day-Ahead Market (MGP)

On MGP electricity supply offers and demand bids can be traded for each hour of the delivery day. The MGP session opens at 8 o'clock of the ninth day before the delivery day and it closes at 12 of the day before the delivery.
The users can submit offers/bids specifying the quantity and the minimum/maximum price at which they are willing to sell/pay.

Once the session is ended, **supply offers** are ranked by **non-decreasing price order**, whereas **demand bids** are ranked by **non-increasing price order**. Offers and bids are accepted until the total demand is satisfied.
If there are offers/bids with the same price the merit order prevails; it means that, in this case, the accepted offer/bid will be the one who was submitted earlier.

3.3.2 Intraday Market (MI)

In MI bid and offers can be traded with the purpose of modifying the injection/withdrawal programs defined on the MGP. In this way it can be defined a much more detailed delivery program (MGP results are approximate).
The way in which offers/bids are submitted and selected is equal to the one in MGP. The participation is optional.

3.3.3 Daily products Market (MSD)

The National TSO (Terna S.p.A) uses this market to acquire resources for ancillary services that are useful to the management of the grid, like:

- Relieving intrazonal congestions;
- Provide energy reserve;
- Balancing injections and withdrawals in real time.

Only allowed units are authorised to supply ancillary services; at the moment, a part from pilot projects, only programmable and relevant units (greater than 10 MVA) can take part at MSD.

The MSD has two different outputs:

- A scheduling substage: **ex-ante MSD (MSD ex-ante)**;
- Balancing market in real time: **MB (Mercato di Bilanciamento)**.

Both ex-ante MSD and MB take place in multiple sessions as shown in Figure 3.3 .

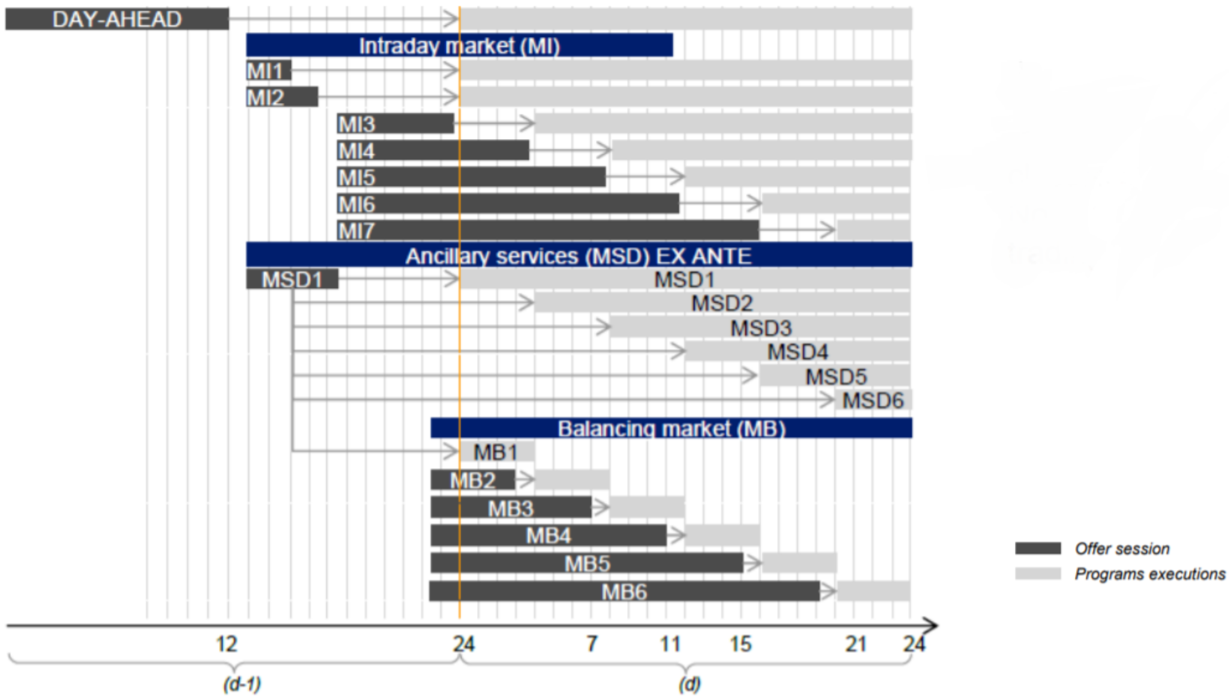


Figure 3.3: Ex-ante MSD and MB sessions [18].

Ex-ante MSD

The sitting for bids/offers submission is a single one and it opens at 3.30 pm of the day before the delivery day and it closes at 5.00 pm of the same day.
In this market Terna gets demand bids and supply offers for:

- relieving residual congestions;
- creating energy reserve margin;

MB

As ex-ante MSD, also MB is divided into different sessions (five in total), but it must be done a little differentiation between them. In fact, in the first substage are taken into account only bid/offers submitted in the ex-ante MSD's last session.
The following substages open at 10.30 pm of the day before the delivery when ex-ante MSD's result is still unknown and they close 1h30 before the first hour that can be negotiated in each session.
For each one of the five sessions, GME transmits to the operators the results defined by Terna.
Terna uses MB for acquiring energy in order to provide:

- service of secondary frequency control.
- balance energy injections and withdrawals into/from the grid in real time.

Results

GME transmits to Terna the offers/bids subjected by the operators.
At the end of each market's session GME publishes the results; many data referred to the single zones are published as:

- Overall quantities purchased/sold accepted;
- Average price of accepted bids/offers;
- maximum offers price and minimum bids price;

3.3.4 Secondary Reserve and Other Services on MSD

As already seen in Section n.2.1, *Secondary Frequency Regulation* is an ancillary service.
For what concern the *Other Services* a further explanation it is needed. When making an offer on MSD, operators can choose if their offer is only for Secondary Reserve or for 'Other Services'. For what concern the latest option, operators have not to offer at the same price all the quantity at their disposable but there are more power steps. The step 0 corresponds with the unit's power from 0 to the technical minimum, from this point to the maximum power can be divided into 3 power steps that are called, in Italian, 'gradini' (**GR**) .
In detail, operators that want to take part to Secondary reserve and/or Other Services must submit offers/bids on MSD as follows:

- **Secondary Frequency Regulation**: Offers/bids must be submitted on ex-ante MSD but the service call is only on MB according to the real need. The operator who submits the offer/bid can also choose:
  - The significant time interval from hour 1 to hour 24;
  - In which zone submit the offer/bid.

  The remuneration is on MB market and it depends on the quantity actually provided during real time management.
- **Other Services**: Offers/bids can be submitted both on ex-ante MSD and MB, the options that can be selected by the operators are the same of secondary control. For each market, selected offers/bids are then rewarded with the pay-as-bid method.

3.4 Causes of MSD reform

In order to accomplish both the need to satisfy a growing demand of electric energy and the will to do it in a eco-friendly way, in the last years the presence of **NPRES** as dispatching service providers has been growing.
Until some years ago, the production units that were enabled to dispatching services were the relevant ones as thermal power plants with a unidirectional power flow from the unit to the grid. With the introduction of **NPRES** some problems have arisen:

- These sources require a bidirectional power flow in substations leading to an increase in losses in the grid;
- For the reason in the previous point and the fact that these sources are not programmable, there is an increase of uncertainty in the injection in the grid $\rightarrow$ It is mandatory to supply on MSD more power than the effective needed for safe margin;
- Due to the fact that fossil fuels release energy when burned, they can be seen like a form of energy storage but this is not the case for wind or solar plants. So **NPRES** make the energy system more volatile requiring new ways to balance and store energy.

At the same time, the need of carbon use reduction results in a growth of electric vehicles in circulation.
One way to take advantage of electric vehicles is the technology **V2G**. In fact **V2G** allows the use of vehicle's batteries as a form of storage system.

Chapter 4

V2G and Pilot Projects

4.1 Vehicle-to-Grid (V2G)

The acronym **V2X** means *vehicle-to-everything* and it includes many cases depending on whether the electricity from an EV battery is send to a home (**V2H**) or to a building (**V2B**).
The case of interest in this thesis is the vehicle-to-grid. In **V2G** the charging power of vehicle's batteries is not only modulated in depend of need but it can be pushed back to the grid from car batteries in order to balance variations in energy consumption and production.
The **V2G** technology enables the use of battery 10X more efficiently compared to unidirectional charge (**V1G**) [19]. It is estimated that there will be 140-240 million electric vehicles by 2030; this means that it will be available an aggregated storage capacity of 7 TWh [19].

4.2 Introduction to Pilot Projects

The massive growth of RES is linked to a reduction in the number of thermoelectric plants in operation with the not negligible consequence of difficulties to perform frequency regulation. At the moment, the main strategy adopted is opening the participation at the grid operations to new technologies with pilot projects.
Arera with the resolution **300/2017/R/eel** [20] aimed to start a process of inclusion in the Italian Ancillary Services Market (MSD) to UP not previous enabled to it like renewable resources that can not be scheduled and storage systems.

Terna implemented the resolution **300/2017/R/eel** [20] via the development of *pilot projects*. These give the opportunity to:

- have knowledge of elements useful to the organic reformation of dispatching;
- have immediately available new sources for dispatching.

The resolution establishes that pilot projects can be related to:

- partecipation in MSD of UP and UC not yet enabled (including storage systems that are equivalent to production units);

- use of storage systems, in particular in combination with relevant UP enabled to take part in MSD, in order to optimize the supply of dispatching resources in compliance with the requirements set by the Network Code;
- how to remunerate ancillary services not remunerated at the moment like voltage regulation.
- way in which UP and UC can be aggregated for the selection of offers in MSD in order not to violate network constraints. The resolution allows the creation of aggregates called **UVA** in the respect of parameters defined by Terna. In detail:
  - **UVAP**: characterized by the presence of only non relevant UP and storage systems;
  - **UVAC**: characterized by the presence of only non relevant UC;
  - **UVAM**: characterized by the presence of only non relevant UP including storage systems (used also in e-mobility) and UC;
  - **UVAN**: characterized by the presence of relevant UP subject to voluntary enabling and/or not relevant and possibly also UC, subtended to the same node of the national transmission network;

Furthermore, ARERA's resolution establishes that pilot projects determined by Terna must be preventive evaluated by operators.
Terna must provide to them the project's regulation (with technical requirements and rules for requiring qualification of new resources to MSD) and a technical report in which project's details are explained with all the potential benefits and costs of it. After this step Terna shows the pilot project to the authority ARERA.

The resolution also highlights the minimum criteria that must be respected by UP and UC in order to take part to pilot projects and the need, for the supply of auxiliaries services, to define Terna's counterparts.
They can be the single dispatching users **BRP**(Balance Responsible Parties) that can correspond with the aggregator **BSP** (Balance Service Provider) the operator who can take part to MSD.

The pilot projects suggested by Terna are:

- Pilot project *Unità Virtuali Abilitate di Consumo (UVAC)*;
- Pilot project *Unità Virtuali Abilitate di Produzione (UVAP)*;
- Pilot project *Unità Virtuali di Produzione Rilevanti (UPR)*;
- Pilot project *Unità Virtuali Abilitate miste (UVAM)*;
- Pilot project *Unità Virtuali di Produzione Integrate (UPI)*;
- Pilot project *Fast Reserve*;

- Pilot project *Voltage Regulation*;
- Pilot project *Secondary Frequency Control*.

The timeline of pilot project's activation is shown in Figure 4.1

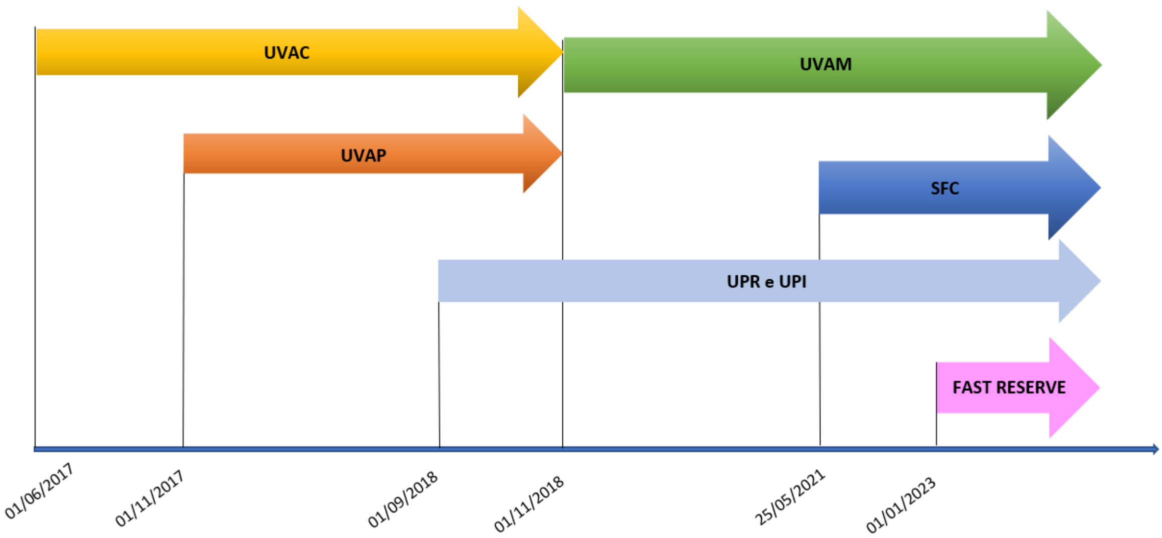


Figure 4.1: Timeline pilot projects [34].

It must be noticed that:

- The pilot project *Fast Reserve* is not activated yet;
- for the pilot project *Voltage Regulation* it has not been defined yet a starting date.

Technology Vehicle-to-Grid is a storage system for e-mobility and so the pilot project that can enable it to the supply of ancillary services is the *UVAM* project.

4.3 Pilot Project for Secondary Frequency Regulation

On the 25 May 2021 ARERA with the resolution **215/2021/R/EEL** [21], approved the Pilot Project for *Secondary Frequency Regulation* proposed by Terna.

4.3.1 Requirements for Qualification

Those who can require the qualification to the supply of the Secondary Frequency Control are:

- Dispatching users in relation to relevant UP:
  - programmable or not programmable;
  - constituted by storage systems.
- Balance Service Providers (**BSPs**) with reference to UVAM, with the technical requirements listed in the following sections.

4.3.2 Process of Qualification

Qualifying tests

- Test of correct configuration of telemeterings.
- Test of correct Telecontrol frequency/power signal chasing.
- Test of minimum time for supplying the service.

Then, there are additional tests specific for virtual units with the purpose of verify the accuracy of measurements at the points of injection/withdrawal.

Technical requirements for enabling new sources to Secondary Frequency control supply

Frequency and Voltage range A qualified unit at the Secondary Frequency control must remain connected to the grid with:

- Normal operation conditions.
- Emergency operating conditions.
- Grid restoration.

In detail, the connection must have no time limit for the **voltage** and **frequency** ranges shown in Table 4.1.

Table 4.1: Voltage and Frequency ranges [22].

		Range
frequency		$47.5Hz \leq f \leq 51,5Hz$
voltage	grid connections at $V_n = 400kV$	$0.85\%V_n \leq V \leq 110\%V_n$
	grid connections at $1kV \leq V_n \leq 400kV$	$0.85\%V_n \leq V \leq 115\%V_n$

These rules are valid for all the points of injection/withdrawal linked to a single virtual unit.

Immunity to frequency variations

A qualified unit at the Secondary Frequency Reserve must keep the connection to the grid and work normally even at the occurances of frequency variations up to 2.5 Hz/s calculated in minimum 5 cycles (100ms).
This rule is valid for all the points of injection/withdrawal linked to a single virtual unit.

Supply Mode

The supply of the Secondary Frequency control depends on the value of a reference signal, called **Level Signal L**, received from Terna.
This segnal is made up of remote commands linked to the variations of the reference value of power that the unit must trade with the grid.
The Level Signal is send by Terna as a percentage variable from 0 to 100% of the positive half-band (SB^+) and/or negative half-band (SB^-) of Secondary Frequency control selected on MSD for each unit.
Table 4.2 explains how the values of the Level Signal affect the power traded between the single unit and the grid.

Table 4.2: Relationship between values of **L** and changes in power supplied.

L value	**Change in power supplied by the unit**
50%	The unit must supply no secondary frequency control at all
100%	The unit must supply all the positive half-band of secondary frequency control (SB^+) selected on MSD.
50% ÷ 100%	The unit must supply a power equal to $2(L - 50\%)SB^+$
0%	The unit must supply all the negative half-band of secondary frequency control (SB^-) selected on MSD.
0% ÷ 50%	The unit must supply a power equal to $2(50\% - L)SB^-$

The service of the Secondary Frequency control must be supplied without any time limit as long as the service is declared operative and the accepted values of positive half-band and/or negative half-band of Secondary Frequency control are not equal to zero.

Management supply of the unit and control of power exchange

The qualified unit must have a management system which can fix the power exchanged between the grid and the unit's points of injection or withdrawal.
This is essential in order to protect the Secondary Frequency control supply.

In detail, there are two main tasks:

- the management system must control that the active power exchanged between the unit and the network is close to a **setpoint**.

  The **setpoint** is equal to the sum of:

- unit's **baseline**[3] that is communicated during the submission of supply offers and demand bids on MSD.
- all services supplied by the unit itself.

- the management system must check that the **control error** is at least less than:
  - the minor between ±1MW and 1% at steady state conditions.
  - 10% at transient conditions in which there is a change in the value of the setpoint. Within 20 seconds from the transient's end, the control error must respect the rule given at steady state conditions explained in the previous point.

The percentages given are referred to the sum of positive and negative half-bands that were accepted on MSD.
For what concerns the virtual units, the instantaneous value of active power is equal to the sum of the power exchanged between the grid and every point of injection or withdrawal of the unit.

4.3.3 Additional Technical Requirements for Virtual Units

Tracking of the Active Power in each point of Injection/Withdraw

A qualified Virtual Unit must guarantee that for each of its points of injection or withdrawal, it can be possible to measure the active power exchanged with the network:

- if the points of injection/withdrawal are connected to the National Electricity Transmission System, there must be a **direct measurement** of the active power for each point.
- In the other cases, the measurement must have a **level of accuracy** better or at least equal to 2.2% of the rated power of the POD for each point of injection/withdrawal.
  It is important to notice that the level of accuracy must include the errors that occur in the measurement chain (A/D conversion ...) and/or errors in the processing algorithm.

It must be noticed that the tracking can be also a presumed value, if it can be demonstrated that the value of the active power depends only by the switches' position in the points of injection or withdrawal. It must have a level of accuracy better or at least equal to 2.2%.
The sampling time of direct measurements for each point must be minor or at least equal to 4 seconds. For the cases in which the tracking is made by presumed values, it must be communicated the status of switches every 4 seconds.

[3]Power schedule of the UVAM that must be communicated to Terna the day before the supply.

Aggregation of measurements

It is required to the qualified virtual units the installation of a specific device called in Italian 'concentratore' in order to:

- arrange the data that must be send to Terna.
- manage the trade of data with each one of the points of injection/withdrawal of the virtual unit and calculate the total active power exchanged between the unit and the grid.

Results

After the qualifying tests, Terna communicates their results to the applicant. If the outcome is positive, Terna transmits to the user the Qualified Unit and its Maximum Positive (Negative) half-band SB^{+}_{max} (SB^{-}_{max}) for which the applicant became enabled to supply the service.
If the result is negative, Terna presents to the user the criticality observed during the tests.

4.3.4 Modality and Constraints of Supply on MSD

Enabled production unit to the supply of Secondary Frequency Reserve can submit offers/bids for one or more of the 24 relevant intervals of time of the reference day on ex-ante MSD.
Offers/bids can be submitted in two ways: asymmetrical or symmetrical.

- asymmetrical:
  - 1 Offer and 1 Bid. With offer's quantity different from bid's quantity and prices eventually different;
  - 1 Offer or 1 Bid.
- symmetrical: 1 Offer and 1 Bid with the same quantity and eventually different prices.

The submitted offers' (bids') quantities are valid if they are greater than 1 MW and smaller than the $SB^{+}_{max}(SB^{-}_{max})$ of the qualified unit who submitted the offers.
If the submitted offers do not respect the constraints mentioned above, Terna changes them:

- If offer's (bid's) quantities are less than 1 MW, they are rectified to 0 MW;
- if offer's (bid's) quantities are greater than $SB^{+}_{max}(SB^{-}_{max})$ of the Qualified Unit, they are rectified and made equal to $SB^{+}_{max}(SB^{-}_{max})$.

Furthermore, offers prices of the Qualified Unit must be not smaller than bid's prices, if this requirement is not respected, Terna equalizes bid's price to offer's price.

4.3.5 Selection and Activation of offers/bids on MSD

Ex-ante MSD

Once the submitting sessions on ex-ante MSD end, Terna selects offers by economic *merit order*. In order to satisfy the demand for secondary frequency reserve, the quantities offered by a qualified unit are considered by applying a *derating factor* between zero and one. Terna uses this factor for taking into consideration the level of reliability of the unit that submits the offer/bid.
At first the value of this component is preventive determined by Terna and then it is updated through time depending on unit's behaviour.

It must be noticed that the selection of offers/bids is such that the total quantity accepted in offer is equal to the one accepted in bid.

MB

Selected offers on ex-ante MSD are then used by Terna in the real time management phase in depends of the need.
Then, each qualified unit gets remuneration only for the quantity actually provided to the grid. Also for Secondary Frequency Reserve the mechanism of remuneration is the *pay-as-bid*, it means that the selected offers are rewarded with the same price with which they were submitted on ex-ante MSD.
Rules for the computing of remuneration to the units are provided by Terna in the Regulation.

4.3.6 Remuneration Rules

Phase 1: Calculation of Q_{MSD} and verification of a first condition for a correct execution

For each relevant interval of time, in case of call in service of a qualified unit during the MB, Terna verifies the correct execution of the accepted quantity only if it is respected the condition expressed in the equation 4.1.

$$|Q_{MSD}(i)| \geq \frac{0.5}{4} MWh \tag{4.1}$$

where i is the relevant interval of time, and

$$\begin{aligned} |Q_{MSD}(i)| = \sum Q^{sell}_{EX-ANTE}(i) - \sum Q^{buy}_{EX-ANTE}(i) + \sum Q^{sell}_{MBNRS}(i) \\ - \sum Q^{buy}_{MBNRS}(i) + \sum Q^{sell}_{MBRS}(i) - \sum Q^{buy}_{MBRS}(i) \end{aligned} \tag{4.2}$$

Where:

- $\sum Q^{sell}_{EX-ANTE}(i)$ and $\sum Q^{buy}_{EX-ANTE}(i)$ are respectively the quantity in offer and in bid accepted in ex-ante MSD for Other Services in the relevant interval of time i with reference to the qualified unit;

- $\sum Q^{sell}_{MBNRS}(i)$ and $\sum Q^{buy}_{MBNRS}(i)$ are respectively the quantity in offer and in bid accepted in MB for Other Services in the relevant interval of time i with reference to the qualified unit;
- $\sum Q^{sell}_{MBRS}(i)$ and $\sum Q^{buy}_{MBRS}(i)$ are respectively the quantity in offer and in bid accepted Secondary Frequency Reserve in the relevant interval of time i with reference to the qualified unit;

Phase 2: Computation of Non-Supplied Quantity

For each qualified unit constituted by an UVAM and each relevant interval of time, if it is respected the condition in 4.1, Terna determines the *non-supplied quantity* $Q_{NF}(i)$ as follows:

a.

$$Q_{NF}(i) = min(-min(Ene_{mis}(i) - (E0(i) + Q_{MSD}(i)); 0)\,|Q_{MSD}(i)|) \tag{4.3}$$

if $Q_{MSD}(i) > 0$;

b.

$$Q_{NF}(i) = min(max(Ene_{mis}(i) - (E0(i) + Q_{MSD}(i)); 0)\,|Q_{MSD}(i)|) \tag{4.4}$$

if $Q_{MSD}(i) < 0$

where:

- i is the relevant interval of time;
- $Ene_{mis}(i)$ is the total injected/withdrawn energy (in MWh) from the points of injection/withdrawal included in UVAM;
- E_0 is the balance of energy totally programmed in injection and/or withdrawal from the BSP (in MWh) and it is computed as in equation 4.5:

$$E_0(i) = \frac{B(i) \cdot 1h}{4} + \Delta B \tag{4.5}$$

Where:

  - B is the **Baseline(i)** is the quarterly value of the Baseline referred to the UVAM in MW;
  - ΔB is $\Delta Baseline$ is the corrective term (in MWh) defined as follows that must be algebraic summed with **Baseline(i)**

a.

$$\Delta B = max(0; \sum_{j=1}^{n}[Ene_{mis}(j) - B\frac{j}{4}]/n)$$

if $Q_{MSD}(i) \geq 0MWh$;

b.
$$\Delta B = min(0; \sum_{j=1}^{n} [Ene_{mis}(j) - B\frac{j}{4}]/n)$$

if $Q_{MSD}(i) \leq 0MWh$.

Where:

- $Ene_{mis}(j) - B\frac{j}{4}$ is the difference between the energy actually injected/withdrawn from the points included in the UVAM and the value of programmed energy in injection/withdrawal by the BSP as communicated to Terna;
- n is referred to the number of quarters of hour before the correction of the baseline. This happens the first quarter hour in which the net value of accepted quantities is greater than 4.1.
  In any case n cannot be greater than 8.

Phase 3: Verification of Correct Execution of Accepted Quantities

For each qualified unit constituted of an UVAM and for each relevant interval of time, Terna verifies that $Q_{NF}(i)$ is equal to zero and:

- if $Q_{NF}(i) = 0$ the accepted quantities are correctly performed by the qualified unit in the interval of time considered.
- if $Q_{NF}(i) \neq 0$, it can be considered two different cases, in fact:
  - if $Q_{MSD}(i) > 0 \rightarrow$ The quantities accepted are not correctly performed by the unit in the interval i and so the user must pay to Terna, for all the quantity $Q_{NF}(i)$, a compensation γ for missing respect of correct execution of accepted quantities, computed as follows:
    * if $\left|\frac{Q_{NF}(i)}{Q_{MSD}(i)}\right| \geq 5\%$
      $$\gamma = Q_{NF}(i) \cdot max(P^{marg}_{MB\uparrow}(i); P^{UP}_{MSD\uparrow}(i))$$
    * if $\left|\frac{Q_{NF}(i)}{Q_{MSD}(i)}\right| \leq 5\%$ or the qualified unit is not available for the supply of the service, the compensation γ would be:
      $$\gamma = Q_{NF}(i) \cdot P^{UP}_{MSD\uparrow}(i)$$
  - if $Q_{MSD}(i) < 0 \rightarrow$ The quantities accepted are not correctly performed by the unit in the interval i and so the user must pay to Terna, for all the quantity $Q_{NF}(i)$, a compensation γ for missing respect of correct execution of accepted quantities, computed as follows:
    * if $\left|\frac{Q_{NF}(i)}{Q_{MSD}(i)}\right| \geq 5\%$
      $$\gamma = Q_{NF}(i) \cdot min(P^{marg}_{MB\downarrow}(i); P^{UP}_{MSD\downarrow}(i))$$

* if $\left|\frac{Q_{NF}(i)}{Q_{MSD}(i)}\right| \leq 5\%$ or the qualified unit is not available for the supply of the service, th compensation γ would be:

$$\gamma = Q_{NF}(i) \cdot P^{UP}_{MSD\downarrow}(i)$$

Where:

* i is the relevant interval of time;
* $P^{marg}_{MB\uparrow}(i)$ is the highest price for accepted offers and in increase for Other Services in MB in the interval i in the market zone in which it is located the qualified unit;
* $P^{UP}_{MSD\uparrow}(i))$ is the weighted average price of unit's accepted offers both for Secondary Frequency Reserve and for Other Services in MB in the interval i;
* $P^{marg}_{MB\downarrow}(i)$ is the lowest price for accepted bids and in decrease for Other Services in MB in the interval i in the market zone in which it is located the qualified unit;
* $P^{UP}_{MSD\downarrow}(i))$ is the weighted average price of unit's accepted bids both for Secondary Frequency Reserve and for Other Services in MB in the interval i.

Phase 4: Calculus of remuneration α

The remuneration α per hour, that follows the method *pay-as-bid* is then computed:

if $Q_{MSD}(i) > 0$ there is net sale, so:

- if there is no penalty ($\gamma(i) = 0$) the remuneration will be equal to the price of offer submitted in hour i;
- if there is penalty ($\gamma(i) \neq 0$) the remuneration will be equal to the price of offer submitted in hour i minus $\gamma(i)$.

if $Q_{MSD}(i) < 0$ there is net purchase, so:

- if there is no penalty ($\gamma(i) = 0$) the remuneration will be equal to the price of bid submitted in hour i;
- if there is penalty ($\gamma(i) \neq 0$) the remuneration will be equal to the price of bid submitted in hour i minus $\gamma(i)$.

Phase 5: Update of unit's Baseline by Terna

For each qualified unit constituted by an UVAM and each relevant interval of time (i), if there are accepted quantities in the real time management for Secondary Frequency Regulation, Terna updates the schedules of injection/withdrawals according to the Electricity Market's results.

Chapter 5

Case Study Analysis and Simulations Results

5.1 Case Study

5.1.1 Technical Analysis of recharge devices in the market

For a better adherence to reality of the simulation, it was previously done a research on the main components of charging stations as connectors and charging stations. It will be done a focus on V2G case.

Charging in DC VS charging in AC

Batteries can store energy only in DC current, so if the charge is in AC, it is needed a AC/DC converter on board that convert the current and voltage before its arrival at the battery, while in DC charging the conversion AC/DC is done in the charging station.

So as a consequence of these differences, the DC charging is faster than the AC because there is no conversion on board.

But it must be noticed that DC charging has some drawbacks:

- extended DC charge can raise battery temperature and this can lead to a reduction of battery life;
- DC charging stations are much more expensive than AC ones because of an higher level of voltage required;
- AC charging stations are more common in Europe than DC stations.

Type of Cable Connectors

In order to recharge the electric car, it is essential that the vehicle's outlet matches with the one of the charging station.
There are four main type of plugs: two in AC and two in DC.

AC plugs

- **Type 1**: The plug in Figure 5.1 is a single-phase plug and it is standard for EVs in America [23] and common in vehicles produced in Asia. The typical power ratings are 3.7 kW/7 kW [24];

Figure 5.1: Type 1 plug [26].

- **Type 2**: Plugs like the one in Figure 5.2 are triple-phase plugs also called *Mennekes* from the company which created it. This type of connector was declared European standard in 2013 [23].
  The typical power ratings are 3.7 kW/7kW and 22 kW in three-phase mode[24]. This type of connector is also used in Tesla cars sold in Europe [25].

Figure 5.2: Type 2 plug [27].

DC plugs

- **CHAdeMO**: This is the first DC connector for fast charging developed by Japan auto makers more than ten years ago. European Parliament tried to enforce the disappearance of this connector from Europe in favor of CCS and, at the moment, only two electric car makers uses CHAdeMO and, one of them, NISSAN, is moving to CCS connectors.
  So it is likely to happen that CHAdeMO connector will become common only in Japan and China [25]. It allows charging up to 100 kW [23].

Figure 5.3: CHAdeMO plug [28].

- **CCS**: CCS exists in two types as shown in Figure 5.4, the same as the AC plugs Type 1 and Type 2 with two more pins added at the bottom.
  In DC charging, these two pins take part to the charging itself, while in the upper part is used only the communication pin and the earth conductor.
  It is currently the most popular plug: Type 1 is common in United States, while Type 2 is a standard in Europe since 2013.
  These connectors can withstand power of up to 350 kW [25].

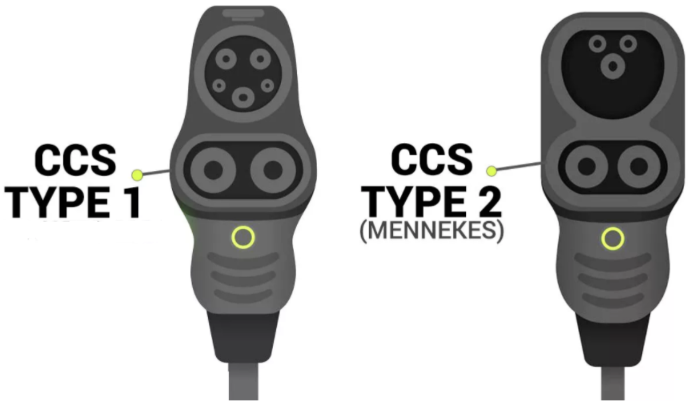


Figure 5.4: CCS plug [29].

Charging Stations

These can be classified according to the output power as shown in Table 5.1.

Table 5.1: Classification of charging stations depending on output power

TYPE	OUTPUT POWER
Slow Chargers	$P \leq 7.4$ kW
Quick Chargers	7.4 kW $< P \leq 22$ kW
Fast Chargers	22 kW $< P \leq 50$ kW
Ultra-Fast Chargers	50 kW $< P \leq 350$ kW

Changing the output power correspond to a different sizing of columns and type of users. Generally the infrastructures characterized by high power are meant for heavy vehicles as trucks. Furthermore, the type of charging stations can be divided also in depends of the type of connection.

ARERA on April 2021 [30] analyzed 225 devices for charging electric vehicles produced by Italian and foreign companies that have already installed charging stations in Italy.
This analysis shows that the majority of the charging stations devices (about 88%) can provide only an AC connection and the remaining 12 % can provide DC charge. The majority of the latter group is composed by *bivalent* devices, so they can provide both AC and DC current.

In detail, the research highlights the subdivision between AC/DC charging among the types of charging stations in Table 5.1. As it can be seen in Figure 5.5, DC configuration is almost missing in *Slow* and *Quick* chargers while, taking also into account bivalent devices, it correspond to nearly half of the *Fast* devices and it prevail among *Ultra-Fast* chargers.

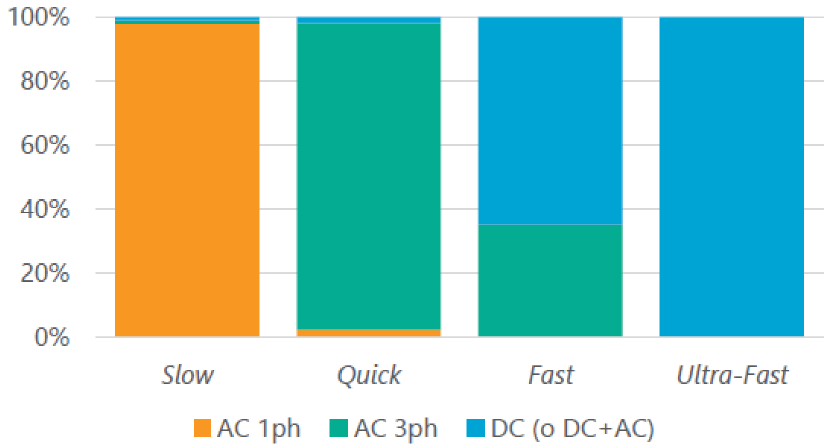


Figure 5.5: Subdivision of charging devices in AC(1ph), AC(3ph) and DC or (DC+AC)[30].

Devices for Vehicle-to-Grid

In order to activate the features **V1G** and **V2G**, the charging device must work with flexibility, that is the ability of modulating the current during the charging. From the research done by ARERA [30], it was highlighted that this feature is common in *Slow* and *Quick* devices (characterized by AC charge) while less than half of *Fast* and *Ultra-Fast* chargers can modulate current (characterized by DC charge).
From these data it is possible to deduce that:

- The supply of service **V1G** is available for two-thirds of AC devices (mostly *Slow* and *Quick* types) and nearly half of devices that can provide DC current;
- Only 2 of the 28 (both are part of *Slow* and *Quick* devices) can manage

bidirectional power (**V2G**) that, at the moment, it is possible only for DC current.

So it is clear that the unavailability on the Italian market of devices that can manage bidirectional power is a limit to the spread of **V2G** functionality, but other three reasons can be identified:

- There are still few models of car whose battery can manage bidirectional power [30];
- until now applications of **V2G** service are related only to DC charging systems based on CHAdeMO standard.
  Few are the tests of **V2G** based on CCS connector due to a delay in the release of the technical regulation that enables the communication between charging device and vehicle [30].
  In fact the first part of this regulation, the **ISO 15118-20**, was released at the end of 2021 and the second part will be released in two years, so many observes as charIN, the developer of CCS standard, stated that **V2G** project would be completed by 2024/2025 [31];
- on the Italian market, the price of a *bidirectional* charging station is four/five times higher than an *unidirectional* one [31];

5.1.2 Hypothesis and Input Data of the Case Study

Hypothesis

For simulating the supply of ancillary services, it was hypothesized a parking lot of a company for 300 plug-in vehicles with the following work schedule:

- 9.30 a.m - 6 p.m. from Monday to Friday;
- close on Saturday and Sunday.

The vehicles participate to the Market as a single aggregator **BSP** connected to the **MV** grid.

Input data

The input data of the case study that are useful to the simulations are:

- type of vehicles;
- distance travelled on the way home-work;
- type of charging infrastructure.

In details:

Type of Vehicles Various types of plug-in model car were considered each one with different specifications of battery capacity and consumption in order to simulate the variety of options of electric car available on the market.
In the Table 5.2 are shown part of the models evaluated[37].

Table 5.2: Battery Capacity and Consumption of some models of BEV cars.

Battery Capacity [kWh]	Consumption [kWh/km]	Model
16	0.126	CITROEN czero
71	0.218	AUDI e-tron
50	0.2	CITROEN c4
76	0.172	FORD Mustang
100	0.225	TESLA model X
24	0.154	VOLKSWAGEN golf
100	0.1915	TESLA model S
73	0.195	TESLA model Y
71	0.218	BMW I3
32.6	0.155	MINI Mini
52	0.16859	VOLKSWAGEN ID.4
17.6	0.1815	SMART forfour
50	0.159	PEUGEOT 2008

Distance travelled on the way home-work The distance travelled by cars before arriving at work is not defined randomly but it was obtained by analysis of ISTAT[4] data on extension of Italian towns and distances between them [37].

Type of charging infrastructure The type of charging station is the *Terra Nova 11 J* shown in Figure 5.6 made by ABB with connector CHAdeMO.
From researches done in *Officine Edison* [34] resulted that the device has:

- average efficiency of 96.5% for V2G modality and 94% for G2V modality;
- the output power changes between V2G and G2V: it is 11 kW in charge (G2V) and 10 kW in discharge (V2G);
- it is not possible to have a power modulation so it is maintained constant in charge and discharge at, respectively, 11 kW and 10 kW.

[4]National Institute of Statistics

Figure 5.6: Terra Nova 11 J ABB [32].

5.2 Simulations

The aim of this thesis is to prove the economic convenience for V2G technology to participate to Secondary Frequency Reserve and this goal has been pursued by simulating the participation of the case study aggregator to the Market by submitting offers/bids.
In order to define when and where it is more convenient to submit offers, it was previously done an analysis on the Italian Market results in the year 2019 as first step of simulations.

So, the simulation part is made up of two steps:

- Step 1: Analysis of the Italian Electricity Market public data of the year 2019 available on GME site;
- Step 2: Simulation of the participation on the market of the aggregator in our case study and it is calculated the UVAM's remuneration for Secondary Frequency Control.

All the simulations were developed using Matlab software and in Figure 5.7 are shown the functions developed in this thesis:

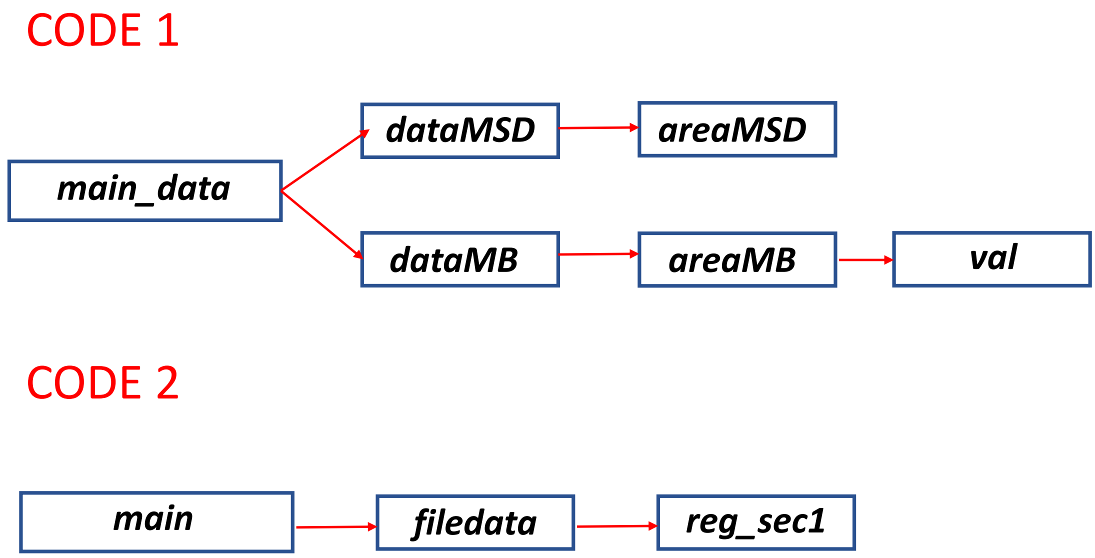


Figure 5.7: List of Matlab functions.

5.2.1 Code 1 : Analysis of the Italian Electricity Market

Due to the fact that there is no comprehensive knowledge of all the bids and offers submitted on the market, it was asked to Edison Market experts which is the more feasible solution for simulating the reality. They replied that the practicable path that can be pursued in order to make a selection of UVAM's offers/bids is statistical with the hypothesis that it is acceptable to compare the UVAM to other technologies, as thermoelectric or hydroelectric, due to their high reaction speed.
This hypothesis is relevant: in fact, it has as main consequence the fact that the probability for an offer to be accepted, it does not depend on who make it on the market.

So, the aim of this simulation is the definition of the probability for an offer/bid to be accepted on the Market. In detail, due to the fact that the focus of the thesis is on ancillary services, the analysis was on MSD's results of the year 2019 that are available on the GME site.

Definition of probability ρ

The value of the probability ρ for an offer to be accepted can be calculated in two ways:

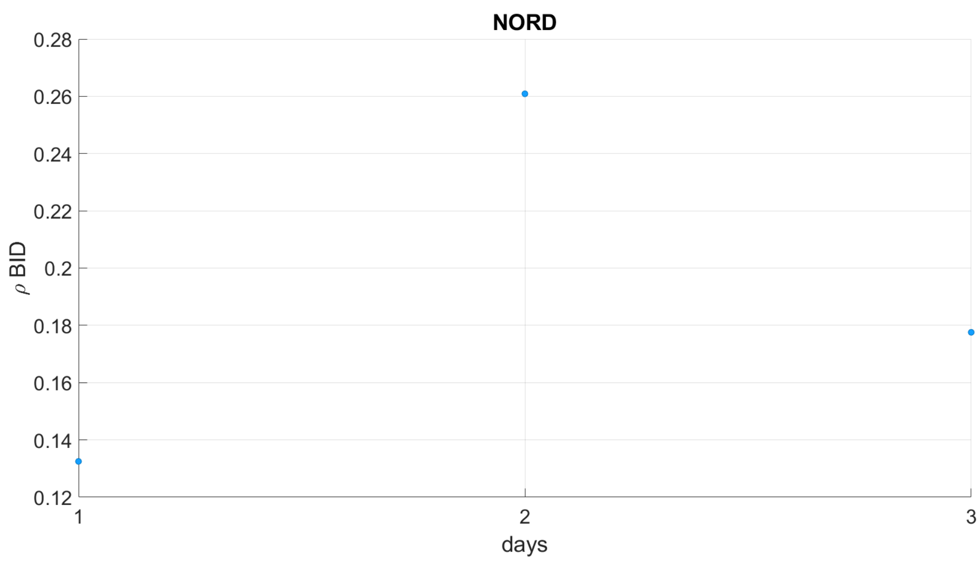
- taking into consideration the *number of offers* $\rightarrow \rho$ is calculated as the ratio between the number of accepted offers and the number of submitted offers for a service:

$$\rho = \frac{\text{n° accepted offers}}{\text{n° submitted offers}} \tag{5.1}$$

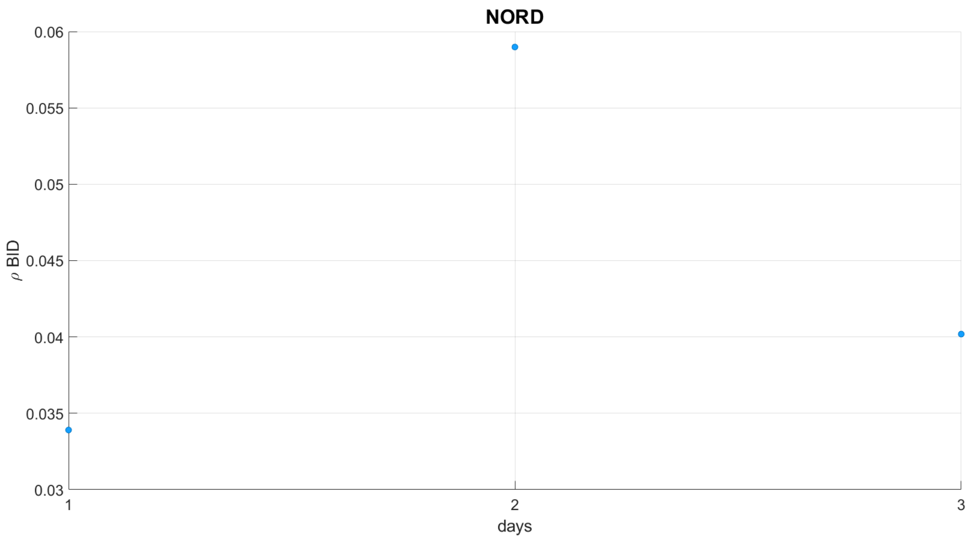
- taking into consideration the *quantity* $\rightarrow \rho$ is calculated as the ratio between the total quantity accepted and the total quantity submitted for a service:

$$\rho = \frac{\text{accepted quantity}}{\text{submitted quantity}} \tag{5.2}$$

In the graphs in Figure 5.8 are considered the first three days of January 2019 in the NORD area for making a comparison between the two methods for computing the values of ρ.
Generally, values computed using the number of offers is greater than the ones with quantities, this follows the change in the relative weight of an offer from the first case to the second one.
In fact, for example, in the first method there is no difference between an offer of 150 MW and one of 2 MW while their relative weight differs if it is taken into consideration the quantity offered.



(a) (1) values of ρ calculated with first method.



(b) (2) values of ρ calculated with second method.

Figure 5.8: Comparison between the two methods of calculating ρ

The simulation results that are introduced in the following sections are made with the first method, the one based on the number of offers. This choice was linked to the need of calculating ρ not for a generic plant but for the one in the case study that can offer a maximum power of 3 MW; so it was decided to impose a quantity constraint to the offers accepted.

Probability ρ for Ancillary Services

Secondary Frequency Reserve For participating to Secondary Frequency Reserve, operators must submit offers/bids on Ex-Ante MSD but they got remuneration only if Terna calls them to provide the service on MB, depending on real needs.

It was hypothesized that all the offers/bids submitted on Ex-Ante MSD were automatically accepted to MB while it was object of analysis the probability for an accepted offer to be called in service by Terna during real time management.

So, for summing up:

- $\rho_{approval}$ on Ex-Ante MSD equal to 1 by hypothesis;
- trends of ρ_{call} on MB extracted from Market's results analysis.

Other Services Offers/bids for *Other Services* can be submitted both on Ex-Ante MSD and MB and the accepted ones got remuneration in each market.

So, for each day two different values of ρ are calculated using simulations:

- $\rho_{approvalMSD}$: it is the probability for an offer/bid submitted on Ex-Ante MSD to be accepted and gets remuneration;

- $\rho_{approvalMB}$: it is the probability for an offer/bid submitted on MB to be accepted and gets remuneration;

Offers/Bids Public-Domain files

Files with the public-domain bids and offers are available on GME site under the heading '*Results and Statistics* '. Their type is **XML** and they can be open as Excel files for an easier consultation.

Structure of Excel files For each day, two files must be analyzed: one with Ex-Ante MSD results and one with MB results.
In Figure 5.9 is shown the Excel table of MB results for a single day with details on the principal fields [35].

PURPOSE_CD	TYPE_CD	STATUS_CD	MARKET_CD	UNIT_REFERENCE_NO	INTERVAL_NO	BID_OFFER_DATE_DT	TRANSACTION_REFERENCE_NO
OFF	REG	ACC	MB	UP_ALTOADDA_1	8	20190101	9,95893E+14
OFF	REG	ACC	MB	UP_ALTOADDA_1	8	20190101	9,95893E+14
OFF	REG	ACC	MB	UP_ALTOADDA_1	8	20190101	9,95893E+14
BID	REG	ACC	MB	UP_ALTOADDA_1	13	20190101	9,95893E+14
BID	REG	ACC	MB	UP_ALTOADDA_1	14	20190101	9,95893E+14
BID	REG	ACC	MB	UP_ALTOADDA_1	14	20190101	9,95893E+14
BID	REG	ACC	MB	UP_ALTOADDA_1	14	20190101	9,95893E+14
BID	REG	ACC	MB	UP_ALTOADDA_1	14	20190101	9,95893E+14

(a) Details on MB results table.

QUANTITY_NO	AWARDED_QUANTITY_NO	ENERGY_PRICE_NO	MERIT_ORDER_NO	PARTIAL_QTY_ACCEPTED_IN	ADJ_QUANTITY_NO	ADJ_ENERGY_PRICE_NO	GRID_SUPPLY_POINT_NO
225,5	6,587	105,5	0	Y	225,5	105,5	PSR_283
225,5	9,41	105,5	0	Y	225,5	105,5	PSR_283
225,5	2,687	105,5	0	Y	225,5	105,5	PSR_283
0	2,572	51,22	0	Y	0	51,22	PSR_283
0	2,967	51,22	0	Y	0	51,22	PSR_283
0	2,967	51,22	0	Y	0	51,22	PSR_283
0	2,967	51,22	0	Y	0	51,22	PSR_283
0	2,967	51,22	0	Y	0	51,22	PSR_283

(b) Details on MB results table.

ZONE_CD	AWARDED_PRICE_NO	OPERATORE	SUBMITTED_DT	BILATERAL_IN	SCOPE	QUARTER_NO	BAType
NORD	105,5	EDISON SPA	2,01812E+16	FALSO	GR1	2	NREV
NORD	105,5	EDISON SPA	2,01812E+16	FALSO	GR1	3	NREV
NORD	105,5	EDISON SPA	2,01812E+16	FALSO	GR1	4	NREV
NORD	51,22	EDISON SPA	2,01812E+16	FALSO	GR1	4	NREV
NORD	51,22	EDISON SPA	2,01812E+16	FALSO	GR1	1	NREV
NORD	51,22	EDISON SPA	2,01812E+16	FALSO	GR1	2	NREV
NORD	51,22	EDISON SPA	2,01812E+16	FALSO	GR1	3	NREV
NORD	51,22	EDISON SPA	2,01812E+16	FALSO	GR1	4	NREV

(c) Details on MB results table.

Figure 5.9: Excel Table of daily MB results.

The fields have the following meaning:

- PURPOSE_CD: Purpose of bid/offer;
- STATUS_CD: Status of bid/offer after market execution.
  There are 6 type of status:
  - ACC: accepted

  - REJ: rejected
  - INC: inadequate
  - REP: replaced
  - REV: revoked
  - SUB: submitted

- INTERVAL_NO: Relevant period to which the bid/offer refers;
- QUANTITY_NO: Volume submitted by the participant;
- AWARDED_QUANTITY_NO: Volume awarded by the market;
- ENERGY_PRICE_NO: Price submitted by the participant;
- MERIT_ORDER_NO:Merit order of the bid/offer as calculated by the market solution algorithm;
- ADJ_QUANTITY_NO: Submitted volume, possibly adjusted by the system;
- ADJ_ENERGY_PRICE_NO: Price possibly adjusted by the system.
- ZONE_CD: Zone to which the unit belongs;
- AWARDED_PRICE_NO: Price awarded by the market;
- SCOPE: it indicates the purpose of the bid/offer. There are types of scope:
  - AS: Minimum Stable Operation or Switching-Off;
  - RS: Secondary Reserve;
  - GR1: step 1;
  - GR2: step 2;
  - GR3: step 3;
  - GR4: step 4;
  - AC: switching-on;
  - CA: change of operating conditions;
- QUARTER_NO: Only for the MB: it indicates the quarter of hour in the hour of flow.

Structure of Code 1

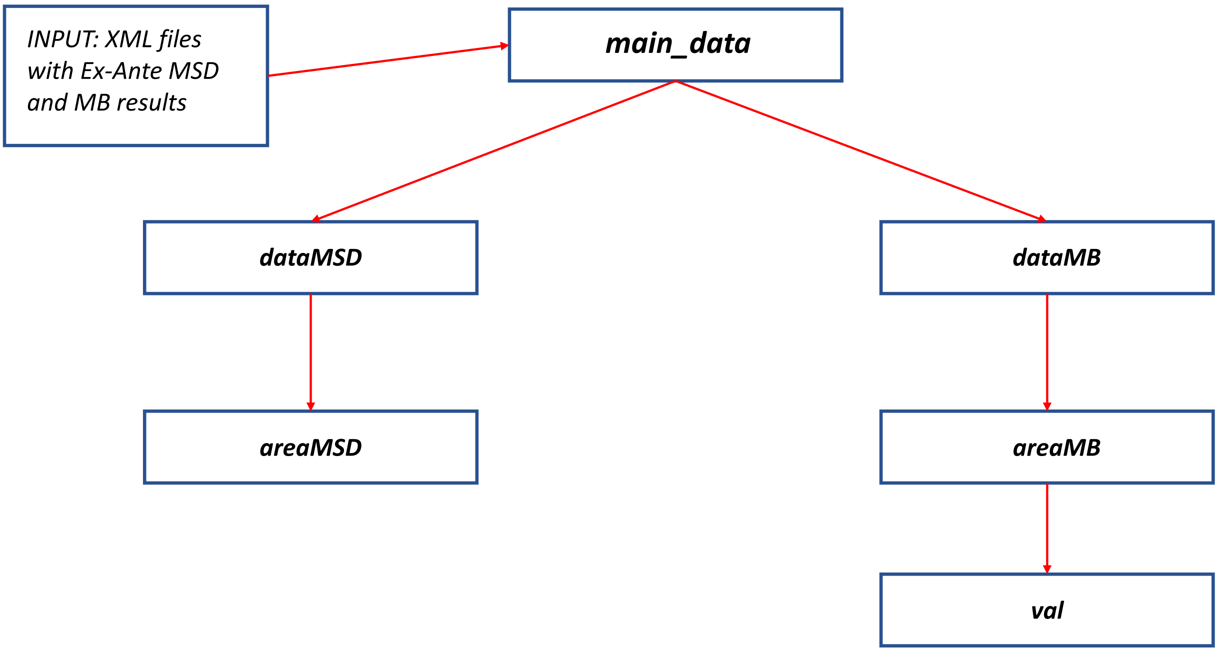


Figure 5.10: Structure of code 1.

As it is shown in Figure 5.10, the main script of Code 1 is main_data which receives in input the XML files both for Ex-Ante MSD and MB.
Before running the code, user can also choose whether to conduct the analysis for Secondary Frequency Control or Other Services and if he wants to set up a maximum quantity accepted/called in **GR/RS** from a unit for each relevant interval of time.

After having detected all the XML files available, they are analyzed in a 'while' loop which is an iterative structure that remains in execution until all the files in the directory have been examined. For each iteration is analyzed one day of data, so both Ex-Ante MSD results file and MB results file.
Then, within the loop, MSD and MB files are examined using two different functions: DataMSD and DataMB. In each script, all the information about Market's results are extracted from XML files and then data is firstly divided in two tables one for the bids (**BID**) and the other for the offers (**OFF**). Then, for each table, only the rows related to the ancillary service in which the user is interested in are kept while the others are deleted.

In order to obtain relevant results, the analysis goes deeper and there is another subdivision of offers/bids that depends on the zone in which they are submitted. So, both in DataMSD and DataMB functions, there is a 'for' loop in which, for each iteration, it is taken into consideration one of the seven zones of the Italian Market.

The analysis of data by area is done in a function called, respectively, areaMSD and areaMB.
Finally, the function val is recalled in areaMB and it is useful for the definition of minimum, maximum, mean and median values of bid's and offer's quantities and prices.

This is the main structure of Code 1 and it can be noticed a symmetry in the way Ex-Ante MSD and MB are analyzed but, obviously, the outputs of functions are different depending on the type of market.

5.2.2 Secondary Frequency Reserve in Code 1

Once that the user chooses for Secondary Frequency Reserve analysis and sets up a maximum called quantity, the code will provide the following outputs for all the market's zones:

- Trends of the probability ρ_{call} values on different timescales:
  - annual;
  - biannual;
  - quarterly;
  - monthly;
  - weekly;
  - daily with distinction between workdays and holidays;
  - hourly with distinction between workdays and holidays.
- Values daily and hourly of weighted average price;
- Values of minimum, maximum, median and mean of daily offers'/bids' prices and quantities.

Furthermore, if a maximum called quantity is not specified by the user, there is one more output that is the daily value of ρ calculated using quantities called/submitted.

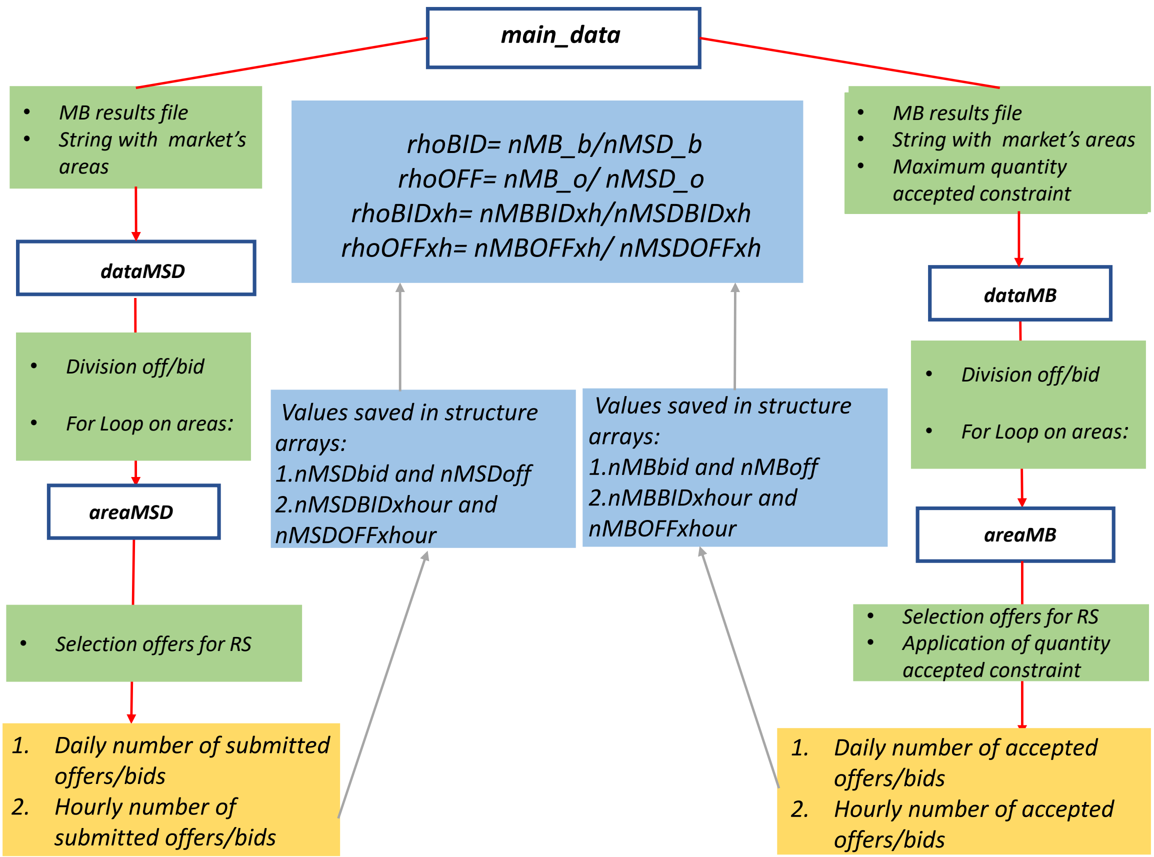


Figure 5.11: Phases of ρ for RS calculation.

Calculus of ρ As already explained in paragraph 5.2.1, on Ex-ante MSD there is the submission of offers/bids for the service, the eventually call is on MB.

As it can be noticed in Figure 5.11, the function dataMSD receives in input the XML file with MSD results and the string with the names of the market's areas. Within the function, the two tables with, respectively, bids and offers, are given as input to the function areaMSD together with the name of the market's zone that changes at every iteration of the for loop.
In this function, after the selection of offers/bids for **RS** and then for the specific area in input, the following data is given as output to dataMSD:

1. the daily number of offers/bids submitted for **RS** service;
2. the hourly number of offers/bids submitted for **RS** service;

These outputs are then associated to their zone and saved in structure arrays: *nMSDbid* and *nMSDoff*, with reference to point 1, and for point 2, *nMSDBIDxhour* and *nMSDOFFxhour*. In these structures are saved daily values so they are updated at each time *dataMSD* is executed.
So all the values just calculated are given as output to main_data and saved in a final structure that will keep all the data from the first to the last day examined.
In this case these structure are: *nMSD_o* and *nMSD_b* for point 1 and *nMSDBIDxh* and *nMSDOFFxh* in relation to point 2.

After Ex-Ante MSD, there is the the analysis of MB in which, if defined by the user, the maximum called quantity constraint is applied to the offers/bids.
The function dataMB receives as input the XML file with MB results, the string with the names of the market's areas and the value of maximum called quantity. In the function there is, firstly, the division between offers and bids and then the 'for' loop with the iterative call of the function areaMB, which has in input the tables with MB's bids and offers, the quantity constraint and the name of the market's zone linked to the iteration.
In this function, after the selection of offers/bids for **RS** and then for the area considered in the iteration of the 'for' loop, the quantity constraint is applied and the outputs useful for the calculus of ρ are defined, in particular:

1. the daily number of offers/bids called for **RS** service in real time;
2. the hourly number of offers/bids called for **RS** service in real time;

As for daily values on Ex-Ante MSD, these outputs are firstly linked to their area and saved in structure arrays in dataMB that are: *nMBbid* and *nMBoff* in relation to point 1 and *nMBBIDxhour* and *nMBOFFxhour* for point 2. Then, these data are given as output to main_data and saved in structure arrays for 365 days that are: *nMB_o* and *nMB_b*, with reference to point 1, and *nMBBIDxh* and *nMBOFFxh* for point 2.

At this point it is possible to calculate, for each day, the value of $\rho_{call,daily}$ (*rhoBID* and *rhoOFF* in the code) and the 24 values of $\rho_{call,hourly}$ (*rhoBIDxh* and *rhoOFFxh* in the code) for each market's zone in main_data both for bids and offers.

For what concern the evaluation of ρ on different timescales, it can be described as example the case of $\rho_{call,weekly}$. For its calculation, it is defined a counter that changes status every seven days examined: when it happens, it is done the sum of the daily number of offers/bids called/submitted in the previous seven days and then it is calculated the ratio for obtaining $\rho_{call,weekly}$.

For what concern the division of working days and holidays, it is defined in main_data a string with 365 elements; each one can be one or zero in depends if the corresponding day in 2019 was, respectively, a workday or an holiday.

Calculus of daily and hourly values of weighted average price The Weighted Average Price of a group of offers/bids is calculated considering the pair Quantity/Price that characterizes each offer/bid as in equation 5.3:

$$\text{WAP} = \frac{\sum(\text{Quantity} \cdot \text{Price})}{\sum \text{Quantities}} \tag{5.3}$$

In this thesis, the calculation of the weighted average price is done only for the offers called to supply the service during real time management.

Among the inputs that the function areaMB receives from dataMB as described in 5.2.2, the tables with MB's offers/bids are essential for the calculation of weighted average prices. In fact, after the selection of offers/bids only for the area considered and the application of quantity constraint, the tables are analyzed using a for loop. For each row, it is made the product of quantity and price that is then summed to the products of other rows in a variable and all the quantities are summed in another variable. At the end of the 'for' loop, it is calculated the ratio between the two variables for obtaining the daily values of WAP.

For what concern the hourly values, the procedure is the same as the one explained before but the ratio of variables is computed hour by hour.

The values for bids and offers just computed are then given as output to dataMB where they are associated to their area in structure arrays *w_av_priceBID* and *w_av_priceOFF* for daily values and *price_av_BID* and *price_av_OFF* for hourly values.
As already seen for ρ values, also weighted average price data are then recalled in main_data and saved in the final structure arrays, that are respectively, *w_ave_priceBID* and *w_ave_priceOFF* and *price_ave_BID* and *price_ave_OFF*.

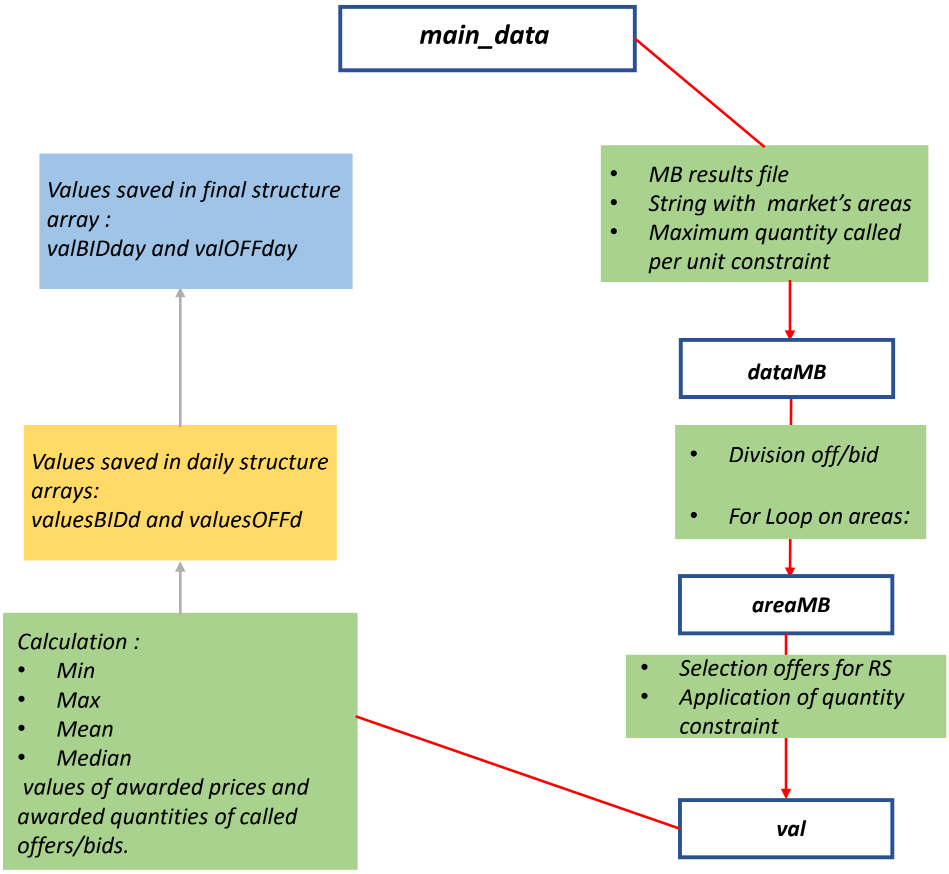


Figure 5.12: Phases of prices' and quantities' remarkable values of called offers calculation.

Computation of values of minimum, maximum, median and mean of daily offers'/bids' prices and quantities The calculation of these values for quantities and prices is done on offers/bids on MB using a particular function called val.
As it can be seen in Figure 5.12, this function is recalled in areaMB and it receives in input only the tables of MB's bids/offers for the area in study. On the columns of awarded quantity and awarded price are applied the following Matlab functions:

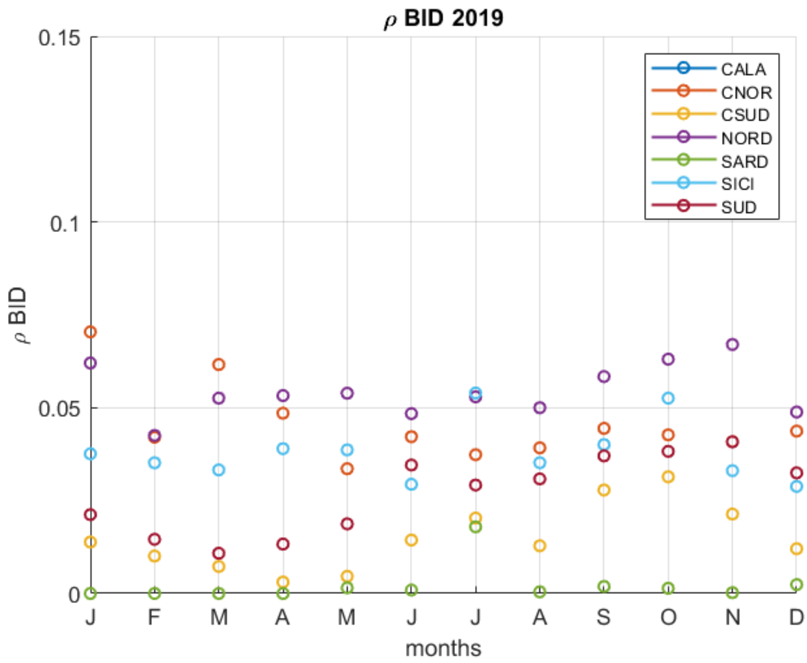
- *min* that computes the minimum value of an array;
- *max* that computes the maximum value of an array;
- *median* that computes the median value of an array;
- *mean* that computes the mean value of an array;

In output of the val function, there are two vectors, one for the bid and the other for the offers. Each vector has eight elements: four values for the quantities and four for the prices.
In dataMB the values are saved in structure arrays called, respectively, *valuesBIDd* and *valuesOFFd*. The structure arrays in which are saved the quantity/prices' values for all the year in main_data are *valBIDday* and *valOFFday*.

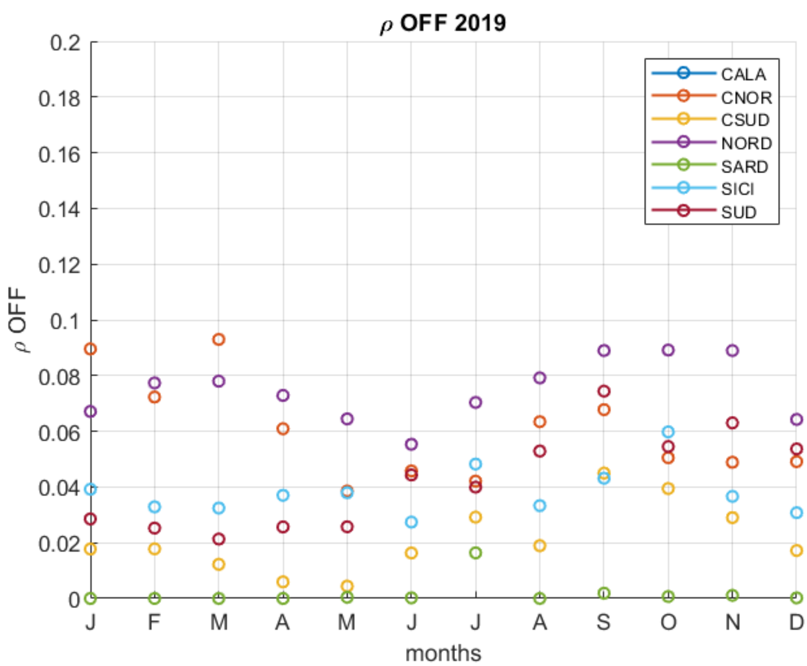
5.2.3 Results of Simulation for Secondary Frequency Reserve

It must be noticed that among the seven zones already mentioned in 3.2.1, the zone **CALA**, that corresponds to the geographical Calabria Region, has no offers/bids submitted through all the year. In its place, it is common the presence of the pole of limited production of Rossano (**ROSN**) that is placed in Calabria. But, due to the fact in thesis it was chosen to focus only on the seven geographical zones, the offers/bids submitted by the pole in Rossano were not taken into consideration.

Trends of Monthly ρ in 2019 for each Market zone



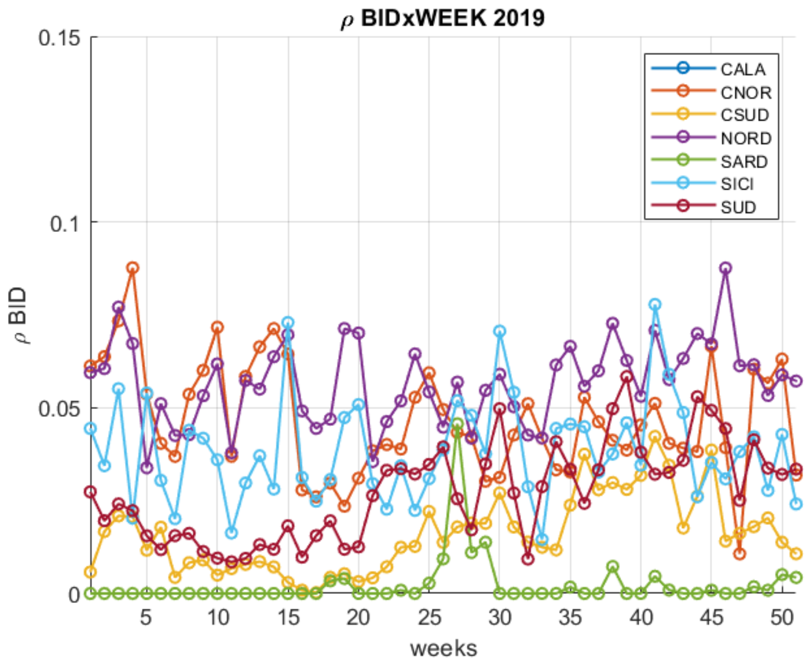
(a) (1) values of ρ for bids in 2019.



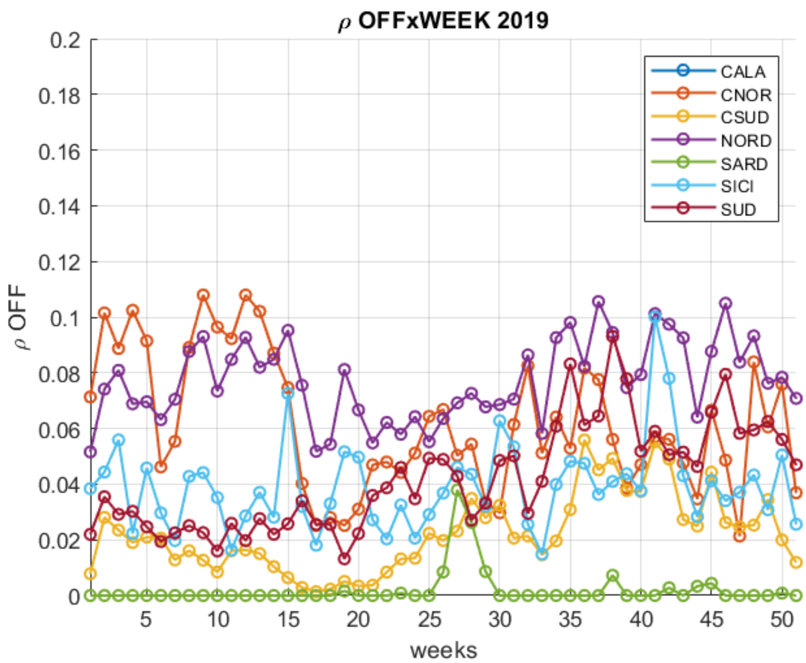
(b) (2) values of ρ for offers in 2019.

Figure 5.13: Values of ρ for offers/bids in 2019.

Trends of Weekly ρ in 2019 for each Market zone



(a) (1) values of weekly ρ for bids in 2019.

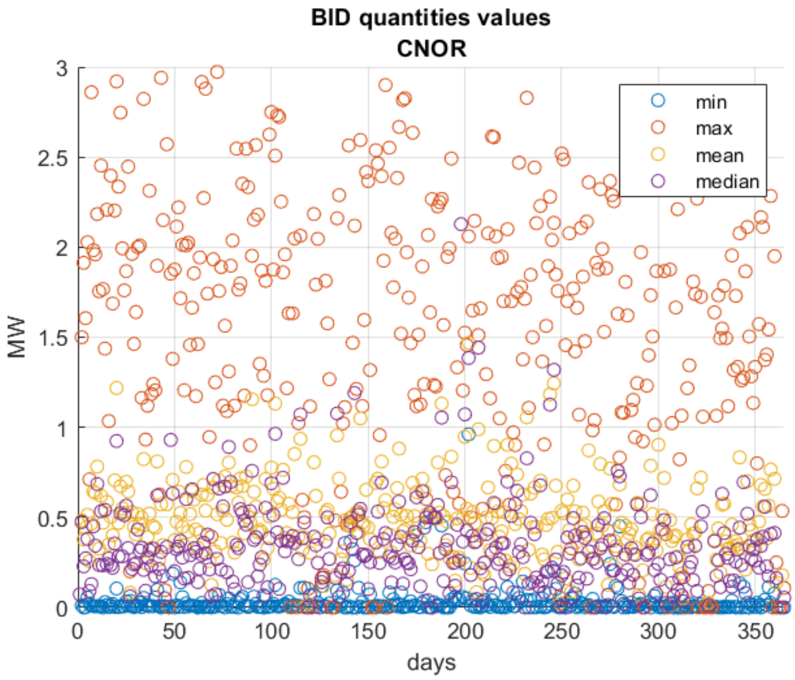


(b) (2) values of weekly ρ for offers in 2019.

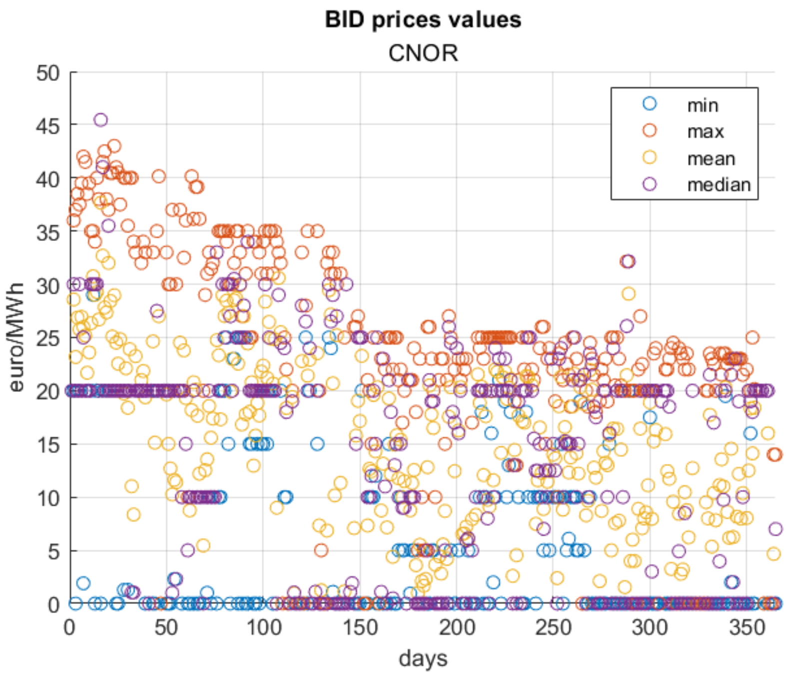
Figure 5.14: Values of weekly ρ for offers/bids in 2019.

Annual trends of min, max, mean and median values of quantities and prices on MB

- **CNOR**:

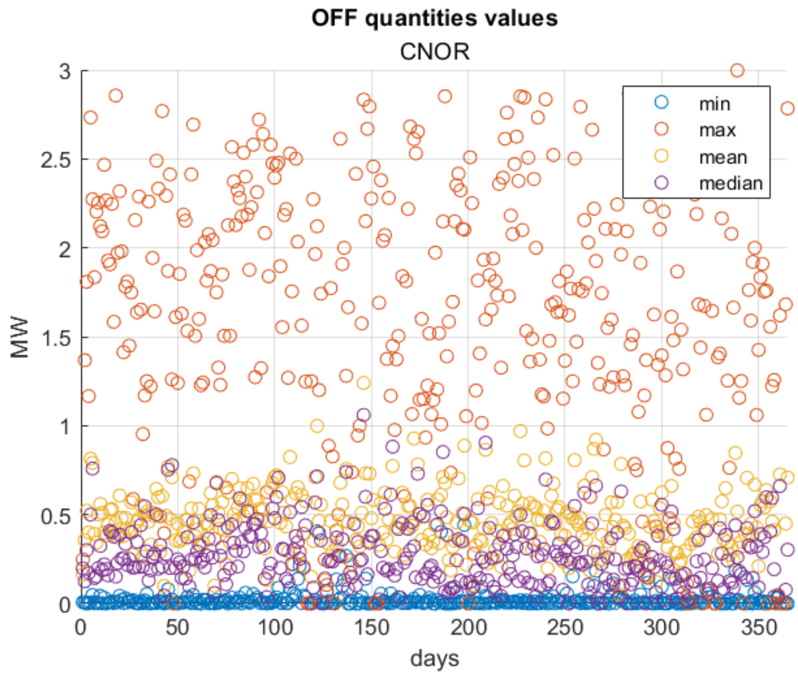


(a) (1) values of quantities for bids in CNOR.

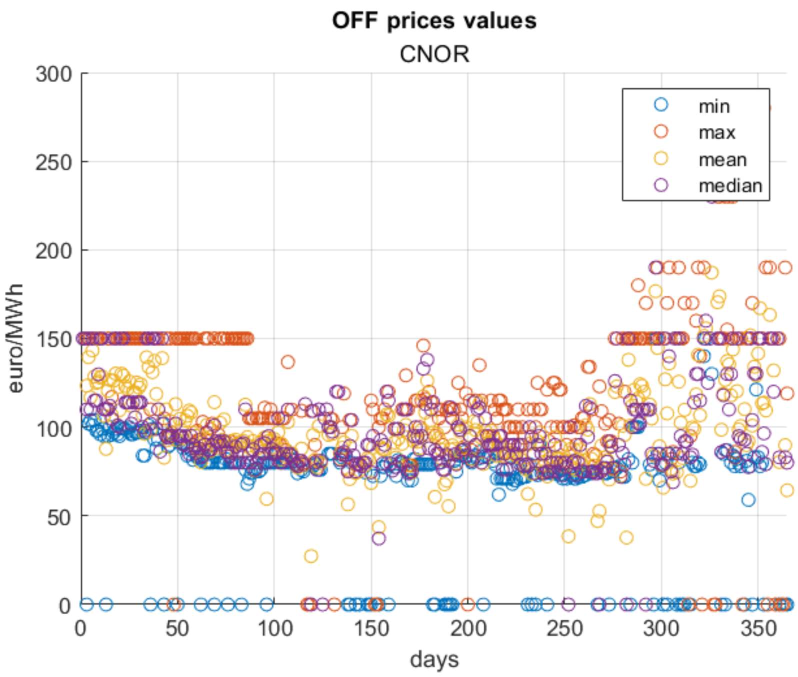


(b) (2) values of prices for bids in CNOR.

Figure 5.15: Values of quantities/prices for bids in CNOR.



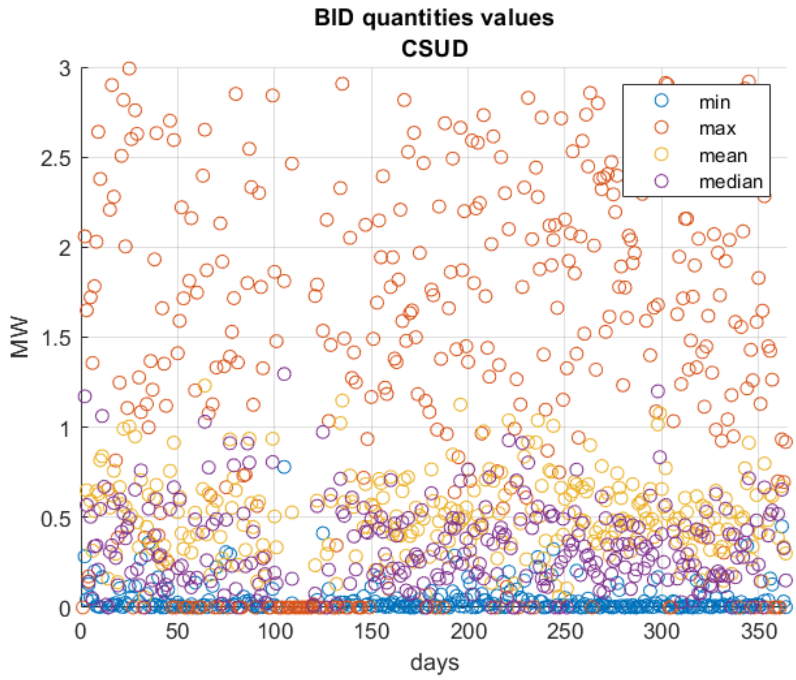
(a) (3) values of quantities for offers in CNOR.



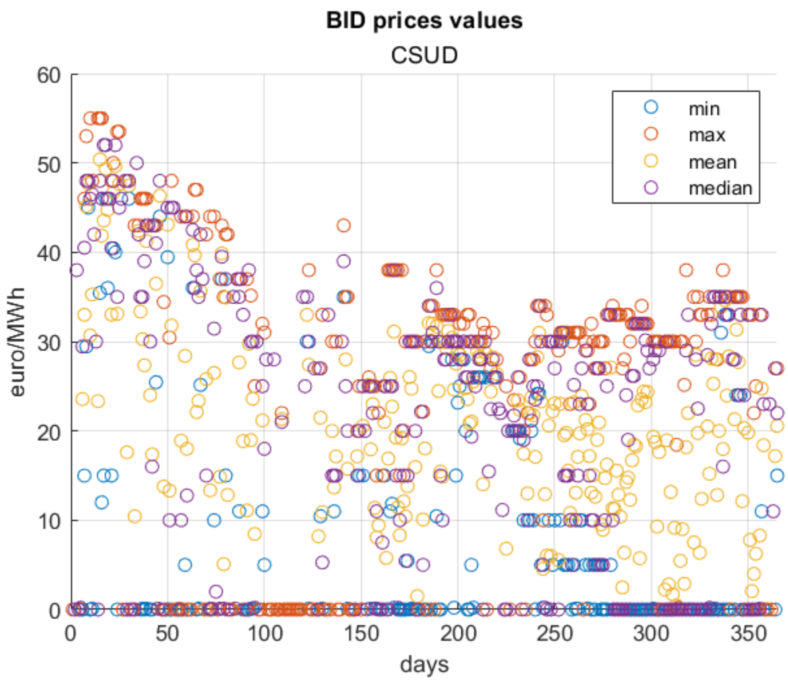
(b) (4) values of prices for offers in CNOR.

Figure 5.16: Values of quantities/prices for offers in CNOR.

- **CSUD**:

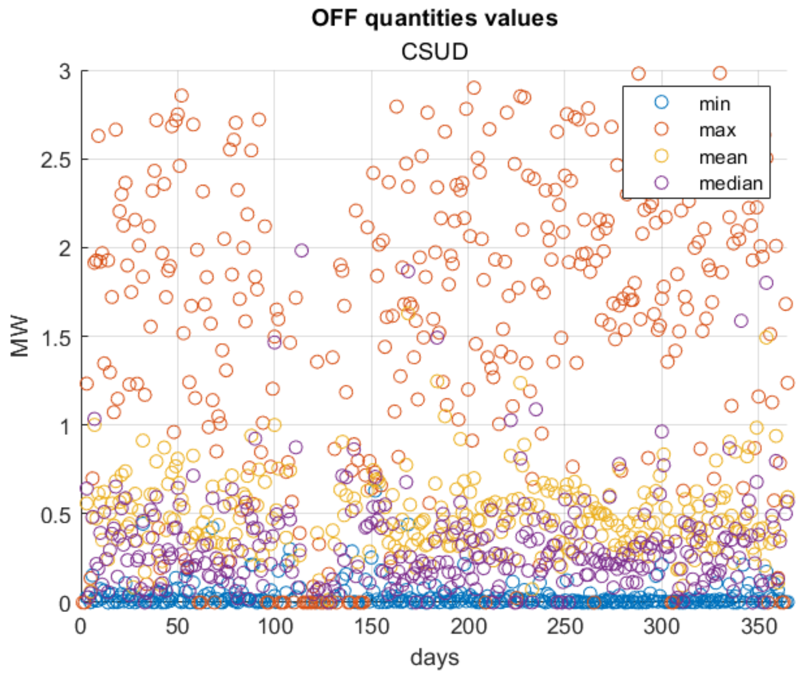


(a) (1) values of quantities for bids in 2019 CSUD.

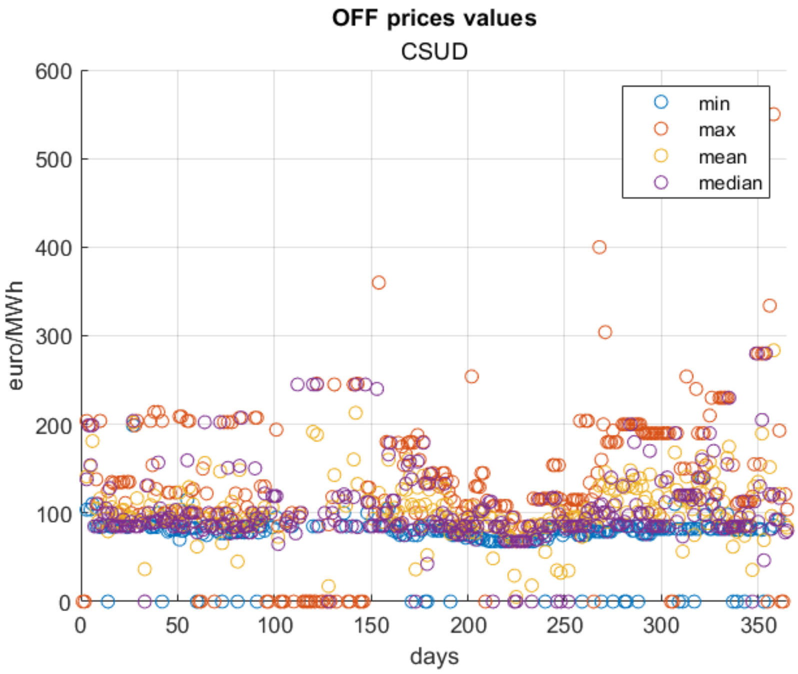


(b) (2) values of prices for bids in CSUD.

Figure 5.17: Values of quantities/prices for bids in CSUD.



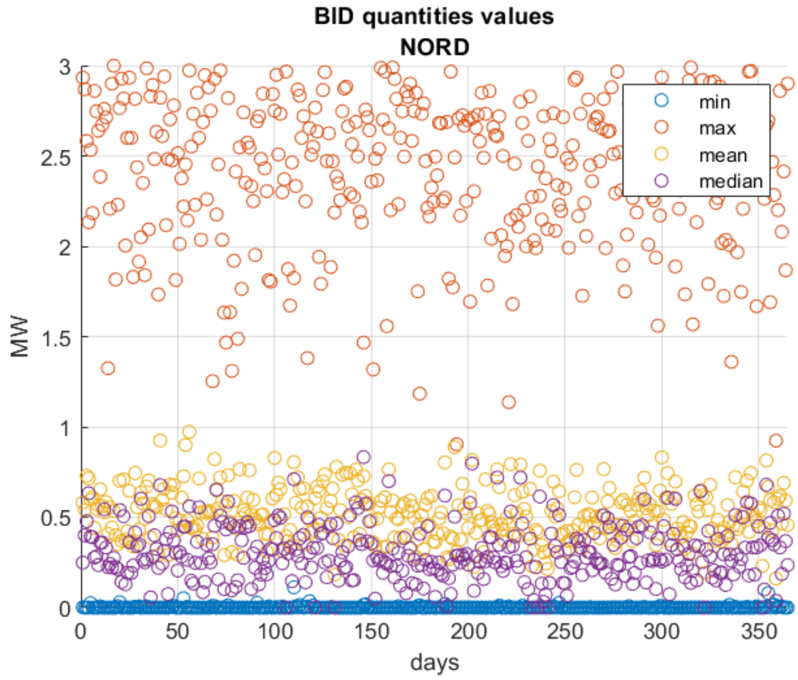
(a) (3) values of quantities for offers in CSUD.



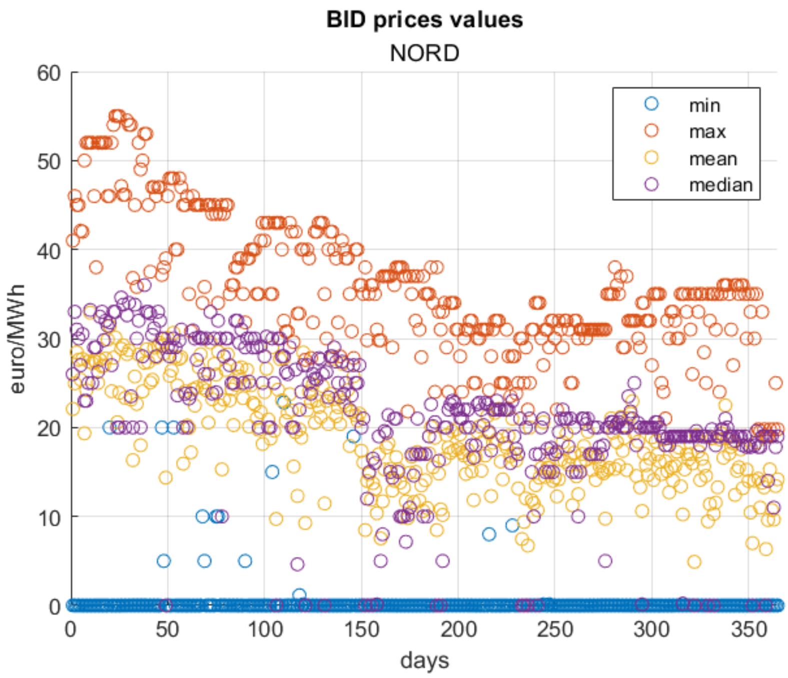
(b) (4) values of prices for offers in CSUD.

Figure 5.18: Values of quantities/prices for offers in CSUD.

- **NORD**:

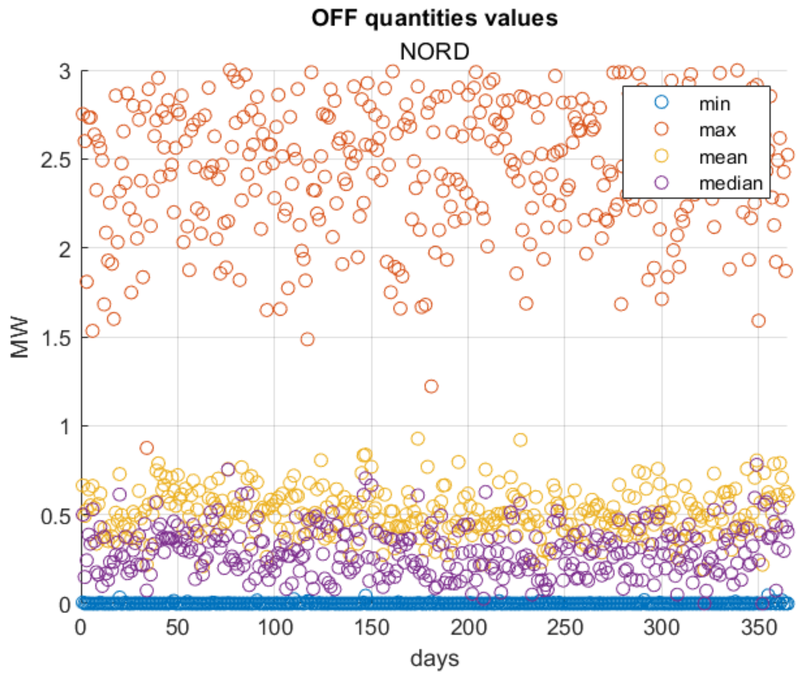


(a) (1) values of quantities for bids in NORD.

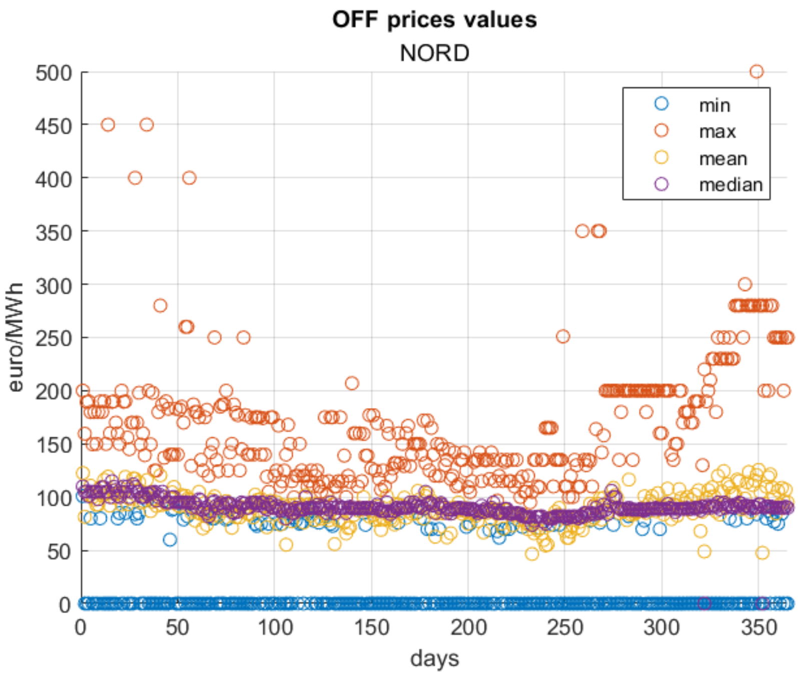


(b) (2) values of prices for bids in NORD.

Figure 5.19: Values of quantities/prices for bids in NORD.



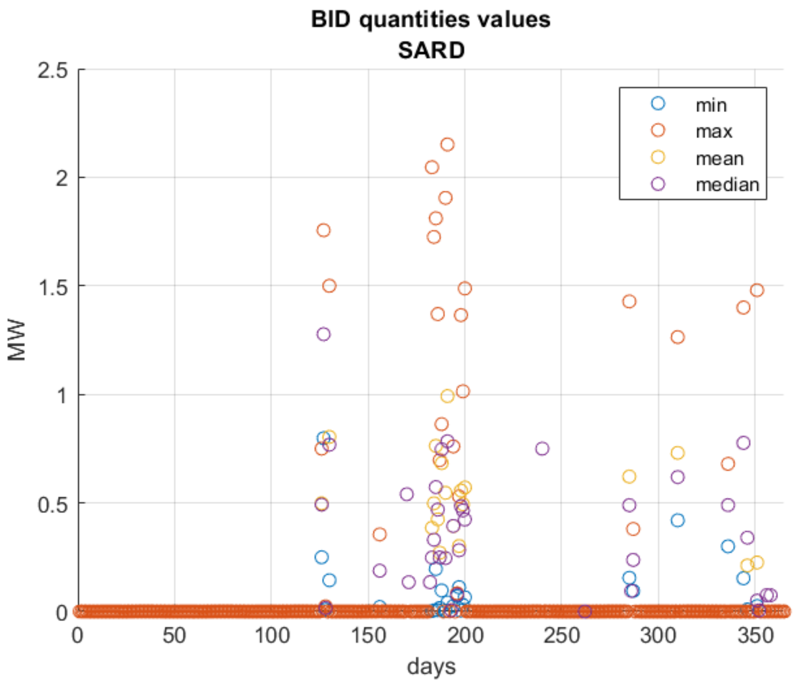
(a) (3) values of quantities for offers NORD.



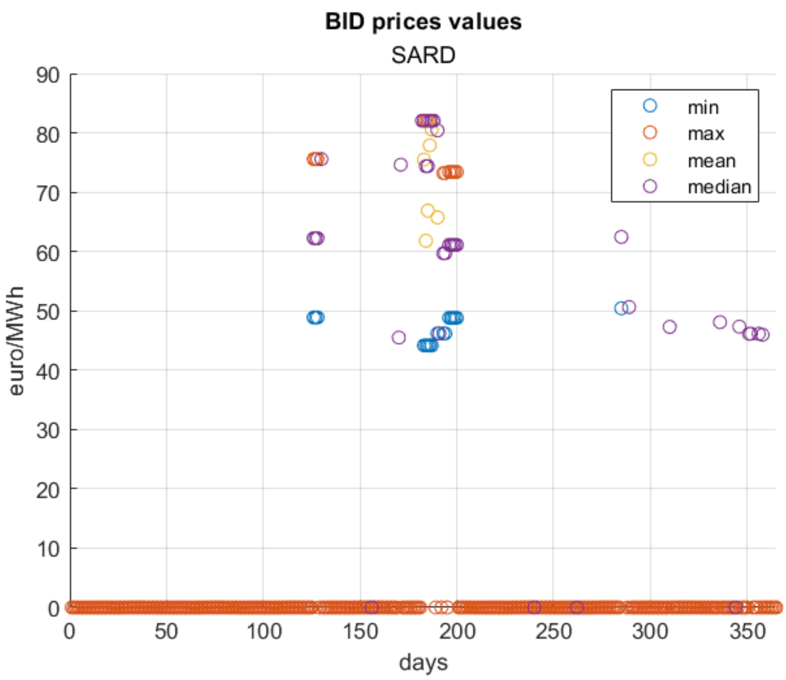
(b) (4) values of prices for offers in NORD.

Figure 5.20: Values of quantities/prices for offers in NORD.

- **SARD**:



(a) (1) values of quantities for bids in SARD.



(b) (2) values of prices for bids in SARD.

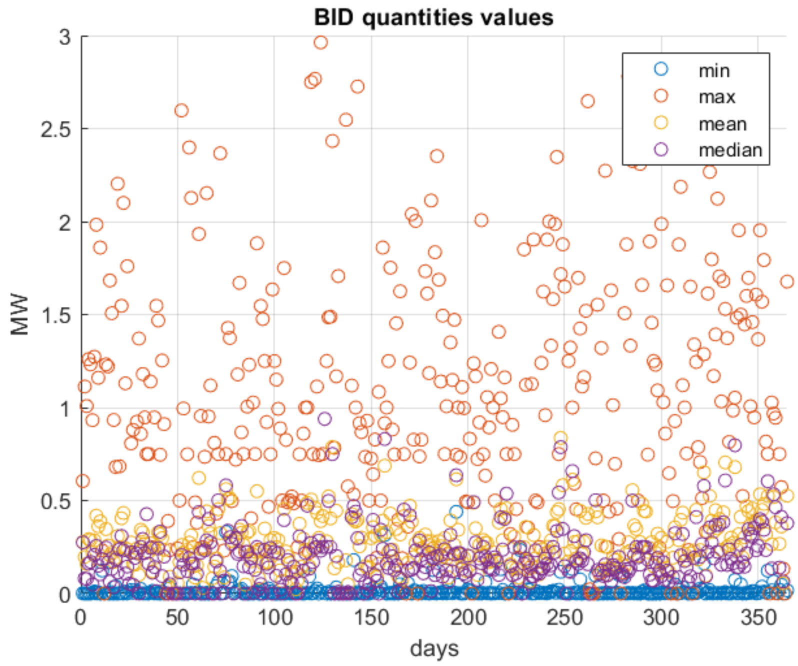
Figure 5.21: Values of quantities/prices for bids in SARD.

(a) (3) values of quantities for offers in SARD.

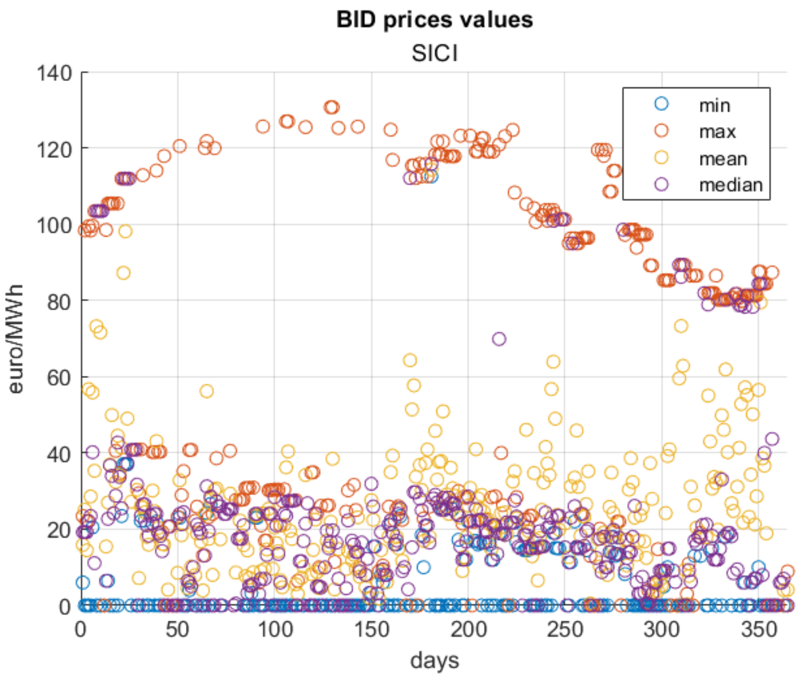
(b) (4) values of prices for offers in SARD.

Figure 5.22: Values of quantities/prices for offers in SARD.

- **SICI**:

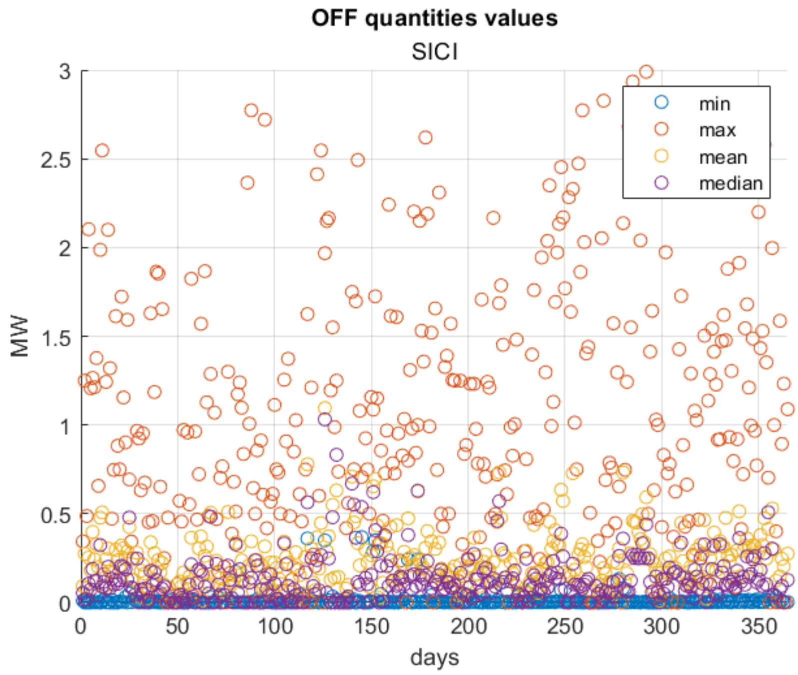


(a) (1) values of quantities for bids in SICI.

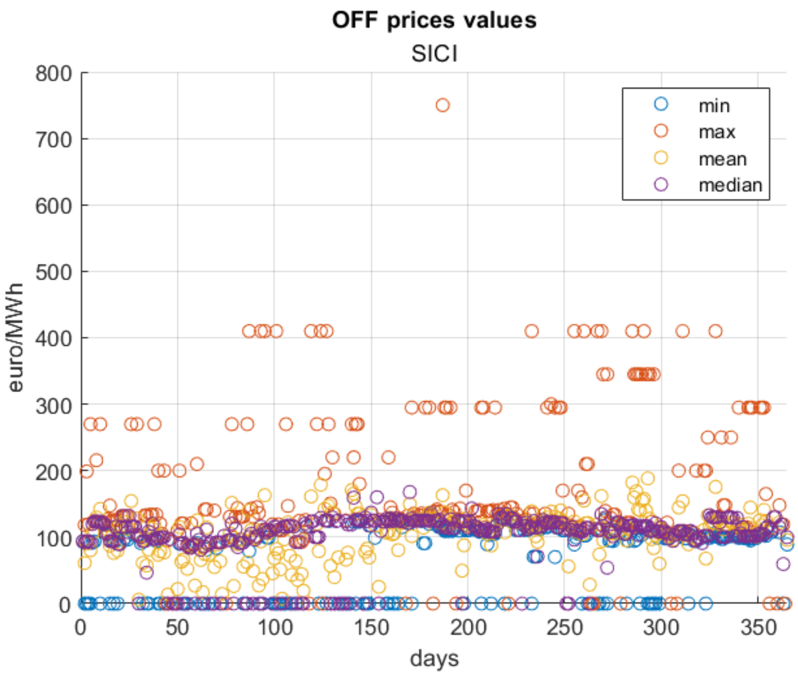


(b) (2) values of prices for bids in SICI.

Figure 5.23: Values of quantities/prices for bids in SICI.



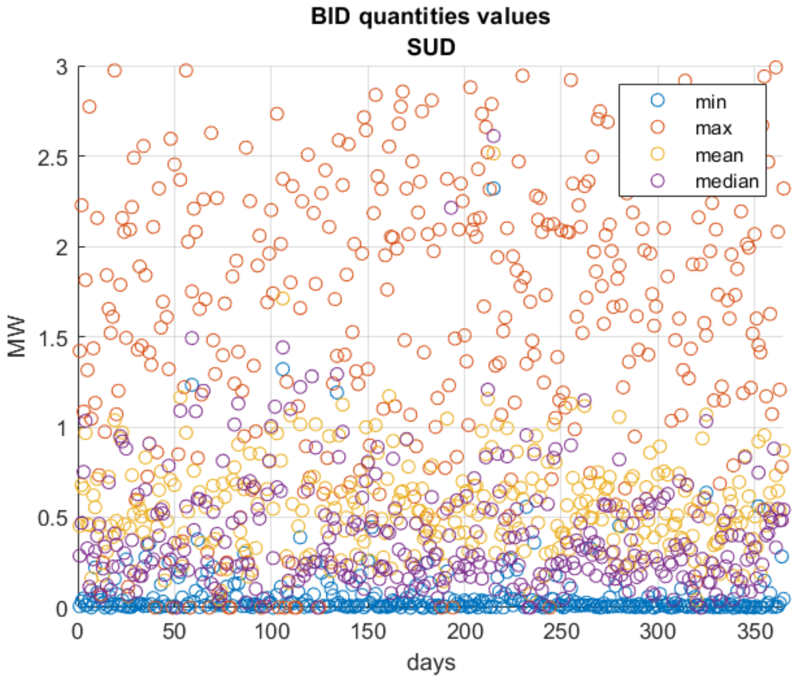
(a) (3) values of quantities for offers in SICI.



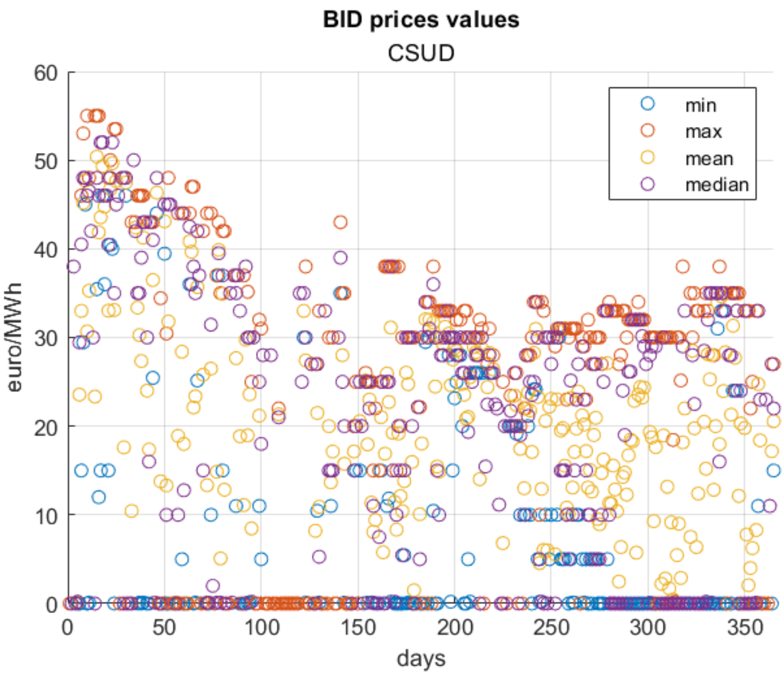
(b) (4) values of prices for offers in SICI.

Figure 5.24: Values of quantities/prices for offers in SICI.

- **SUD**:

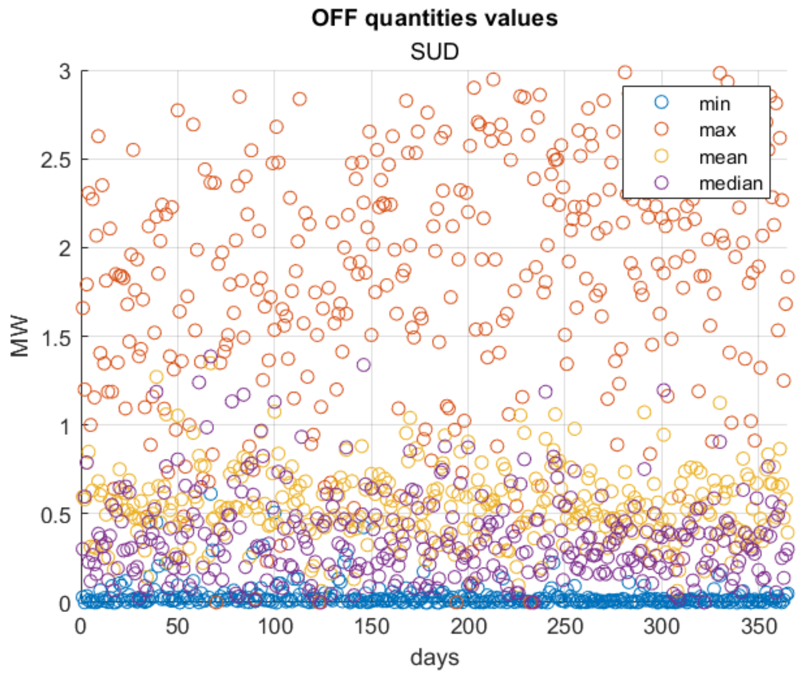


(a) (1) values of quantities for bids in SUD.

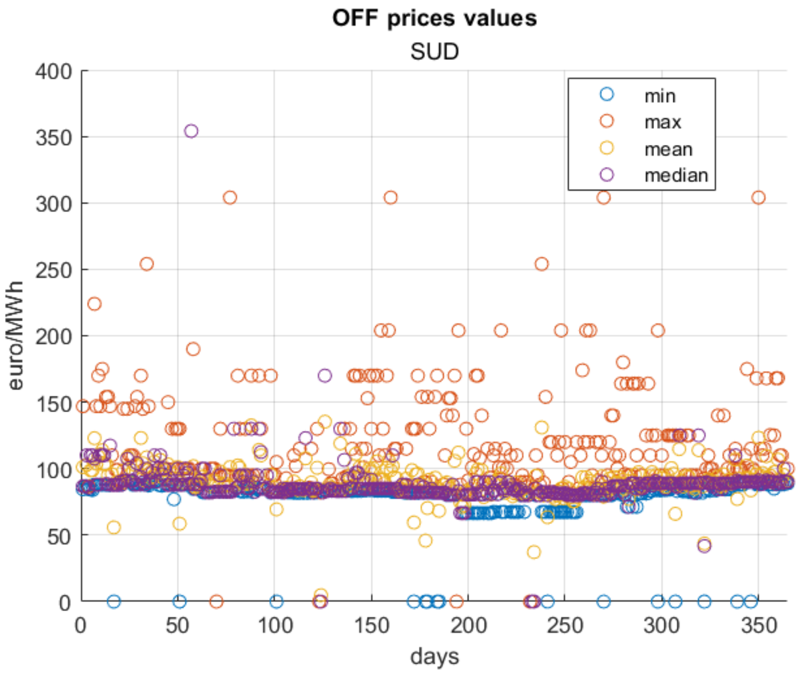


(b) (2) values of prices for bids in SUD.

Figure 5.25: Values of quantities/prices for bids in SUD.



(a) (3) values of quantities for offers in SUD.



(b) (4) values of prices for offers in SUD.

Figure 5.26: Values of quantities/prices for offers in SUD.

Weighted Average Prices of offers/bids per Market Zones

- CNOR

(a) (1) values of Weighted Average Prices for bids in CNOR.

(b) (2) values for Weighted Average Prices prices for offers in CNOR.

Figure 5.27: Weighted Average Prices for offers/bids in CNOR.

- CSUD

(a) (1) values of Weighted Average Prices for bids in CSUD.

(b) (2) values for Weighted Average Prices prices for offers in CSUD.

Figure 5.28: Weighted Average Prices for offers/bids in CSUD.

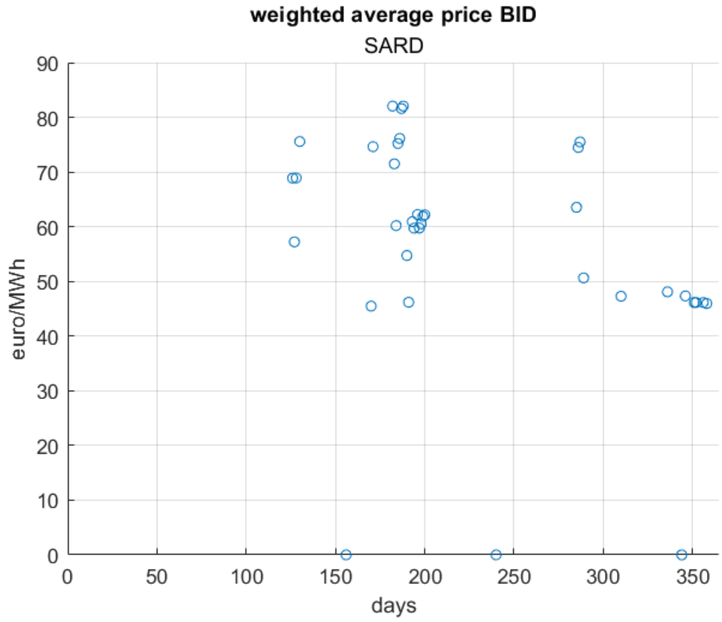
- NORD

(a) (1) values of Weighted Average Prices for bids in NORD.

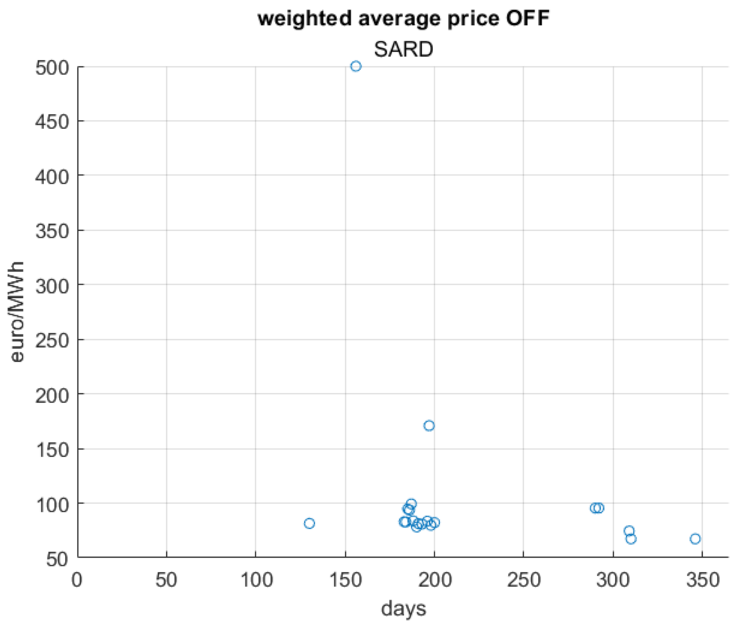
(b) (2) values for Weighted Average Prices prices for offers in NORD.

Figure 5.29: Weighted Average Prices for offers/bids in NORD.

- SARD



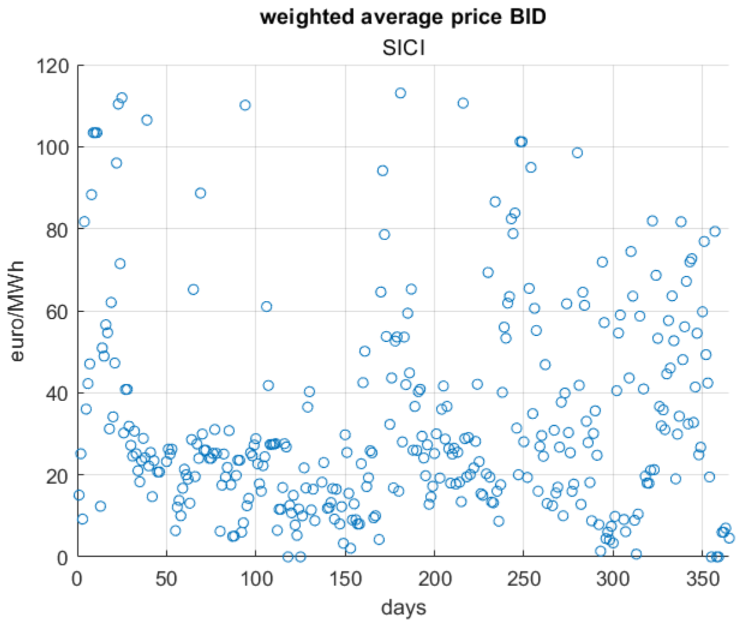
(a) (1) values of Weighted Average Prices for bids in SARD.



(b) (2) values for Weighted Average Prices prices for offers in SARD.

Figure 5.30: Weighted Average Prices for offers/bids in SARD.

- SICI



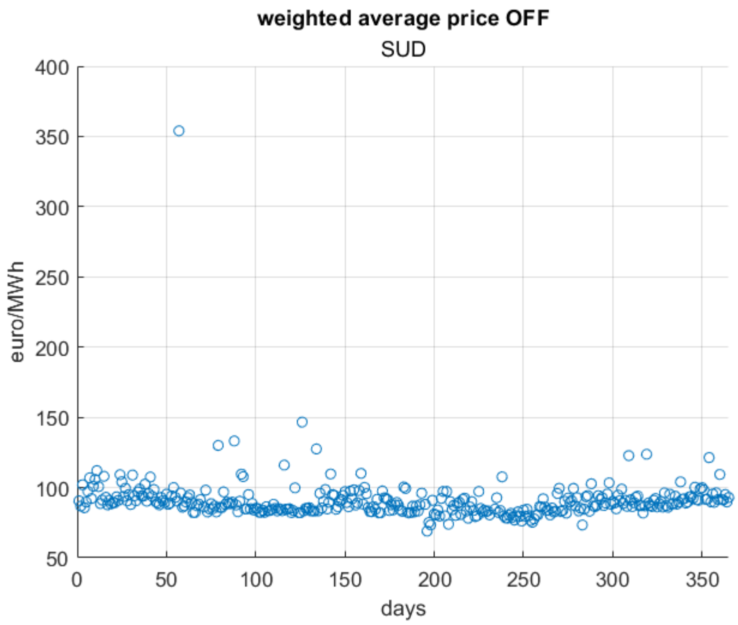
(a) (1) values of Weighted Average Prices for bids in SICI.

(b) (2) values for Weighted Average Prices prices for offers in SICI.

Figure 5.31: Weighted Average Prices for offers/bids in SICI.

- SUD

(a) (1) values of Weighted Average Prices for bids in SUD.



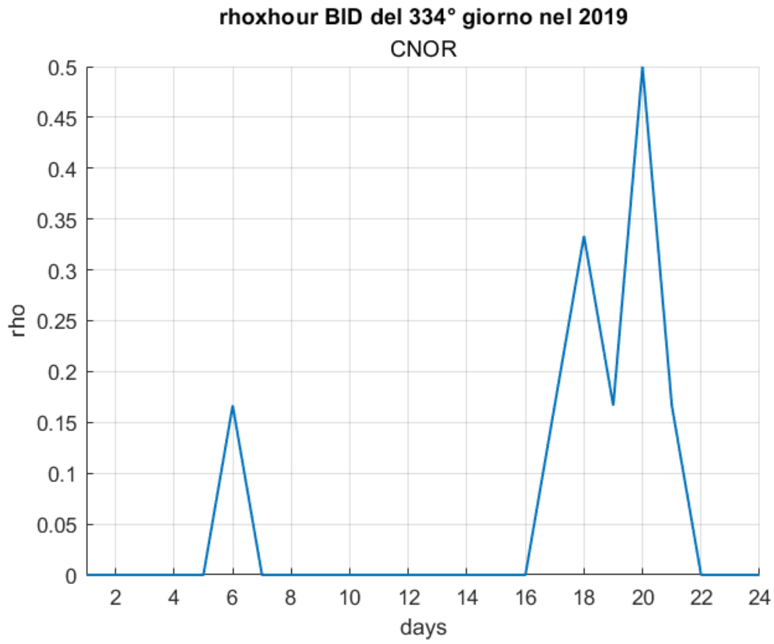
(b) (2) values for Weighted Average Prices prices for offers in SUD.

Figure 5.32: Weighted Average Prices for offers/bids in SUD.

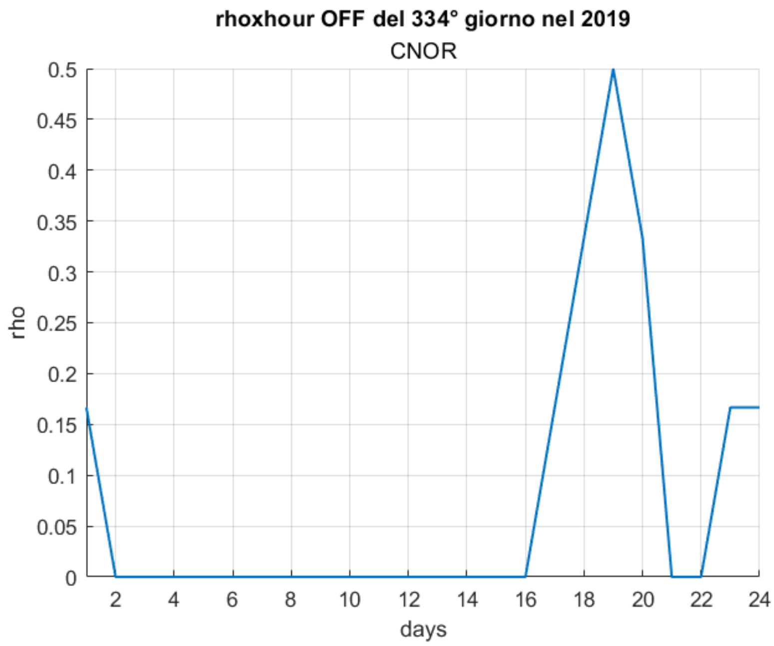
Values of hourly ρ for a random day in 2019

The hourly values of ρ for bids and offers are shown for a day in 2019 that is chosen randomly by the algorithm: 30 $^{\text{th}}$ November 2019.

- **CNOR**:



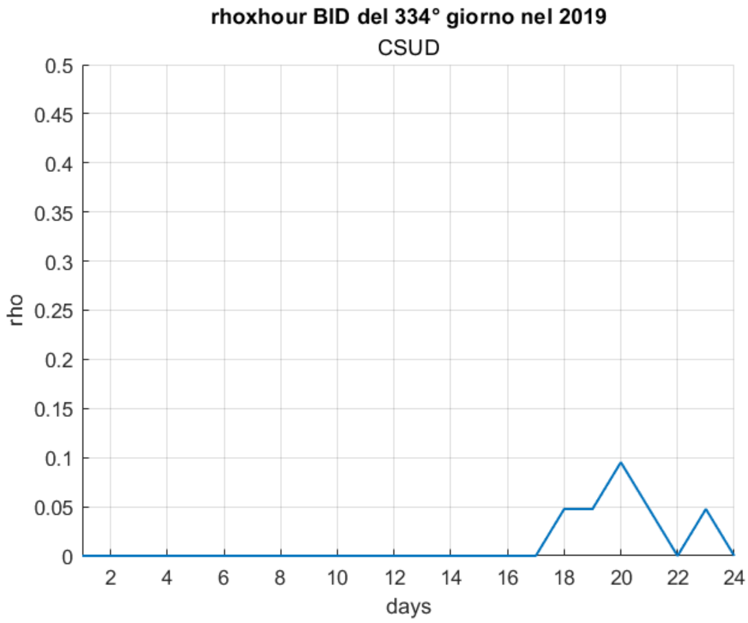
(a) (1)values of ρ for bids in random day in CNOR.



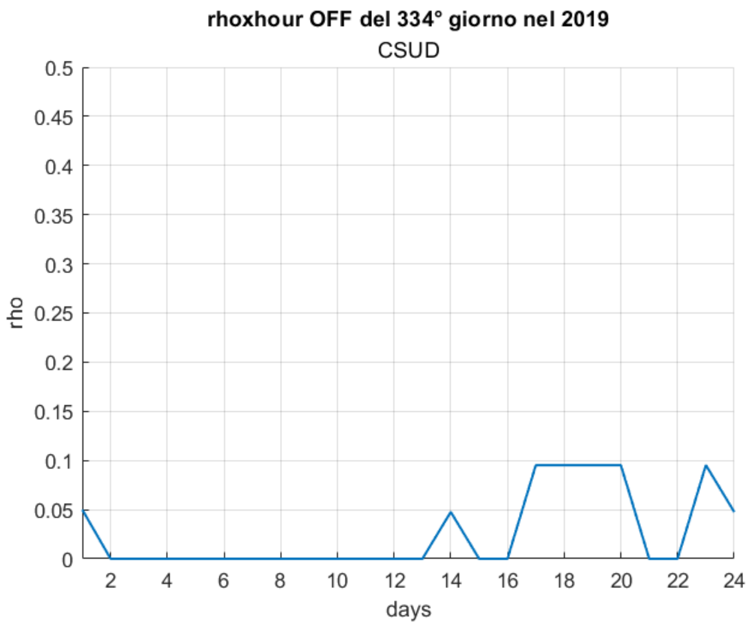
(b) (2) values of ρ for offers in random day in CNOR.

Figure 5.33: Trends of ρ by hour in a random day in CNOR.

- **CSUD**:



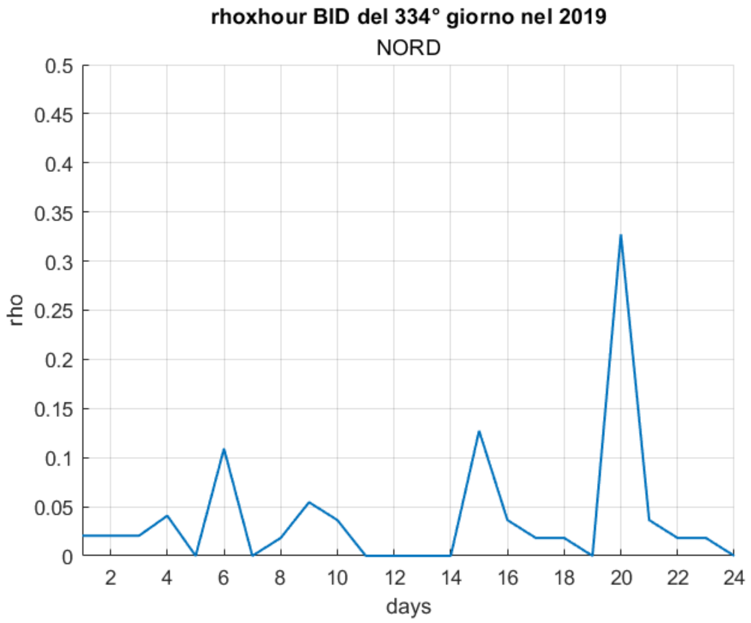
(a) (1) values of ρ for bids in random day in CSUD.



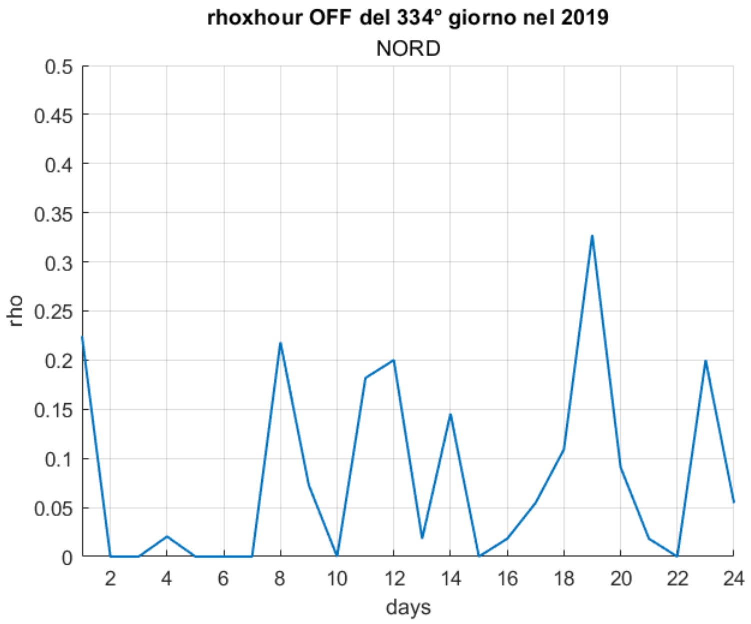
(b) (2)values of ρ for offers in random day in CSUD.

Figure 5.34: Trends of ρ by hour in a random day in CSUD.

- **NORD**:



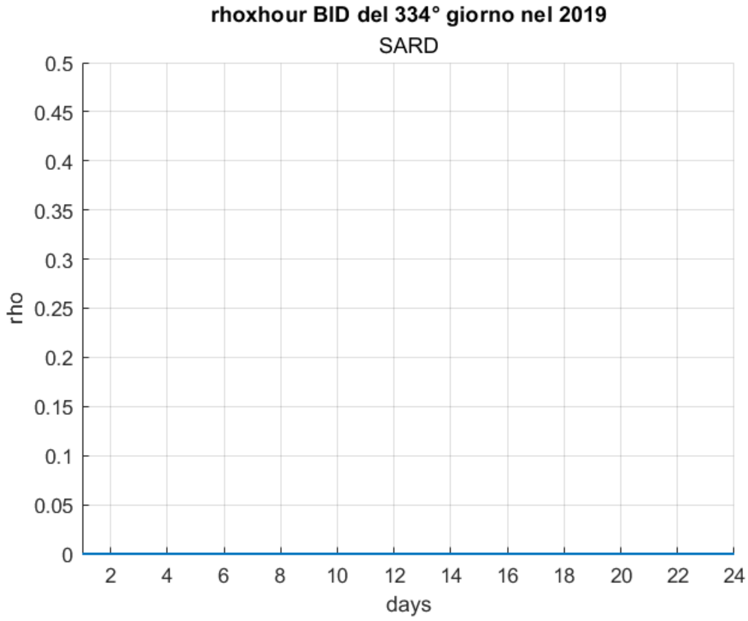
(a) (1) values of ρ for bids in random day in NORD.



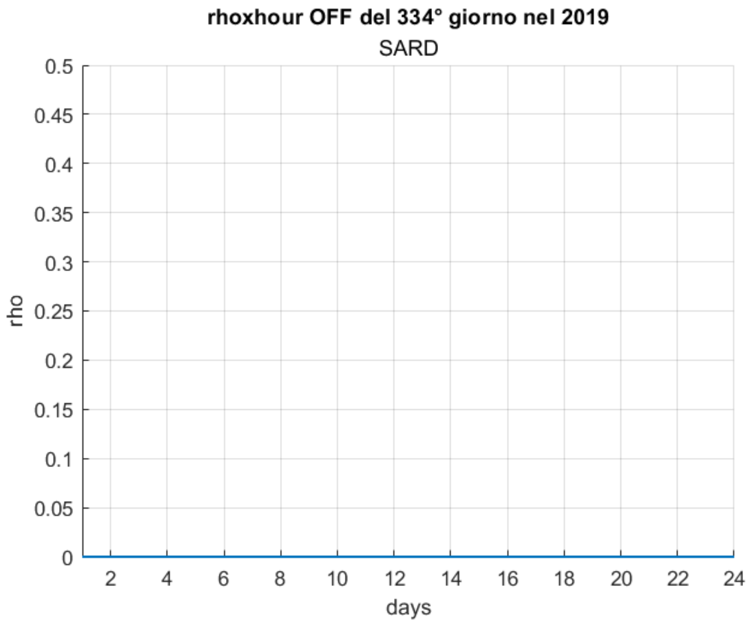
(b) (2) values of ρ for offers in random day in NORD.

Figure 5.35: Trends of ρ by hour in a random day in NORD.

- **SARD**:



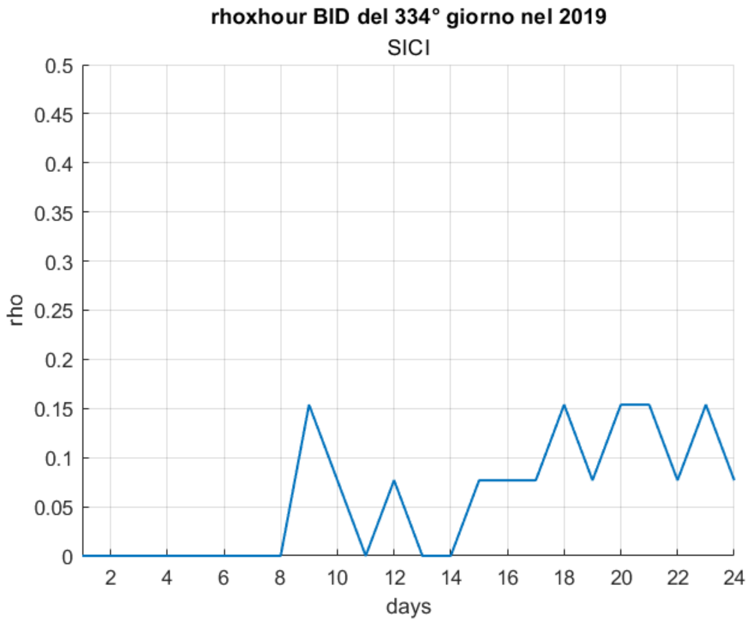
(a) (1) values of ρ for bids in random day in SARD.



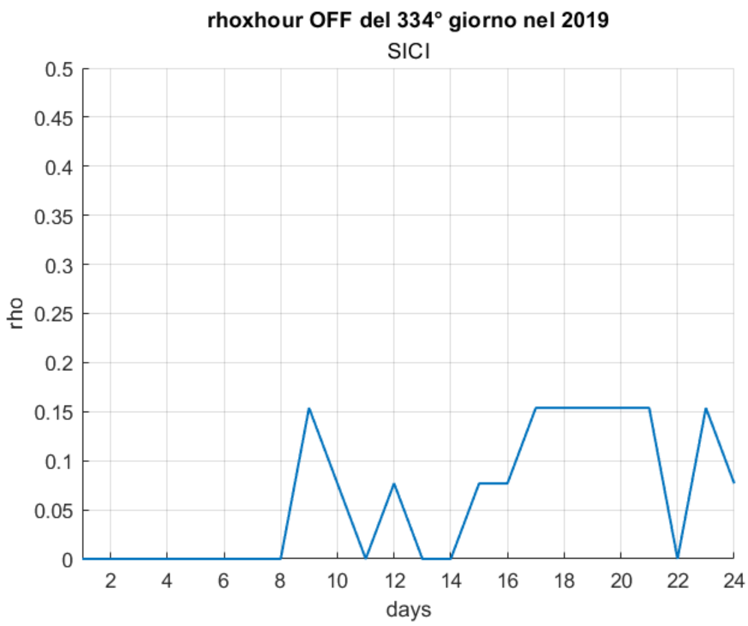
(b) (2) values of ρ for offers in random day in SARD.

Figure 5.36: Trends of ρ by hour in a random day in SARD.

- **SICI**:



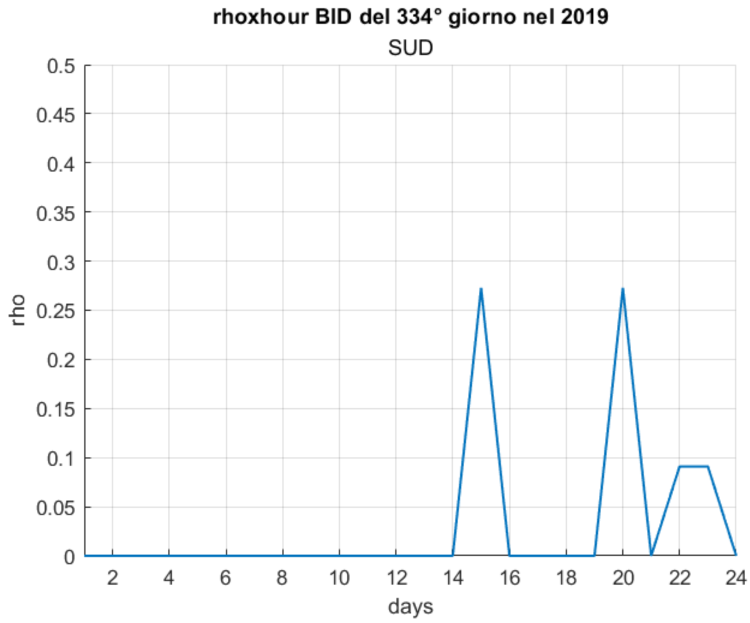
(a) (1) values of ρ for bids in random day in SICI.



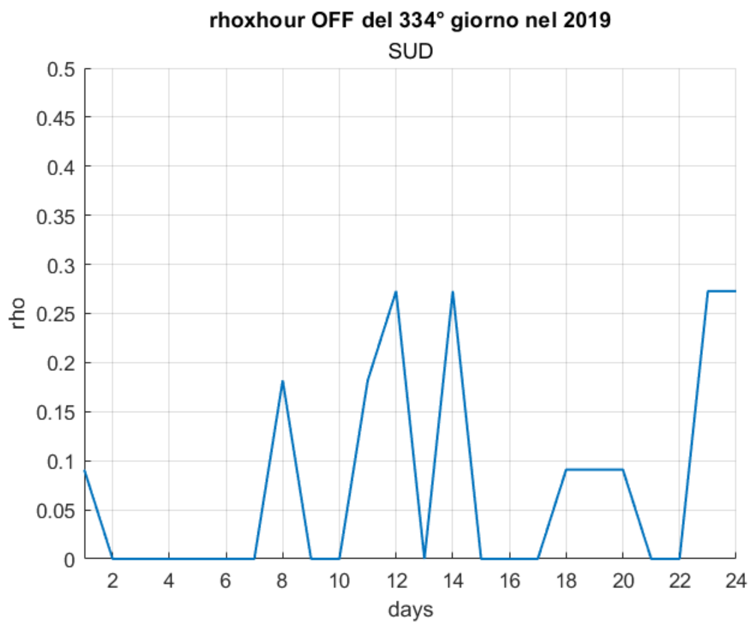
(b) (2) values of ρ for offers in random day in SICI.

Figure 5.37: Trends of ρ by hour in a random day in SICI.

- **SUD**:



(a) (1) values of ρ for bids in random day in SUD.

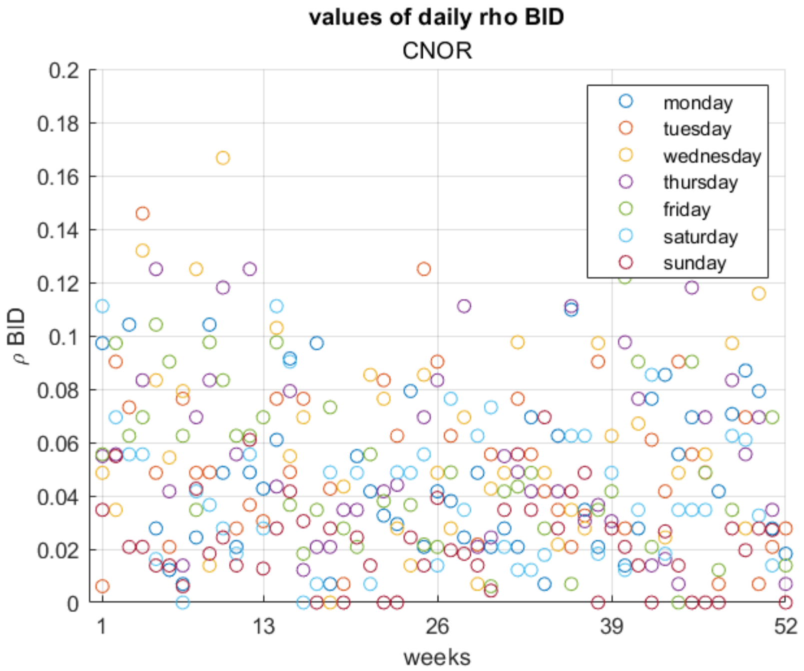


(b) (2) values of ρ for offers in random day in SUD.

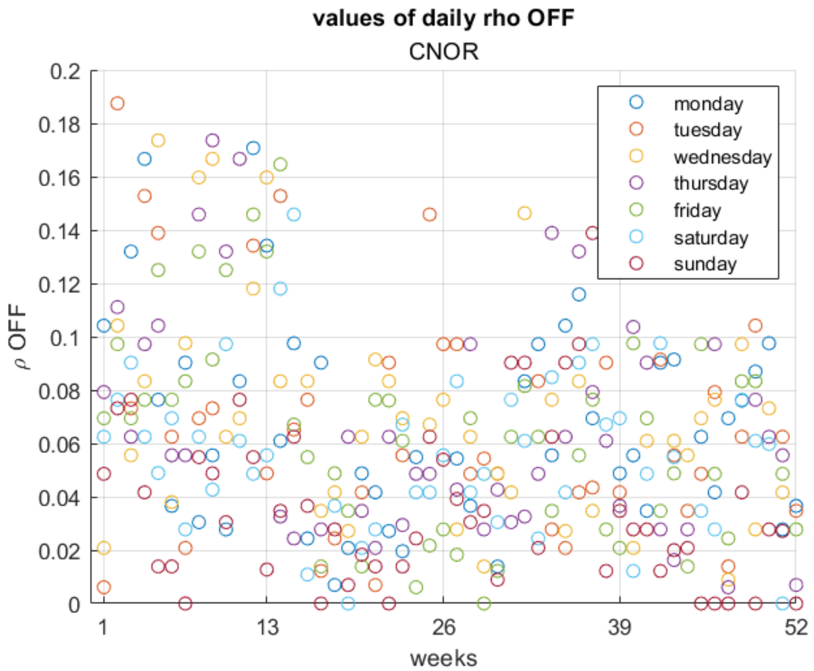
Figure 5.38: Trends of ρ by hour in a random day in SUD.

Values of daily ρ divided for the days of the week

- **CNOR**:



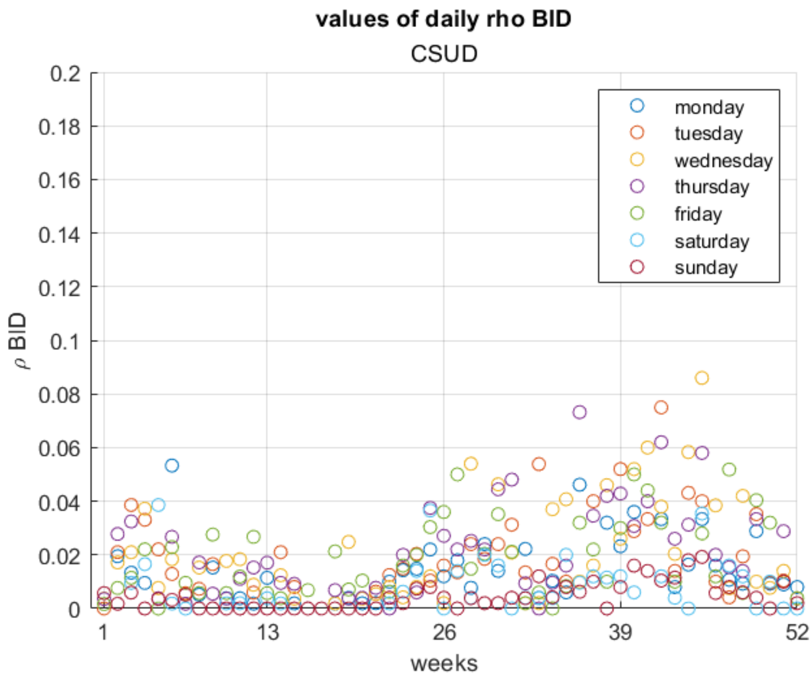
(a) (1)values of ρ for bids in CNOR.



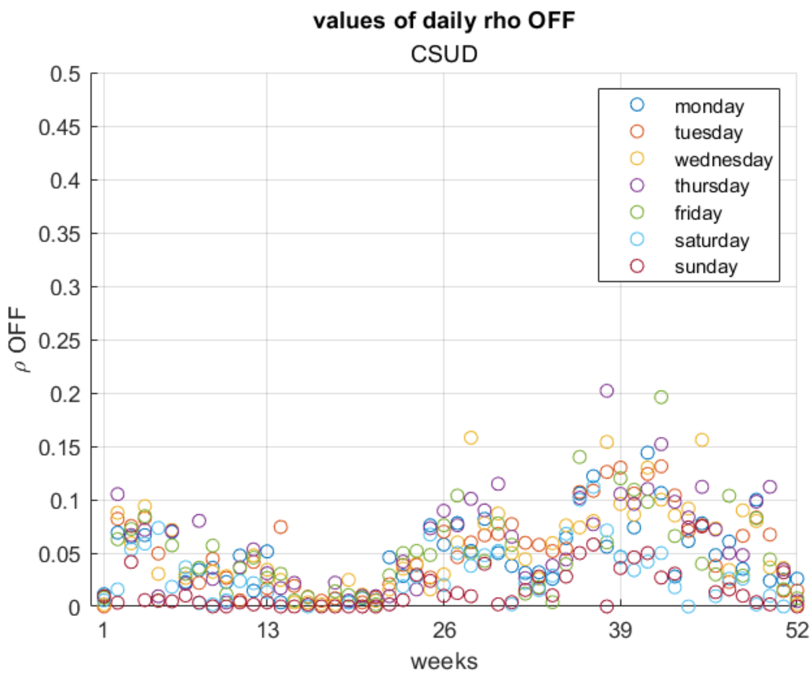
(b) (2) values of ρ for offers in CNOR.

Figure 5.39: Trends of daily ρ in CNOR.

- **CSUD**:



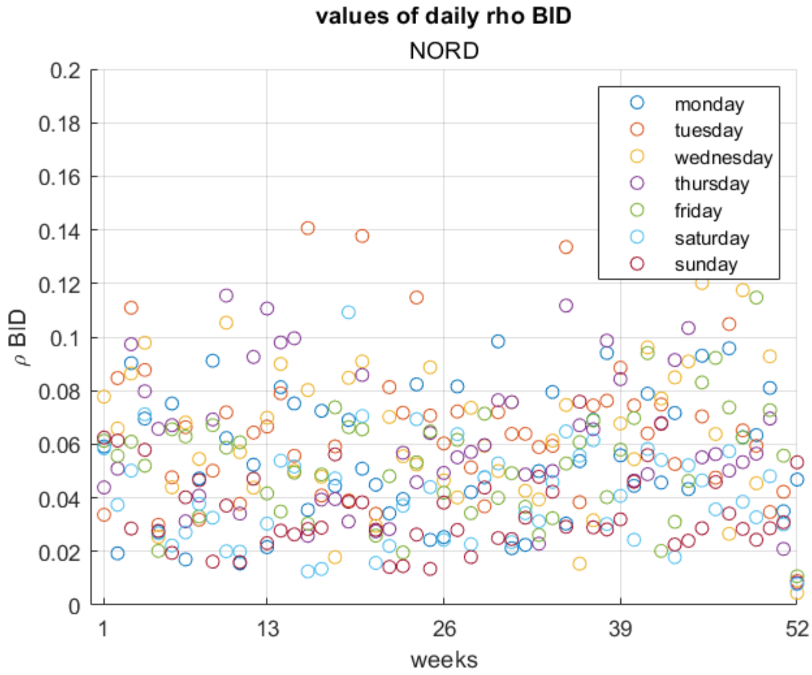
(a) (1) values of ρ for bids in CSUD.



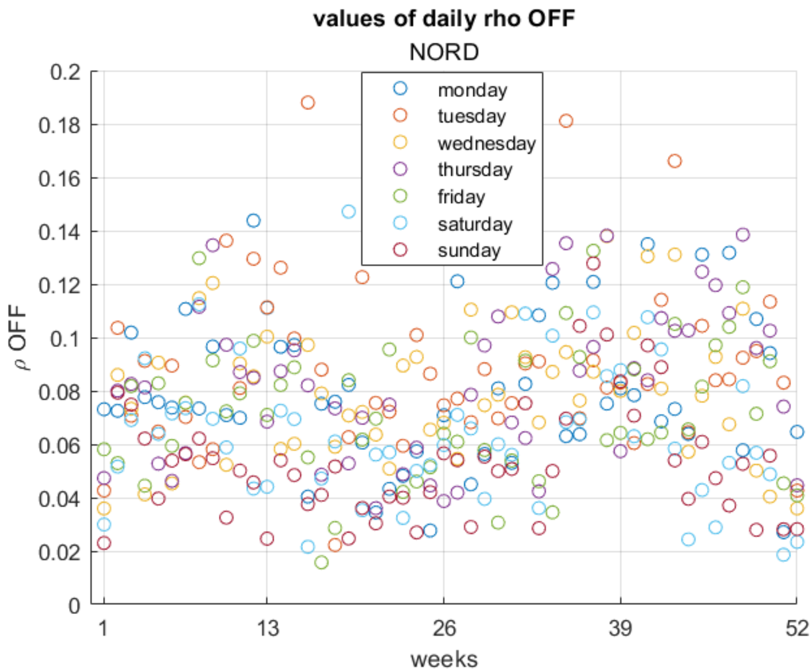
(b) (2)values of ρ for offers in CSUD.

Figure 5.40: Trends of daily ρ in CSUD.

- **NORD**:



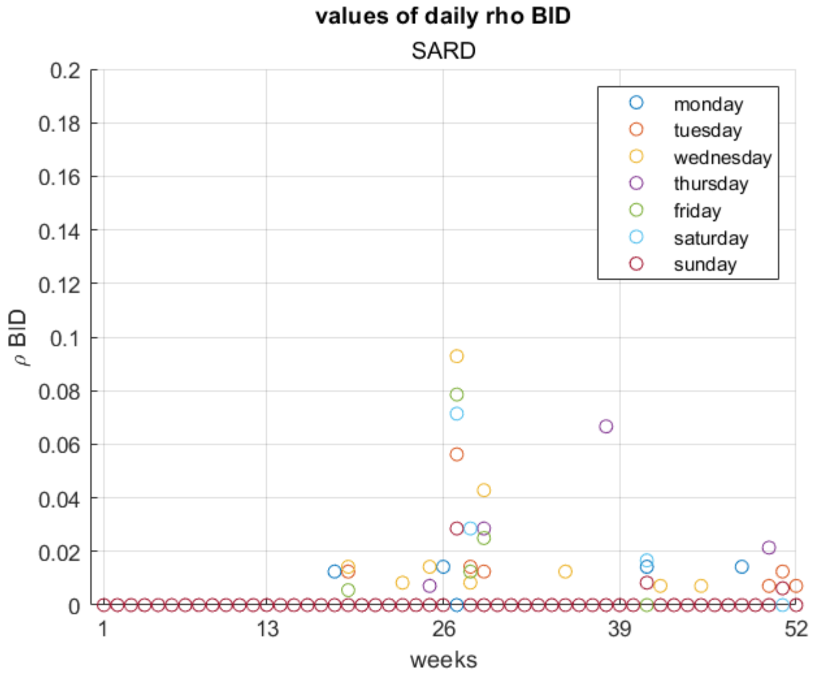
(a) (1) values of ρ for bids in NORD.



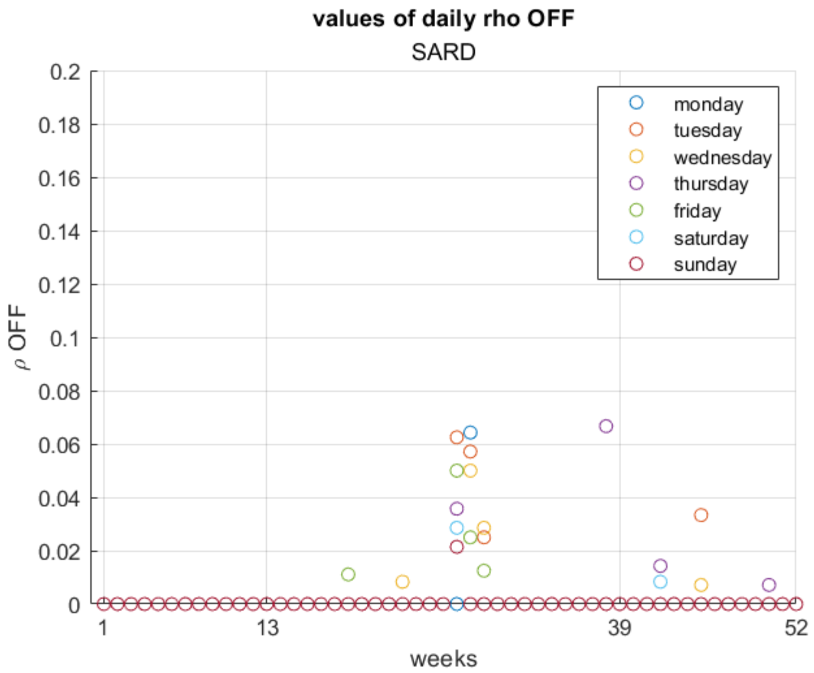
(b) (2) values of ρ for offers in NORD.

Figure 5.41: Trends of daily ρ in NORD.

- **SARD**:



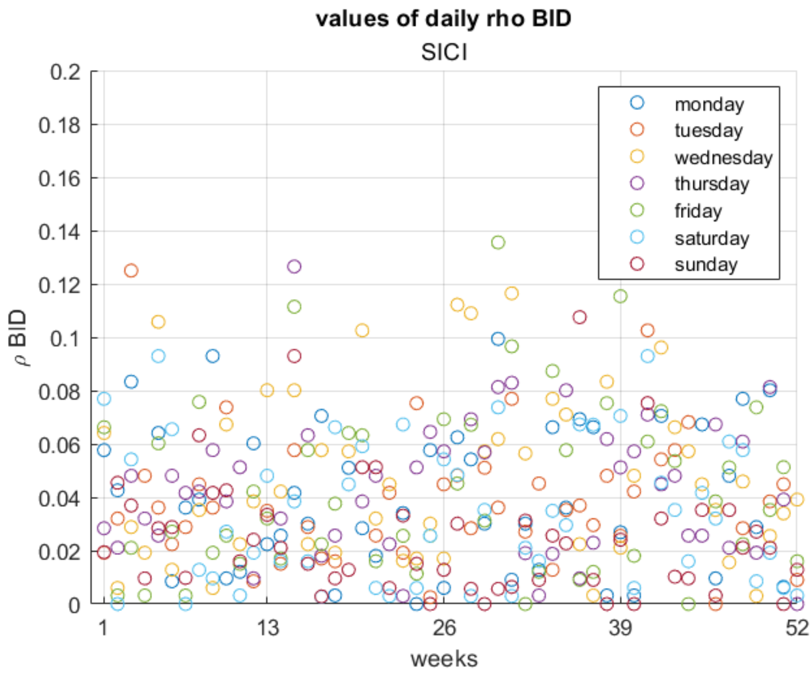
(a) (1) values of ρ for bids in SARD.



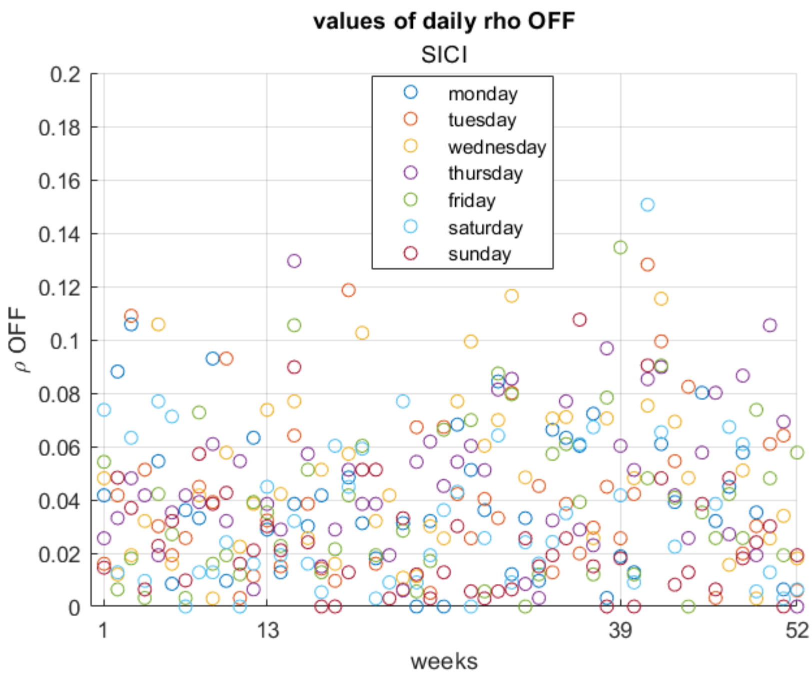
(b) (2) values of ρ for offers in SARD.

Figure 5.42: Trends of daily ρ in SARD.

- **SICI**:



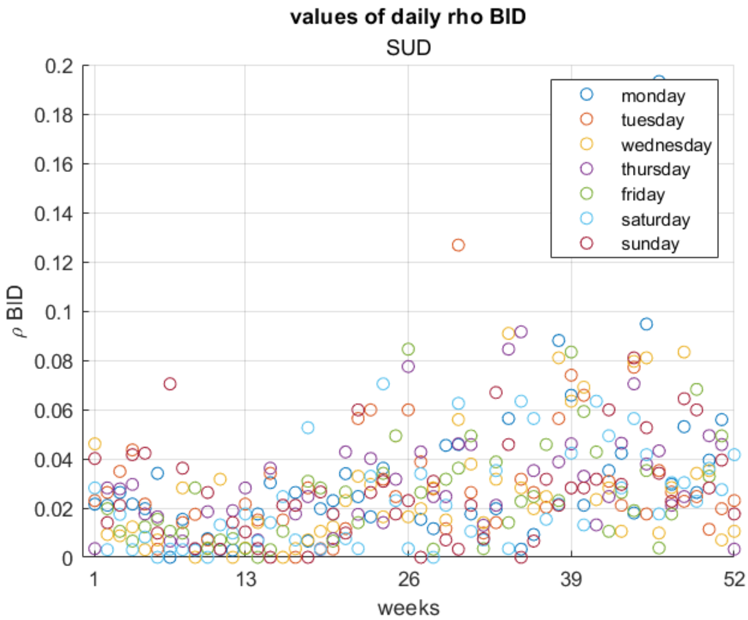
(a) (1) values of ρ for bids in SICI.



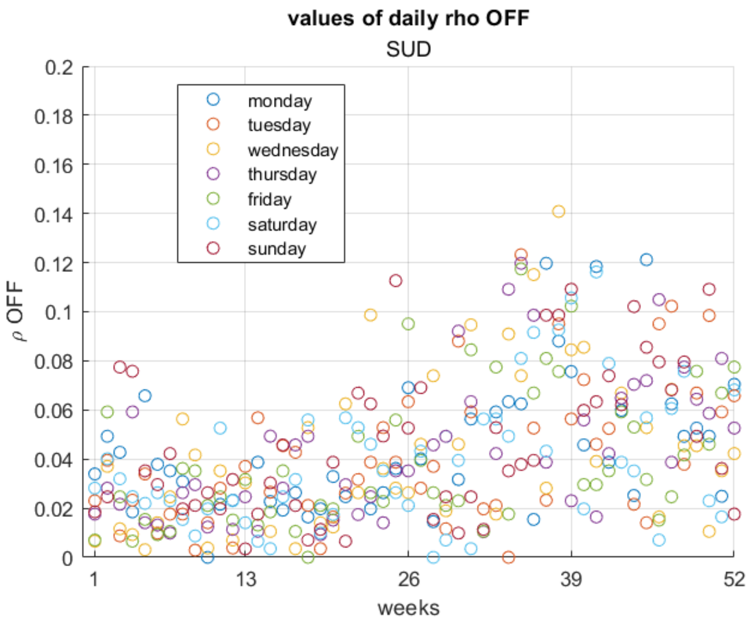
(b) (2) values of ρ for offers in SICI.

Figure 5.43: Trends of daily ρ in SICI.

- **SUD**:



(a) (1) values of daily ρ for bids in SUD.



(b) (2) values of daily ρ for offers in SUD.

Figure 5.44: Trends of daily ρ in SUD.

5.2.4 Other Services in Code 1

Even though the focus of this thesis is not on Other Services, it was done also a brief excursus on this topic because it is relevant in the computation of equations for **aFRR** remuneration as already said in 4.3.6.

With reference to paragraph 5.2.1, the code will provide the following outputs:

- values of daily and hourly $\rho_{approvalMSD}$;
- values of daily and hourly $\rho_{approvalMB}$;
- values of hourly marginal prices;
- values of minimum, maximum, median and mean of daily offers'/bids' prices and quantities.

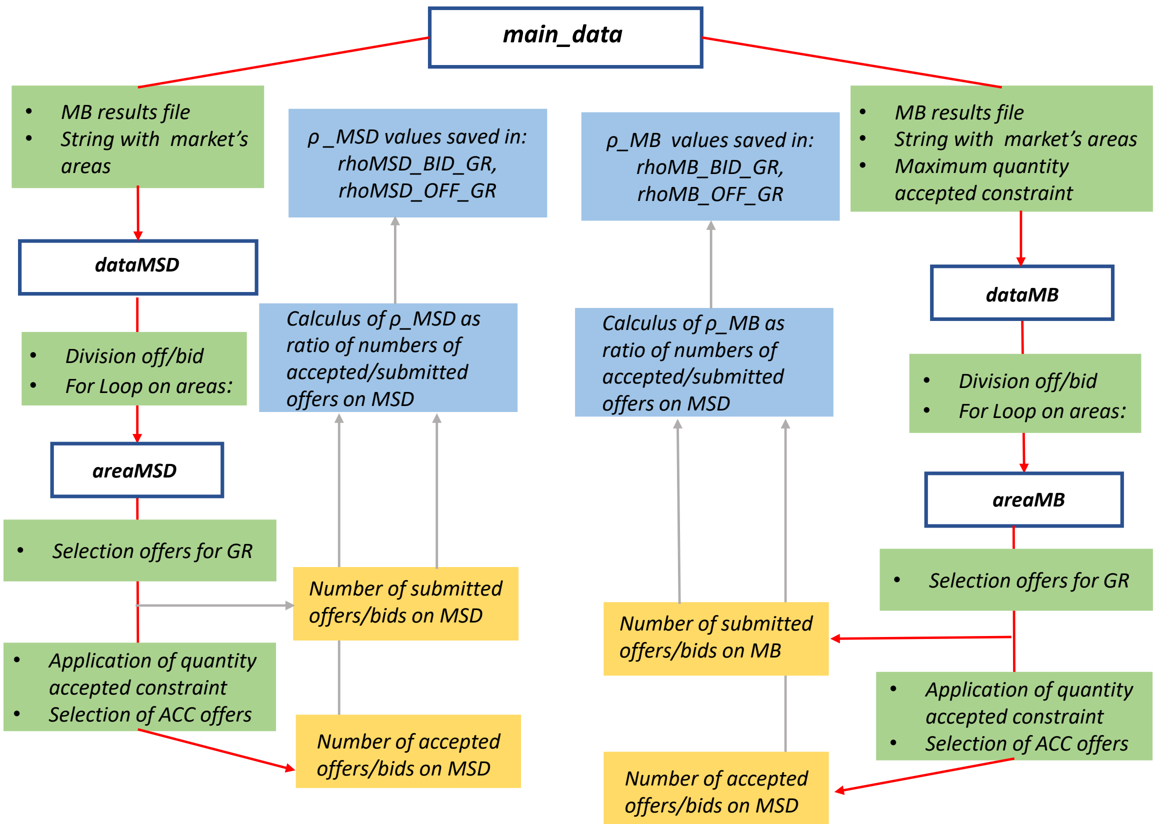


Figure 5.45: Phases of $\rho_{approvalMSD}$ and $\rho_{approvalMB}$ calculation.

Computation of $\rho_{approvalMSD}$ The function dataMSD receives in input the XML file with MSD results and the string with the names of the market's areas. Within the function, the two tables with, respectively, bids and offers, are given as input to the function areaMSD together with the name of market's zone that changes at every iteration of the 'for' loop and the maximum accepted quantity constraint.

In this function, after the selection of offers/bids for **GR** and then for the area considered, the heights of offers/bids tables is saved in two variables because they correspond to the total submitted offers/bids on Ex-Ante MSD. For what concern the hourly basis, it was pursued the same strategy with an additional division of offers/bids in depends of the hour.

Then the quantity constraint is applied to the offers/bids and only the accepted ones are selected. The height of two tables at this stage corresponds only to the daily accepted offers/bids, with the further hourly division are then defined the accepted offers/bids hour by hour.

These values are then given as output to dataMSD function in which the values are associated to the area of reference and the daily $\rho_{approvalMSD}$ are computed and saved in variables with the following name: *rhoMSD_BID_GR* and *rhoMSD_OFF_GR*. For what concerns the hourly basis, the number of submitted/accepted offers/bids per hour are saved in daily structure arrays named, respectively: *nMSDBIDxhour_tot* and *nMSDBIDxhour_tot* / *nMSDBIDxhour* and *nMSDBIDxhour*.

Then, the values in dataMSD are recalled in main_data and saved in the final structures. For what concern daily values of $\rho_{approvalMSD}$, the structure array is called *rhoMSD_BIDGR* and *rhoMSD_OFFGR*.
Instead, the hourly values of $\rho_{approvalMSD}$ are not calculated yet, so after having saved the outputs from dataMSD in the corresponding structures, (in detail: *nMSDBIDxh_tot* and *nMSDOFFxh_tot/ nMSDBIDxh* and *nMSDOFFxh*), the values of *rhoOFF_MSD_GR_xh* and *rhoBID_MSD_GR_xh* are finally defined.

Computation of $\rho_{approvalMB}$ The calculation strategy used for $\rho_{approvalMB}$ is the same described in 5.2.4 for $\rho_{approvalMSD}$, there is difference only in the functions used and the name of variables, in detail:

- in dataMB:
  - the values of daily $\rho_{approvalMB}$ are saved in *rhoMB_BID_GR* and *rhoMB_OFF_GR*;
  - the values of hourly number of submitted/accepted offers on MB are saved in, respectively, *nMBBIDxhour_tot* and *nMBOFFxhour_tot* / *nMBBIDxhour* and *nMBOFFxhour*;
- in main_data:
  - the values of daily $\rho_{approvalMB}$ are saved in the final structures named *rhoMB_BIDGR* and *rhoMB_OFFGR*;
  - the values of hourly number of submitted/accepted offers on MB are saved in, respectively, *nMBBIDxh_tot* and *nMBOFFxh_tot* / *nMBBIDxh* and *nMBOFFxh*.
    Then it is made the ratio for obtaining values of hourly $\rho_{approvalMB}$ and they are saved in *rhoMB_BIDGR* and *rhoMB_OFFGR*.

Calculation of hourly marginal prices The marginal price is the maximum/minimum price and in increase/decrease of accepted GR offers/bids. It was calculated on MB; so, in areaMB function after the selection of offers/bids for GR for the area given as input, it is applied the quantity constrained on accepted rows.

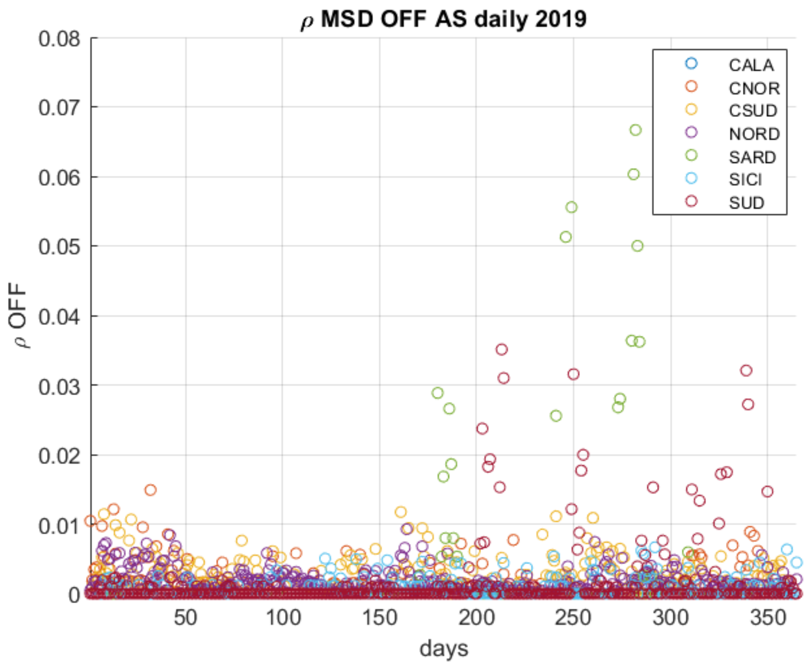
Then it is calculated the marginal price among the column of AWARDED_PRICES with the additional hourly division of offers/bids. The values are then given as output in dataMB and saved in daily structure arrays named: *pricem_OFF* and *pricem_BID*. Finally, these values are definitely saved in the following structure arrays, *pricemargin_OFF* and *pricemargin_BID*, in main_data.

Computation of values of minimum, maximum, median and mean of daily offers'/bids' prices and quantities The calculation of these values for quantities and prices is done on offers/bids on MB using the same function already mentioned for **RS**, that is called val.

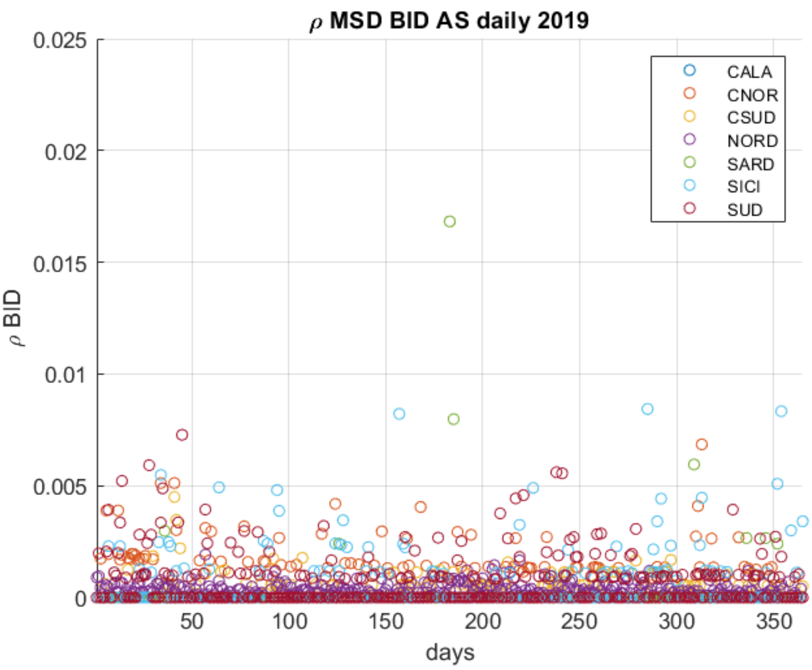
The principles of operation are the same described in 5.2.2 but the names of variables changes from Secondary Frequency Reserve simulation. In fact, in dataMB values are saved in daily structure arrays that are called, respectively, *valuesBIDd* and *valuesOFFd*. The name of the variables in which these values are saved in main_data are: *valBIDday* and *valOFFday*.

5.2.5 Results of GR simulations

Trends of daily ρ in Ex-Ante MSD and MB for each Market zone

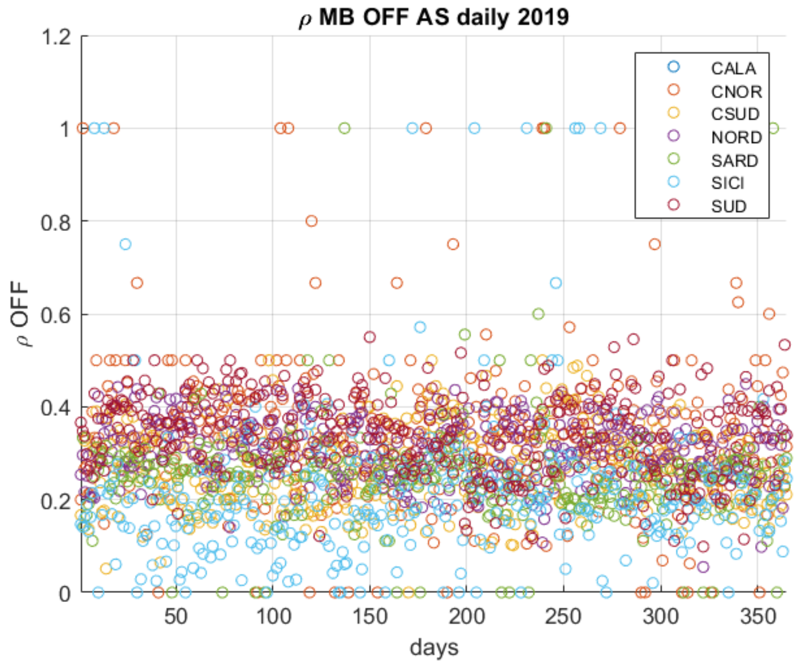


(a) (1) Values of daily ρ for offers in Ex-Ante MSD.

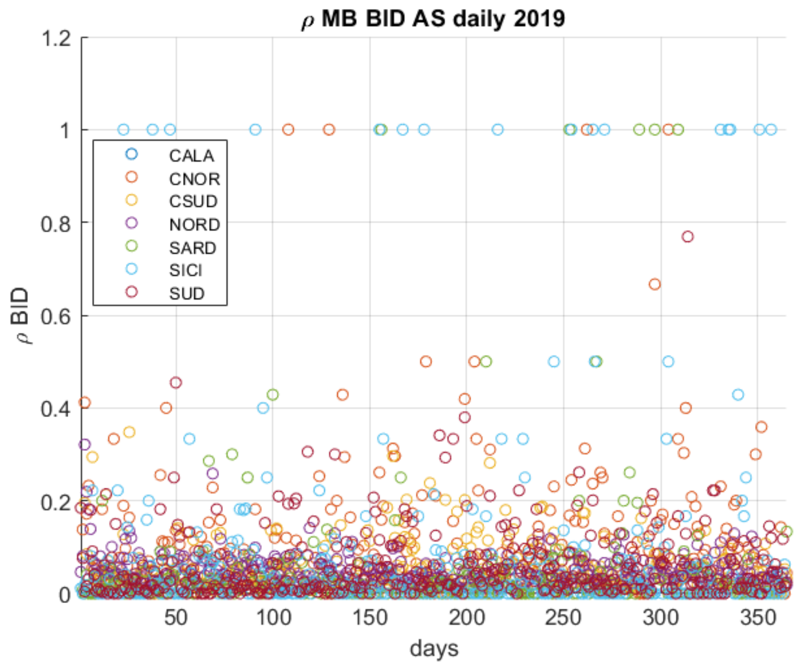


(b) (2) Values of daily ρ for bids in Ex-Ante MSD.

Figure 5.46: Values of daily ρ for bids/offers in Ex-Ante MSD.



(a) (1) Values of daily ρ for offers in MB.



(b) (2) Values of daily ρ for bids in MB.

Figure 5.47: Values of daily ρ for bids/offers in MB.

5.2.6 Code 2: Participation of the aggregator to the Secondary Frequency Reserve

In Matlab Code 2 it is simulated the participation of the case study's aggregator to MSD market for submitting offers to Secondary Frequency Reserve. This code is part of a more general Matlab script CalcoloEnergia in which it is simulated the participation of aggregator to ancillary services using a statistical method called Monte Carlo.
This method is useful for making estimations on simulations. The case study analysis day per day is done within a loop with one thousand interactions and for each one are randomly defined:

- the number of available vehicles in all the days of month;
- the values of vehicle's SOC in the morning;

Structure of Code 2

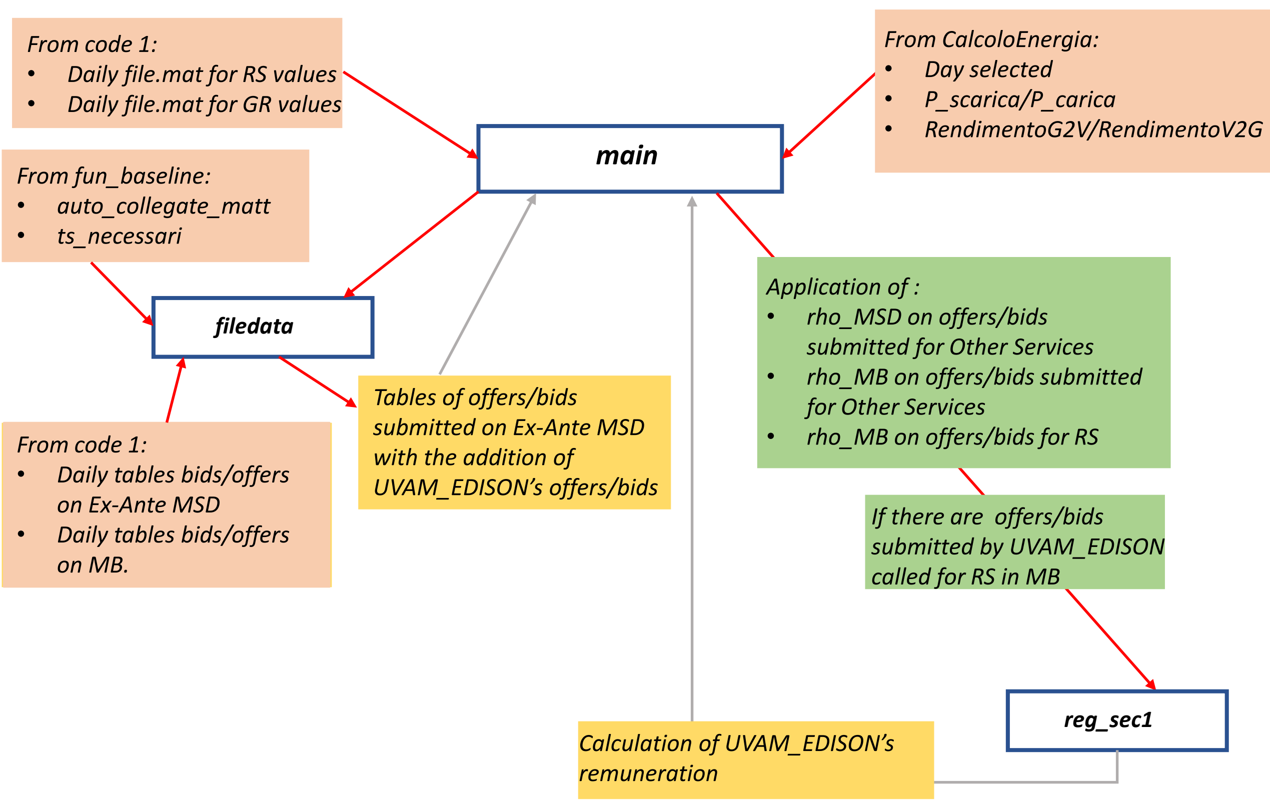


Figure 5.48: Structure and main steps in Code 2.

As it can be seen in Figure 5.48, the main script of code 2 is called main which is recalled in the general function CalcoloEnergia and receives in input:

- the day analyzed in the iteration;
- the power in charge of the charging station, *P_carica*;
- the power in discharge of the charging station, *P_scarica*;
- the efficiency in charge of the charging station, *Rendimento_G2V*;
- the efficiency in discharge of the charging station, *Rendimento_V2G*;

At first, there is the acquisition of data from Code 1, in fact the variables listed in the following bulleted lists are daily saved in files.mat that are then recalled in this function.

- data linked to Secondary Frequency Reserve:
  - hourly values of ρ for bids, *rhoBIDxh*;
  - hourly values of ρ for offers, *rhoOFFxh*;
  - daily values of weighted average price of bids, *w_ave_priceBID*;
  - daily values of weighted average price of offers, *w_ave_priceOFF*;
- data linked to Balancing:
  - hourly values of ρ for MSD bids, *rhoBID_MSD_GR_xh*;
  - hourly values of ρ for MSD offers, *rhoOFF_MSD_GR_xh*;
  - hourly values of ρ for MB bids, *rhoBID_MB_GR_xh*;
  - hourly values of ρ for MB offers, *rhoOFF_MB_GR_xh*;
  - hourly values of marginal price on MB for bids, *pricemargin_BID*;
  - hourly values of marginal price on MB for offers, *pricemargin_OFF*;

At this point in main, another function, filedata, is recalled.

filedata is particularly relevant in fact in this function there is the addition of the case study's aggregator offers/bids to the tables of MSD offers/bids.
filedata receives inputs from different functions, in fact:

- from Code 1, it receives in input the tables with all the daily submitted offers/bids on Ex-Ante MSD and the two tables with offers/bids on MB;
- from function fun_baseline, it receives in input data about:
  - the number of daily vehicles available in the morning with an arrival time scheduled at 9.30 a.m., *auto_collegate_matt*;
  - the time step (made up of 15 minutes) at which each vehicle is ready to supply the service, *ts_necessari*.
    This number quantifies, starting from the arrival SOC, the charging time needed for the vehicle's battery to reach the 80% of the SOC.

- from function main, it receives in input data:
  - the power in charge/discharge of the charging station, *P_carica*/*P_scarica*;
  - the efficiency of charge/discharge,*Rendimento_G2V*/*Rendimento_V2G*;
  - daily values of weighted average price of **RS** bids, *w_ave_priceBID*;
  - daily values of weighted average price of **RS** offers, *w_ave_priceOFF*;

Starting from the number of vehicles available and the time step at which all of them are ready to supply the service, it can be defined the total quantity that can be offered *Q_offers* and the first hour at which it is possible to submit offers.

Then it is simulated the participation to the market by adding rows to Ex-Ante MSD tables, in detail:

- the STATUS_CD of offers sumbitted for **RS** on Ex-Ante MSD are displayed as rejected (REJ);
- the UNIT_REFERENCE_NO is UVAM_EDISON;
- the INTERVAL_NO slot was filled with the hour in which it was decided to submit the offer/bid starting from the first hour useful for submitting;
- For filling the ENERGY_PRICE_NO slot it was chosen the daily weighted average price defined in code 1;
- It was assumed that no adjustment on the submitted price was made by Terna, so the ENERGY_PRICE_NO and the ADJ_ENERGY_PRICE_NO are the same;
- The zone of submitting is NORD. This choice was made after the examination of monthly values of ρ shown in Figure 5.13.

Finally, it must be noticed that, in order to simplify the analysis, it was chosen to submit offers/bids only for **RS**. So the quantity of the UVAM_EDISON accepted in offer/bid for Other Services is equal to zero, this detail will be important in the remuneration definition phase.

The modified Ex-Ante MSD tables are then given as output to function main. The core part of this function is a for loop on the zones of Italian market in which market's results are analyzed for a single day. For each iteration, there is firstly the analysis of Ex-Ante MSD and then of MB, with the additional subdivision between **GR** and **RS**.

At first there is the selection of only the offers/bids submitted on Ex-Ante MSD for the specific zone analyzed. Then, the probability ρ is applied to offers/bids for Other Services: for each offer it is generated a single uniformly distributed random number

in the interval $(0, 1)$. If this number is smaller than ρ value, the offer is accepted otherwise it is rejected. For the Other Services offers/bids that result accepted on MSD, it was implemented also the remuneration function.
For what concern Secondary Frequency Reserve in Ex-Ante MSD, as it was already written in 5.2.1, it was hypothesized that all the submitted offers for **RS** are automatically accepted to MB.

On MB market, as already done for Ex-Ante MSD, there is at first the selection of offers/bids for the zone in analysis and then the application of respective ρ values both to Other Services and Secondary Frequency Reserve. Also in MB, ρ values are applied with the same strategy described for Ex-Ante MSD.
At this point, the focus is on the case study aggregator UVAM_EDISON: among the called offers/bids on MB for **RS**, it is firstly verified if there are offers/bids submitted by the aggregator. If the check has a positive outcome, it is made a for loop on the hours and it is defined for UVAM_EDISON:

- the hourly total quantity among BIDs supplied by the UVAM;
- the hourly total quantity among OFFs supplied by the UVAM;
- the hourly value of bids' weighted average price;
- the hourly value of offers' weighted average price;
- the hourly value of variable Emis that is in the remuneration's equations;

Then it starts what was called *Phase 1* in 4.3.6, so there is the calculation of hourly value of Q_{MSD} and the following verify hour by hour. Then there is a for loop on the hours, in which, if for that interval of time the verify had a positive outcome, the function for the calculation of **RS** remuneration, is executed.
The name of this function is reg_sec1 and it receives many inputs:

- from main:
  - hourly value of Q_{MSD};
  - name of the area in analysis;
  - *pricemargin_BID*;
  - *pricemargin_OFF*;
  - hourly weighted average prices for UVAM's bids/offers called on MB;
  - hourly value of Emis;
  - hourly values of total quantity supplied by the UVAM.
- from CalcoloEnergia, the value of daily Baseline communicated to Terna.

In this code, using the data in input, the hourly value of Non-Supplied Quantity Q_{NF} is calculated following the equations defined in 4.3.6. Then there is the verification of the correct execution of accepted quantities with the eventually calculus of penalty γ as indicated in 4.3.6.
Finally following the equations defined in 4.3.6, hourly remuneration α is defined. The value is then given as output to the function main, where it is associated to the corresponding area in the structure array named *remunerationRS*.

Example of participation to Secondary Frequency Reserve

The 4th of January 2019 is taken into consideration as example. The input data from CalcoloEnergia are:

- the total number of vehicles available in the morning;
- according to the SOC of arrival, the maximum number of time steps for charging until 100% of SOC.

These data are useful in filedata for defining the first hour in which the aggregator is ready for submitting offers to Secondary Reserve and the total quantity offered Q_offers, that is defined as in 5.4:

$$Q\_offers = auto\_collegate\_matt\_tot \cdot P\_scarica \cdot Rendimento\_V2G \tag{5.4}$$

Taking into consideration the fact that it was decided to guarantee to the owners of the cars a minimum SOC of 80% at 6 p.m., this example consider the worst case condition: so there is the submission of offers/bids from the first hour in which the batteries are ready to 5 p.m. leaving only one hour for charging the batteries.

After the application of ρ values, it is resulted that in all cases the offers/bids submitted are then called in MB. Furthermore it is hypothesized that the quantity submitted is entirely called or not, so it is not implemented the possibility of a partial quantity called.
Then the remuneration is calculated in reg_sec1 and finally, there is the check of SOC value.

The latter one is done without taking into consideration the differences between batteries of different car models. So starting from an initial SOC equal to 100% before the supply of the service, the final SOC is computed as follows:

$$SOC\_fin = SOC\_in - \frac{\text{total quantity supplied}}{auto\_collegate\_matt\_tot} \tag{5.5}$$

If the value of SOC_fin is not greater than 80 %, there is a phase of charge batteries until 6 p.m. .

On the 4th of January, the input data from CalcoloEnergia are:

- Number of available vehicles in the morning: 245;
- Maximum number of time-steps needed for fully charge the batteries: 7.

From these data, it is possible to define the following variables:

- Q_offers = 2.36 MW;
- the first hour useful for submitting offers/bids: 11 a.m. .

The strategy chosen in submitting offers/bids is *asymmetrical*, so for each hour, is submitted an offer or a bid with a quantity offered equal to Q_offers.
In this case all the submitted offers/bids get remuneration, in Table 5.3 and Table 5.4 are shown details and the final SOC is equal to 94.2% so it is not needed a recharge.

Table 5.3: Remuneration of submitted bids for the second case.

BIDS	**13 p.m.**	**14 p.m.**	**16 p.m.**	
Q_MSD	-2.36	-2.36	-2.36	MW
Q_NF	1.18	1.18	1.18	MW
γ	0.05	11.82	5.91	euro
pricemargin_BID	0	10	5	$\frac{\text{euro}}{\text{MWh}}$
P_upBID	26.98	26.98	26.98	$\frac{\text{euro}}{\text{MWh}}$
sum_priceBID	26.98	26.98	26.98	$\frac{\text{euro}}{\text{MWh}}$
Remuneration_RS	26.96	21.98	24.48	$\frac{\text{euro}}{\text{MWh}}$
remun_RS_euro	63.76	51.98	57.89	euro

Table 5.4: Remuneration of submitted offers for the second case.

OFFERS	**11 p.m.**	**12 p.m.**	**15 p.m.**	
Q_MSD	2.36	2.36	2.36	MW
Q_NF	1.18	1.18	1.18	MW
γ	107.57	117.91	94.57	euro
pricemargin_OFF	91	99.75	80	$\frac{\text{euro}}{\text{MWh}}$
P_upOFF	26.98	26.98	26.98	$\frac{\text{euro}}{\text{MWh}}$
sum_priceOFF	26.98	26.98	26.98	$\frac{\text{euro}}{\text{MWh}}$
Remuneration_RS	-18.51	-22.88	-13.01	$\frac{\text{euro}}{\text{MWh}}$
remun_RS_euro	-43.76	-54.10	-30.75	euro

Chapter 6

Conclusion

From the analysis of Italian Electricity Market carried out with the Matlab functions explained in 5.2.1, it can be noticed, at first, that values of ρ are pretty small for plants with little nominal power like the one in the case study. This is explainable by the fact that, at the moment, Terna still prefers traditional plants with a greater power because they allow an easier modulation.
Furthermore, starting from daily values of ρ to monthly ones, there is a reduction in their variability.
This is linked to the fact that the greater is the number of offers/bids taken into consideration, the smaller will be the relative weight of each of them in the final result.
By the comparison of ρ trends for different Italian Market Zones, **CNOR** and **NORD** are the ones in which it is higher the probability to have an offer/bid called in service for Secondary Reserve.
Finally, it can be object of further studies, the analysis of how the presence of **RES** influences the prices of offers/bids submitted on the market.

For what concern the results of the simulation implemented in Code 2 as already explained in 5.2.6, it can be noticed that due to a low variability in the value of Q_offers, the weight of *prices* that are used for the calculation of the penalty γ is greater. In fact, where there is the submission of bids characterized by low marginal prices respect to the ones in offers, it is possible to make profit.

Appendix A

Economy Pills

In order to have a complete understanding of the work done in this thesis, it is important to know some basic economy pills [36].

First of all it must be noticed that economic observations can be done in two different scenarios:

- **Short-run**: In this period of time at least one production factor cannot change.
  Ex. The electricity infrastructure.
- **Long-run**: Period of time in which all inputs can be varied.

From a mathematical point of view another concept has to be pointed out and it is the difference between **Average Value** and **Marginal value**:

- **Average values** are the benefit or cost per unit of a good.
- **Marginal values** show the additional benefit or cost from consuming an additional unit of a good.

A.0.1 Utility and Demand Curve

Utility can be defined as the measure of satisfaction an individual gets from the consumption of a good or service.
So it depends on the intensity of the desire and this implies that utility is very difficult to measure because it can change from one individual to another according to the need.

Utility and the Law of Diminishing Marginal Utilities

The extra utility added by the last unit consumed of a good diminishes as high quantity of a good is consumed.

So, as it can be seen in Figure A.1 when the quantity of unit consumed p increases:

- The utility increases with the consumed quantity;

- The utility of the last consumed unit is decreasing → The marginal utility decreases;

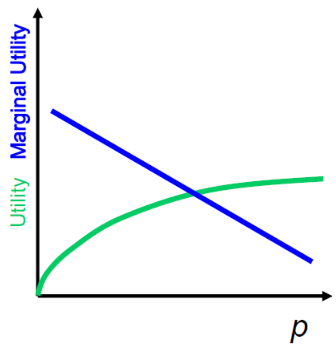


Figure A.1: Marginal Utility and Utility curves [36].

Demand Curve

The curve of the **marginal utility** represents the **Demand Curve** of a good in the market. It expresses the price v the buyers are willing to pay as a function of the quantity demanded.

$$v = d(p) \tag{A.1}$$

Demand Elasticity Demand elasticity is the relative variation in the quantity demanded p for a relative variation of price v:

$$\epsilon = \frac{\frac{\Delta p}{p}}{\frac{\Delta v}{v}} \tag{A.2}$$

Three different behaviours in terms of elasticity can be identified:

- **Elastic**: if the price increase 1%, the demand quantity will reduce more than 1%;
- **Unit elasticity**: If the price increase 1%, the demand quantity will reduce 1%;
- **Inelastic**: if the price increase 1%, the demand quantity will reduce less than 1%;

In a graph $v = d(p)$:

- a **vertical line** corresponds to $\epsilon \to 0$ so the consumer is willing to pay any price in order to obtain the demanded quantity;
- a **horizontal line** corresponds to $\epsilon \to \infty$ so the price is fixed apart from the quantity demanded.

A.0.2 Production Cost and Supply Curve

The **Production cost** is the sum of total costs undertaken by the firm in order to produce the quantity **p** of a good.
It is the sum of fixed and variables costs:

$$c(p) = c_F + c_V(p) \tag{A.3}$$

- **Fixed cost**: c_F cost that, in the short period, do not depend on the production quantity. E.g.: the cost of land, machines and so on.
- **Variable cost**: $c_V(p)$ costs that depend on the production quantity. E.g.: amount of fuels and electricity needed and so on.

Then, it can be defined:

- **Average Cost**: The total cost for producing a unit of product at a specific level of production p.
$$\overline{c}(p) = \frac{c(p)}{p} \tag{A.4}$$
- **Marginal Cost**: It is the derivative of cost related to the quantity **p** computed in p, where p is a given level of production.
$$c_m(p) = \frac{dc(p)}{dp} \tag{A.5}$$

The marginal cost curve intersects the average total cost curve at its minimum.

$$\frac{dc(p)}{dp} = 0 \leftrightarrow \overline{c}(p) = c_m(p) \tag{A.6}$$

Law of Diminishing Marginal Returns

If one input in the production of a good is increased while the other inputs are held fixed, it will be reached a point at which the same additions of extra input, results in a smaller extra output.

Supply curve

Due to the fact that as the production quantity increases, more expensive resources for production are needed, the **marginal production cost** increases so the supply curve has an **upward sloping**.

In the market the supply/demand curve is made up of the aggregation of the individual curves of each market participants (**offers** and **bids**).

- The quantities p of the bids to buy with the same price v^* are summed in the demand/aggregate bid curve.

- The quantities p of the offers to sell with the same price $v*$ are summed in the supply/aggregated offer curve.

The concepts above are represented in Figure A.2

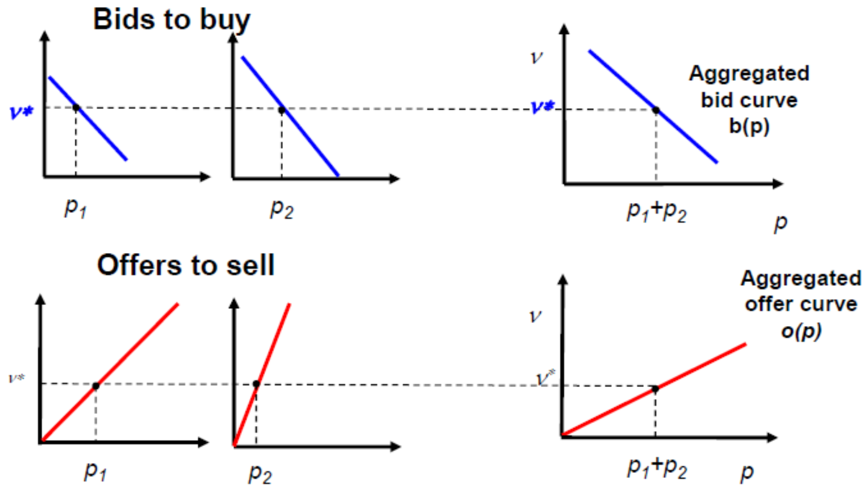


Figure A.2: Details of demand/offer curve creation [36].

Cost VS Price At this point it must be explained the difference between *cost* and *price*:

- **Cost**: money paid for producing a good.
- **Price**: money that consumers need to spend in order to acquire a good.

A.0.3 Revenue and Profit

Definitions

- **Total Revenue r**: It is the total amount of income generated by the sale of goods and services.
$$r = v(p) \cdot p \tag{A.7}$$
- **Marginal Revenue** r_m: At a specific level of production **p**, it represents the additional revenue given by the sell of an additional unit of good.
$$r_m = \frac{dr(p)}{dp} \tag{A.8}$$
- **Profit** π: it is the financial gain and it is obtained from the difference between revenues and the total costs.
$$\pi = r(p) - c(p) \tag{A.9}$$

  The goal of every company is the **maximization** of profit.

The profit is maximum when the *marginal revenue* is equal to the *marginal costs*.

$$\frac{d\pi}{dp} = r_m - c_m = 0 \rightarrow r_m = c_m \tag{A.10}$$

A.0.4 Market Equilibrium

The market equilibrium is the **intersection point** of demand and supply curve in the short run as shown in Figure A.3.

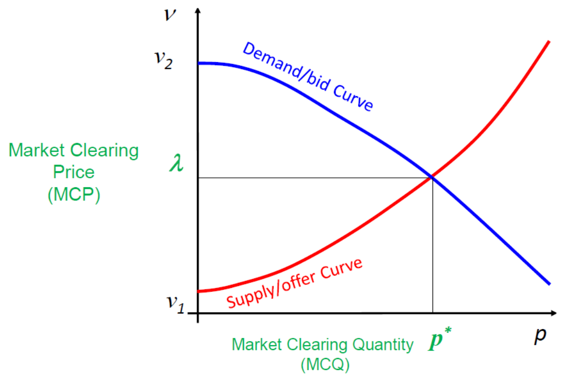


Figure A.3: Market Equilibrium [36].

The equilibrium point is characterized by a Market Clearing Price (MCP) λ and a Market Clearing Quantity (MCQ) p^*.
In a competitive market:

- The equilibrium quantity p^* is such that the price that consumers are willing to pay for that is equal to the price that producers receive in order to supply the same quantity.
- The equilibrium price λ is such that the quantity that producers are willing to sell is equal to the one buyers are willing to buy.

A.0.5 Reference Markets

- **Perfect Competition**: It is an ideal type of market structure where the supply curve is coincident with the aggregate marginal cost of the producers and demand curve with the aggregated marginal utility of the consumers. Perfect competition arises when there is a large number of small firms, each one producing an identical product and each is too small to affect the market price.
- **Non perfect Competition**: The supply curve is higher than the aggregate marginal cost of producers and demand curve is lower than the aggregated marginal utility of consumers.
- **Monopoly**: It is characterized by the absence of competition in fact there is only one industry that dominates and it can use its position at its advantage

at the expense of its customers.
Generally, MCQ is lower and MCP is higher than in a competitive market.
It is possible to have **Natural Monopolies** when there are:

- high fixed costs;
- low variable cost;
- small size of the market.

For example the Transmission national System and, locally, the Distribution System.

- **Oligopoly**: It refers to a small number of producers working to restrict output quantities and/or fix prices, in order to achieve above normal market returns. The supply curve is between the aggregate marginal cost of producers (Perfect competition's supply curve) and the supply curve of Monopoly.

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