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D2.1

MAGNITUDE technical and commercial functional architecture

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D2.1 – MAGNITUDE technical and commercial functional architecture

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Executive Summary

The present report is a public deliverable (Deliverable D2.1) of the MAGNITUDE H2020 funded European project. The MAGNITUDE project aims to develop business and market mechanisms, as well as coordination tools to provide flexibility to the European electricity system, by enhancing the synergies between electricity, heating/cooling and gas systems. In particular, MAGNITUDE's goal is to identify possible flexibility options to support the cost-effective integration of Renewable Energy Sources (RES) and the decarbonisation of the energy system, and to enhance the security of supply.

In this context, the objective of Deliverable D2.1 is to define the MAGNITUDE conceptual technical and commercial architectures to maximise the flexibility provided by multi-energy systems (MES), stressing the overall organisational structures and high level simplified business use cases. These architectures and business use cases are then used in other Work Packages (WP) of the project, that define more precise use cases descriptions, tailored to their specific needs.

Specifying the technical and commercial functional architectures implies the following activities:

- Describe the project concepts and high level conceptual architecture.
- Identify the project business use cases.
- Analyse the main relevant stakeholders involved in the overall process of flexibility provision by MES, considering the four energy sectors (electricity, gas, heating and cooling).
- Describe them in terms of their roles and their interactions.
- Using the roles and interactions, formalize generic conceptual technical and commercial functional architectures in the form of sequence diagrams which allow to describe the organisation of the stakeholders and the flexibility provision mechanisms.

MAGNITUDE main concepts and high level conceptual architecture

The main concepts and high level conceptual architecture of the MAGNITUDE project are shown in Figure 1, where:

- **The Multi-Energy Systems (MES)** are the providers of flexibility through the control of their technological components and the optimisation of their operation.
- **The aggregation platform** collects the requests and signals from the electricity markets (E-market) and/or the service buyers, aggregates the flexibility of the MESs and proposes offers/bids to the electricity markets and services buyers. The aggregator role is carried out by a so-called "deregulated" player, i.e. a player in competition with the other market participants. This role can be carried out by any such "deregulated player", for instance a supplier, a Balance Responsible Party (BRP), a producer..., or a separate player.
- **The electricity market (E-market) or service layers** are composed of different service procurement mechanisms, each associated with specific services and products traded. All type of commercial relationships could be considered: organised markets and procurement mechanisms, call for tenders, bilateral negotiations, etc.
- **Gas and heating/cooling markets (G-Market and H/C-Market) or services layers** are considered to the extent that they affect or are affected by the MES provision of services to the electricity system. The MES stakeholders indeed procure or provide heat, cooling and/or gas and may also provide services to the gas, heating and/or cooling systems.

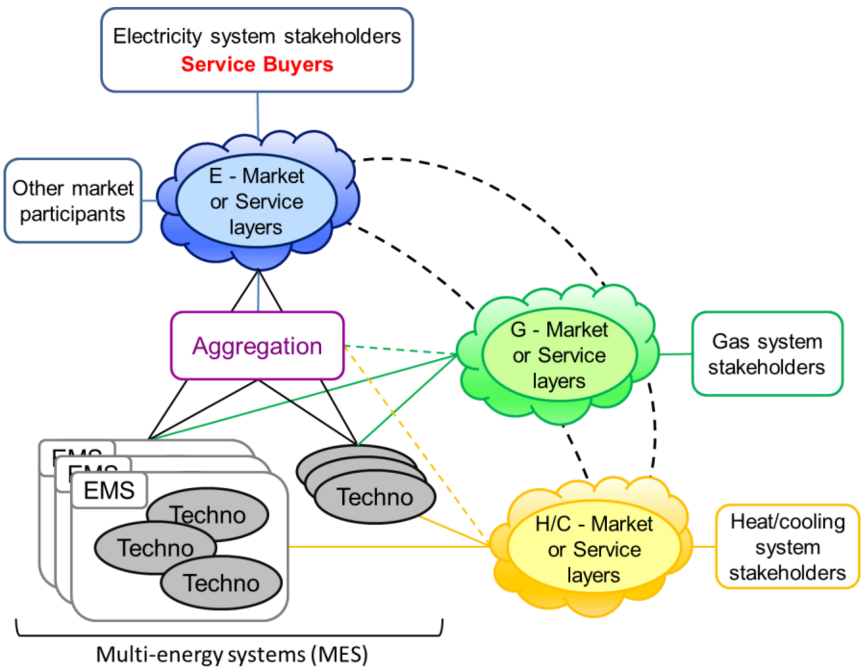


Figure 1 – MAGNITUDE concepts and high level architecture

- **Multi-carrier market integration**: in MAGNITUDE, innovative market designs are proposed and compared with the objective to increase the synergies between the different energy carriers under consideration (electricity, gas, heat/cooling), taking into account the potential coupling between their respective markets. This activity is specifically carried out for the design of day-ahead (DA) multi-carrier energy markets.

High level simplified business use cases

Several dimensions have to be taken into account for the definition of the project high level business use cases, and more specifically:

1. The 7 real-life case studies considered in MAGNITUDE for the validation of the project results:
    - the Milan district heating system of A2A Calore e Servizi (ACS) in Italy,
    - the waste water treatment plant of EMUASA in Spain,
    - the district heating and cooling systems of Mälarenergi in Sweden,
    - an integrated pulp and paper mill in Austria,
    - the HOFOR case study in Denmark consisting of distributed units at consumers' (heat pumps and accumulator tanks for domestic hot water preparation) connected to a district heating network,
    - the Neath Port Talbot Borough Council area in the UK, focusing on several industrial processes and renewable energy plants,
    - the district heating and cooling systems and the decentralized substations of the Paris Saclay site in France.

    For each of the case studies, two types of configurations will be investigated, namely the existing configuration and configurations implementing technological options and/or operation strategies to improve the provision of flexibility to the electricity system. The case studies and their improvement options and strategies are described in detail in MAGNITUDE Deliverables D1.1 [1] and D1.2 [2].

2. The most relevant services to be provided by MESs selected and described in MAGNITUDE Deliverable D3.1 [3], namely:
   - The provision of reserves for Transmission System Operators (TSOs): Frequency Containment Reserve (FCR), Automatic Frequency Restoration Reserve (aFRR), Manual Frequency Restoration Reserve (mFRR), Replacement Reserve (RR) and some dedicated additional balancing mechanisms which may exist in certain countries,
   - Re-dispatching mechanisms or active power control for congestion management at both transmission and distribution levels (ReD),
   - Energy procurement mechanisms and markets: day ahead energy trades/market (DA), Intraday energy trades/market (ID),
   - Capacity requirement mechanisms (Cap), such as capacity markets and strategic reserves.
3. The innovative markets designs for multi-carrier integration developed in the project, described in MAGNITUDE Deliverables D3.2 [4] and D3.3 [5].

Based on these dimensions, two types of high level simplified business use cases have been defined in this deliverable:

- business use cases associated with the provision of services by the MESs considering the current service procurement mechanisms in the case study countries,
- business use cases associated with the simulation of the innovative market designs.

They are summarized respectively in Table 1 and Table 2 below.

Table 1 – High level simplified business use cases for the case studies with current procurement mechanisms

Case study		Business use cases	
Name, Country	**Main business/activity**	**Provision of the following services**	**In configurations**
Mälarenergi, Sweden	District heating and cooling	Day-ahead (**DA**) and intraday (**ID**) energy markets. Strategic reserves (**Cap**)	Without improvement strategies With improvement strategies (NB. for HOFOR, the services can be provided only in the configuration with improvement strategy)
Paper mill, Austria	Integrated pulp and paper mill	**aFRR, mFRR,** intraday energy market (**ID**)	
HOFOR, Denmark	Distributed units + district heating	Day-ahead (**DA**) and intraday (**ID**) energy markets. Congestion management service (**ReD**)	
ACS, Italy	Milan district heating	**FCR, aFRR, mFRR**	
Neath Port Talbot, UK	Industrial MES sites and large RES	Congestion management service (**ReD**) Capacity market (**Cap**)	
EMUASA, Spain	Waste water treatment plant	**mFRR**, day-ahead (**DA**) and intraday (**ID**) energy markets	
Paris Saclay, France	District heating & cooling + distributed units	Day-ahead (**DA**) and intraday (**ID**) energy markets	

Table 2 – High level simplified business use cases for the assessment of innovative multi-carrier market designs

Case study	Business use cases	
Name, Bidding zone	**Provision of the following service**	**with innovative market designs**
ACS, Bidding zone of Italy North	Day-ahead energy markets (**DA**)	MD1.1 - Decoupled multi-carrier market design with decentralised clearing.
		MD5.1 - Integrated multi-carrier market design with centralised clearing.

Main stakeholders involved in the four energy sectors (electricity, gas, heating and cooling), their roles and interactions

It appears that the main essential functions in all 4 sectors are very similar, when taking into account appropriate adaptations, which result from the rather different characteristics of the electricity, gas and heat/cooling networks in terms of time constants, inherent resilience and dynamic behaviours, and therefore from the associated operation needs and requirements which also differ considerably.

Nevertheless, the functional similarities lead to the identification of very similar roles in the 4 sectors.

An integrated and coherent definition of the roles has then been proposed and for each of 7 real-life case studies, a detailed analysis has been carried out for the 4 energy sectors (electricity, gas, heating and cooling) in the current situation, regarding:

- the main stakeholders involved in the case study,
- the roles they carry out,
- the main interactions between these roles.

For each energy sector, the results are presented in the following way:

- A table mapping the actual stakeholders involved in the case study, with the roles they carry out.
- Sequence diagrams presenting the sequences of the main interactions between the roles involved, which are relevant for the MAGNITUDE project goals. They are structured according to the following three main phases of the service provision process:
  1. **Procurement and negotiation**: corresponding to the planning and product procurement phase.
  2. **Technical delivery**: corresponding to the product delivery phase.
  3. **Settlement**: corresponding to the settlement or post-delivery phase.

A comparative analysis of the current role models (roles and main interactions) of the case studies has then been conducted for the four energy sectors. This analysis has allowed to highlight the similarities between the case studies and to propose generic role models able to represent their main characteristics, as described below.

Conceptual technical and commercial functional architectures

Using the roles and interactions identified in the case studies, the conceptual technical and commercial architectures are formalized in the form of generic sequence diagrams which describe the organisation of the stakeholders and the flexibility provision mechanisms. Such generic sequence diagrams are given for the four energy sectors, namely electricity, gas, heating and cooling sectors.

The generic sequence diagram for the electricity sector is further extended to integrate the interactions between the multi-energy systems and the aggregation platform as proposed in MAGNITUDE for the provision of services to the electricity system.

The objective of these sequence diagrams is to show the main principles of the whole process and to be as generic as possible. Actually, the whole process may be much more complex when integrating all the specificities that can be found in the considered countries. Indeed, the detailed studies performed in this report and in Deliverable D3.1 [3] have shown that there is a large diversity of situations, market mechanisms and rules that can be found in the case study countries, despite some harmonisation initiatives that have been and/or are being carried out. It is not possible to represent here all the situations in detail with the same role model. Additionally, this is a very fast evolving field: some rules or mechanisms can change from one year to the other, or sometimes even faster.

Finally, the roles involved in the two business use cases for the assessment of innovative multi-carrier market designs have been identified, and the associated sequence diagrams have been elaborated.

Further steps

As previously mentioned, the architectures and business use cases defined in Deliverable D2.1 are used in other Work Packages (WP) of the project to define systems use cases (and software use cases) tailored to their specific needs and to develop the different modules of the MAGNITUDE software tools.

The business use cases will be assessed and compared through the simulations carried out in WP6 on the 7 case studies, using the Key Performance Indicators (KPIs) previously proposed in Deliverables D6.1 [6] and D3.2 [4].

An economic analysis of their costs and potential benefits will be carried out in the task devoted to the elaboration of business models. For this purpose, this task will rely in particular on the detailed description of the stakeholders and their interactions for each case study reported in the present deliverable.

The sequence diagrams will also be used in the investigations carried in the next phases of WP2 on the development of multi-energy data hubs.

Last but not least, the MAGNITUDE business use cases and architectures will be proposed to different standardisation or pre-standardisation bodies, which presently extend their activities to energy system integration or multi-energy systems.

Finally, it should be reminded that in the provision of services to the electricity system, multi-energy systems are complementary and/or in competition with other flexibility resources. A detailed comparative assessment with other flexibility sources would be necessary. This is however not in the scope of the MAGNITUDE project.

Table of content

Table of figures

Table of tables

List of Acronyms

Abbreviation/ Acronym	Description
ACS	A2A Calore e Servizi
aFRR	automatic Frequency Restoration Reserve
AP	Aggregation platform
BRP	Balance responsible party
BUC	Business use case
Cap	Capacity requirement mechanism
CCGT	Combined Cycle Gas Turbine
CHP	Combined Heat and Power plant
CS	Case study
DA	Day ahead energy market
DH	District heating
DHC	District heating and cooling
DSO	Distribution System Operator
EMS	Energy Management System
EU	European Union
FCR	Frequency Containment Reserve
ICT	Information and Communication Technology
ID	Intraday energy market
LV	Low Voltage
MC	Multi-Carrier
MD	Market Design
MES	Multi-energy system
mFRR	manual Frequency Restoration Reserve

Abbreviation/ Acronym	Description
MS	Market Scheme
MV	Medium Voltage
NPT	Neath Port Talbot
OCM	On-the-day Commodity Market
OTC	Over-The-Counter
OPEX	Operational expenditure
PV	Photo-voltaic
ReD	Re-dispatching mechanisms or active power control
RES	Renewable energy sources
RR	Replacement Reserve
SGAM	Smart Grid Architecture Model
TSO	Transmission System Operator
UC	Use case
UML	Unified Modelling Language
UK	United Kingdom
USA	United States of America
WP	Work Package

1 Introduction

The present report is the public Deliverable D2.1 of the MAGNITUDE H2020 European project.

1.1 The MAGNITUDE project

The MAGNITUDE project aims to develop business and market mechanisms, as well as supporting coordination tools to provide flexibility to the European electricity system, by enhancing the synergies between electricity, heating/cooling and gas systems. In particular, MAGNITUDE's goal is to identify possible flexibility options to support the cost-effective integration of Renewable Energy Sources (RES) and to enhance the security of supply.

To achieve its goals, MAGNITUDE will:

- Provide technological and operational tools to enable the provision of flexibility to the electricity system by Multi-Energy Systems (MESs).
- Develop enhanced business and market mechanisms and identify potential regulatory evolutions to exploit the full potential value of the flexibility provided.
- Validate the project results on seven real life case studies (CS) of multi-energy systems of different sizes and technological features (including key "cross-sector" technologies), located in seven European countries with different regulations, support schemes, and geopolitical characteristics (Austria, Denmark, France, Italy, Spain, Sweden, United Kingdom).
- Propose recommendations and contribute to the definition of policy strategies in a pan-European perspective, and spread the project achievements towards stakeholders in the electricity, heat and gas sectors to raise awareness and foster a higher collaboration.

MAGNITUDE addresses the challenge to bring under a common framework, technical solutions, market design and business models, to ensure that its results can be integrated in the overall ongoing policy discussion in the energy field.

More specifically the project approach is based on the following main activities:

- Select the most relevant flexibility services towards the electricity system that could be provided by multi-energy systems, and which allow to
    - increase the share of RES in the final energy demand,
    - enhance security of supply,
    - increase trading between energy sectors.
- Study the actual flexibility options that sector-coupling technologies and systems can provide to the electricity sector as well as their compatibility with the current regulation and market design.
- Simulate and optimize control strategies to improve the operation of such technologies and systems to maximize flexibility provision.
- Propose innovative market designs for synergies maximization that will be modelled in a market simulation platform.
- Quantify the benefit of pooling flexibilities from decentralized multi-energy systems through an aggregation platform.

- Exploit the achieved results by developing policy strategy and recommendations – including technology, market, business models, and regulation – and related considerations for feasibly increasing synergies between networks in representative EU countries.

1.2 Scope and structure of Deliverable D2.1

The objective of Deliverable D2.1 is to define the MAGNITUDE conceptual technical and commercial functional architectures to maximise the flexibility provision by MESs, stressing the overall organisational structures and high level simplified business use cases. These architectures and business use cases are then used in other Work Packages (WP) of the project, that define more precise use cases descriptions, tailored to their specific needs.

Specifying the technical and commercial functional architectures of the project, implies the following activities:

- Describe the project concepts and high level conceptual architecture.
- Identify the project business use cases.
- Analyse the main relevant stakeholders involved in the overall process of flexibility provision by MES, considering the four energy sectors (electricity, gas, heating and cooling).
- Describe them in terms of their roles and their interactions.
- Using the roles and interactions, formalize generic conceptual technical and commercial functional architectures in the form of sequence diagrams which allow to describe the organisation of the stakeholders and the flexibility provision mechanisms.

More specifically, Chapter 2 describes the MAGNITUDE main concepts and high level conceptual architecture. Chapter 3 is devoted to the identification and characterisation of the high level (simplified) business use cases that will be investigated in the project. In Chapter 4, the concept of roles and role models is first introduced, as well as the main roles involved in the electricity, gas, heating and cooling systems, which are relevant for the MAGNITUDE project. The roles currently identified in the 7 case studies for the 4 energy sectors are then described and the main interactions between the identified roles in the current situation are provided in the form of generic sequence diagrams. Chapter 5 describes the proposed interactions between the aggregation platform and the multi-energy systems for the provision of flexibility to the electricity systems and further extends the generic sequence diagram for the electricity system. Chapter 6 is devoted to the description of the roles and the interactions involved in the innovative market designs proposed for multi-carrier market integration and hence the enhancement of the synergies at market level. Conclusions and future perspectives are given in Chapter 7.

Finally the appendices of Chapter 9 provide the results of the detailed analysis carried out for each of the 7 real-life case studies in the current situation for the 4 energy sectors considered (electricity, gas, heat and cooling), regarding:

- the stakeholders involved in the case study,
- the roles they carry out,
- the main interactions between these roles in the form of sequence diagrams.

2 MAGNITUDE concepts

The main concepts and high level architecture of the MAGNITUDE project are shown in Figure 2 below.

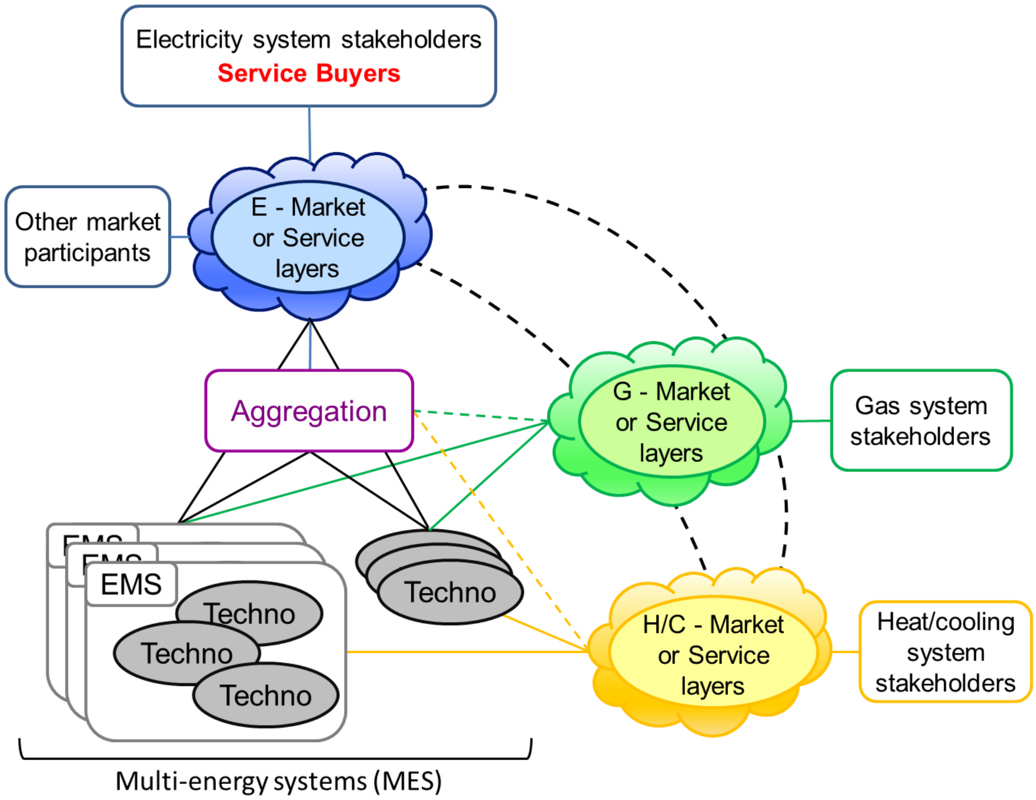


Figure 2 – MAGNITUDE concepts and high level architecture

In this conceptual high level architecture,

- **The Multi-Energy Systems (MES)** are the providers of flexibility through the control of their technological components and the optimisation of their operation. As described in Sections 3.1, they may have different purposes and include different types of "cross-sector" technologies and energy carrier networks (electricity, gas, heat, cooling, etc.). Depending on the case and on their size, these technologies can be located in a large (industrial, commercial or public) site or distributed at consumers' or prosumers' premises. They may also be operated through an Energy Management System (EMS) or an equivalent device, which can perform a local aggregation at the level of the site. Considering the voltage frontiers between transmission and distribution electricity grids in the considered countries, the MES are mainly connected to the distribution networks. The MES considered in the project are described in more detail in Section 3.1.
- **The aggregation platform (AP)**:
    - Collects the requests and signals from the electricity markets (E-market) and/or the service buyers,
    - Gathers and aggregates the flexibility of the MESs and integrate it in its portfolio of resources.
    - Proposes offers/bids to the electricity markets and services buyers.

For these purposes, the AP performs forecasting of market prices and MES flexibility, and carries out optimizations at portfolio level, both for the preparation of the bids and the optimal dispatch between the MES and the other potential resources in its portfolio. More details are given in Chapter 5.

The aggregation role is carried out by a so-called "deregulated" player, i.e. a player in competition with the other market participants. This role can be carried out by any such "deregulated player", for instance a supplier, a Balance Responsible Party (BRP), a producer..., or a separate player.

- **Electricity market (E-market) or service layers**: All type of commercial relationships should be considered: organised markets and organised procurement mechanisms, call for tenders, bilateral negotiations or Over-The-Counter (OTC) trading, etc. However due to access limitations to available data, mainly organised markets and mechanisms and some calls for tenders are studied in detail in the project.

  The electricity markets or service procurement mechanisms are composed of different layers, each associated with specific services and products traded. The following services have been selected as most relevant for MAGNITUDE's targets: day-ahead and intraday energy trading, balancing and frequency regulation, congestion management, and capacity requirements for system adequacy. These services are described in more detail in Section 3.3.
- **Gas and heat/cooling markets (G-Market and H/C-Market) or services layers**: in MAGNITUDE, the gas and heat/cooling markets or services provision mechanisms are not studied in full detail but are mainly considered to the extent that they affect or are affected by the MES provision of services to the electricity system. Indeed, the MES stakeholders procure or provide heat, cooling and/or gas and may also provide services to the gas or heat systems. The resulting potential constraints/barriers and opportunities/benefits have to be taken into account.
- **Coupled multi-carrier markets**: in MAGNITUDE, innovative market designs are proposed and compared for coupled multi-carrier markets. This activity focusses mainly on the design of day-ahead (DA) multi-carrier energy markets but could also be extended to the intraday energy markets. In this context the evolution of the aggregation role and of the overall MAGNITUDE conceptual architecture has to be investigated. This topic is described in more detail in Chapter 6.

The MAGNITUDE high level conceptual architecture is further detailed in Chapters 4 and 5 in terms of the roles involved and of their interactions. More specifically the following main types of interactions are described:

- between the multi-energy systems (MES) and the aggregation platform (AP),
- between the MES and the other stakeholders.

3 Project business use cases (BUC)

This chapter is devoted to the identification of the high level (simplified) business use cases that will be studied in the MAGNITUDE project.

First some definitions and further explanation of the scope of this deliverable are provided in Section 3.1. Then Section 3.2 describes the first dimension of the project business use cases, namely the 7 real-life case studies and the configurations that will be studied. Section 3.3 is devoted to the second dimension of the business use cases, i.e. the relevant services that have been identified and selected for the provision by MESs. Section 3.4 introduces a third dimension in terms of innovative market designs that have been proposed and discussed for further consideration. Finally, Section 3.5 summarizes the MAGNITUDE business use cases selected for further investigation in the project.

3.1 Definitions and terminology

First, some definitions from the use case methodology [7] need to be introduced:

- **Party**: "*Parties are legal entities, i.e. either natural persons (a person) or judicial persons (organizations). Parties can bundle different roles according to their business model"*. In other words, a Party is an actual company or stakeholder.
- **Role**: "*a Role represents the intended external behaviour (or responsibility) of a Party. Parties cannot share a Role. Parties carry out their activities by assuming Roles, e.g. system operator, trader. Roles describe external business interactions with other Parties in relation to the goal of a given business transaction*". A Party has to carry out a role entirely or in other words two Parties cannot share the carrying out of two different parts of the same role. Otherwise this Role has to be split in two different Roles. But the same Role can be carried out by different Parties. Examples of such Roles are: Balance Responsible Party, Network Operator, Market Operator, Supplier, etc.
- **Actor**: "*An Actor represents a Party that participates in a (business) transaction. Within a given business transaction an Actor performs tasks in a specific Role or a set of Roles. EXAMPLES: Employee, Customer, Electrical vehicle, Demand-response system*". In other words, an Actor is part of a Party and represents it in the transaction being considered.

According to [7], two main types of use cases can be distinguished:

- **Business Use Cases** "*describe how Roles of a given system interact to execute a business process. These processes are derived from services, i.e. business transactions, which have previously been identified*". Business Use Cases involve only Business Roles (carried out by entities or organisations). In other words, a Business Use Case describes the Roles involved in the provision of a service, along with their associated interactions.
- **System Use Cases** "*describe how Actors of a given system interact to perform a […] Function required to enable/facilitate the business processes described in Business Use Cases. Their purpose is to detail the execution of those processes from an Information System perspective*". In other words, System Use Cases involve System Roles (carried out by information systems, devices, technological components or software tools). They describe functions supporting or enabling Business Use Cases.

Referring to the Smart Grid Architecture Model (SGAM) described in [8] (see Figure 3), Business Use Cases are linked with the description of the Business Layer whereas System Use Cases are linked with the description of the Function Layer.

As described in [8] and [9], the business layer represents the business view on the information exchanges. It is associated with

- the regulatory and economic (market) structures, rules and policies,
- the business models and business portfolios (products & services) of the parties involved,
- the business capabilities and business processes.

And it interacts with the function layer.

The function layer describes the functions to be executed to support, from a technical perspective, the business processes of the above level, as well as their relationships from an architectural viewpoint. The function layer interacts with elements of the underlying levels, namely data models (Information Layer), protocols (Communication Layer), and components (Component Layer).

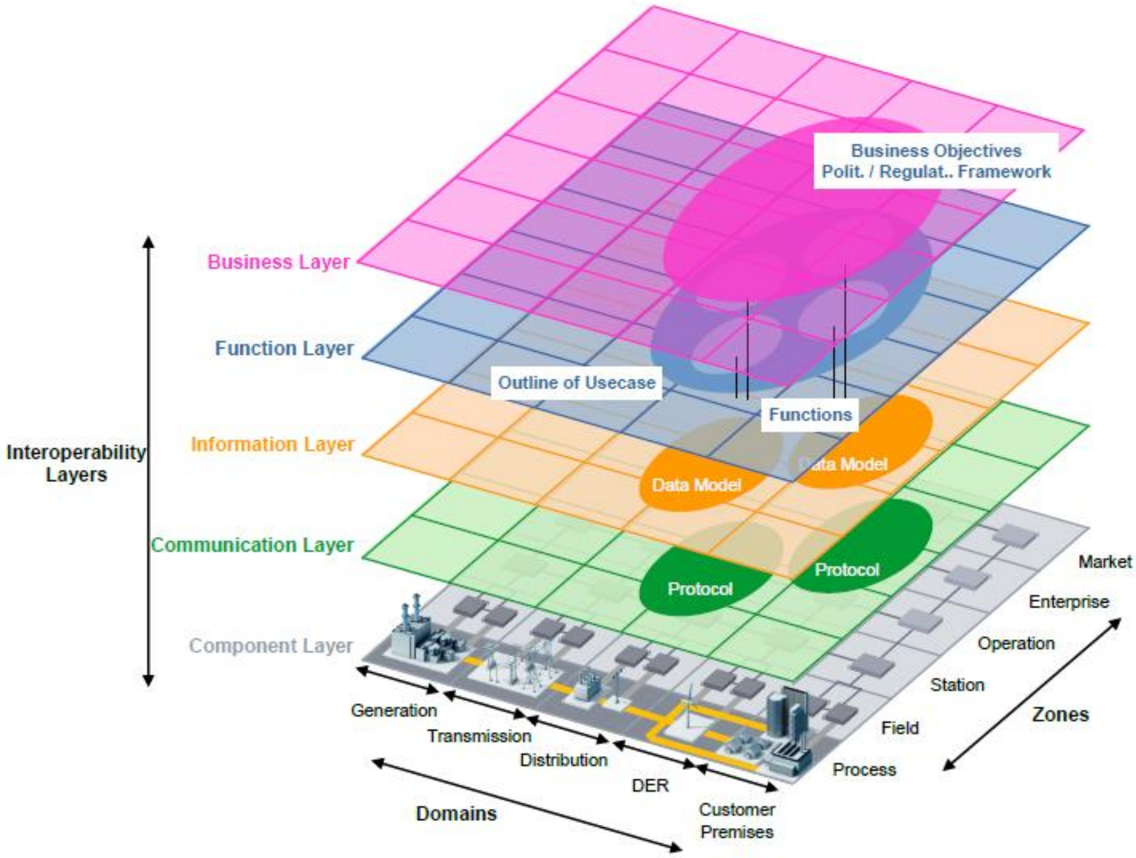


Figure 3 – Smart Grid Architecture Model – SGAM (Source: CEN-CENELEC-ETSI Smart Grid Coordination Group [8])

Going further in the definitions, one of the objectives of this deliverable D2.1 is to describe the high level simplified business use cases (BUCs) that will be considered in the MAGNITUDE project. A **High Level Use Case** [7] is "a use case that describes a general requirement, idea or concept independently from a specific technical realization like an architectural solution".

The scope of D2.1 is mainly to define the concepts of the project that will be further defined and detailed in the other Work Packages (WPs) of the project. Therefore, a rather informal description of these high level BUCs will be provided here in the form of text descriptions supported by sequence diagrams close to (but not actual) UML representations.

3.2 MAGNITUDE case studies

As previously mentioned the project results will be validated on seven real life case studies (CS) of multi-energy systems (MES) of different sizes and technological features, located in seven European countries (Austria, Denmark, France, Italy, Spain, Sweden, United Kingdom) with different regulations, support schemes, geopolitical characteristics, as well as different stakeholders and business models. Namely the case studies are the following:

- the Milan district heating system of A2A Calore e Servizi (ACS) in Italy,
- the waste water treatment plant of EMUASA in Spain,
- the district heating and cooling systems of Mälarenergi in Sweden,
- an integrated pulp and paper mill in Austria,
- the HOFOR case study in Denmark consisting of distributed units at consumers' (heat pumps and accumulator tanks for domestic hot water preparation) connected to a district heating network,
- the Neath Port Talbot Borough Council area in the United Kingdom (UK), focusing on several industrial processes and renewable energy plants,
- the district heating and cooling systems and the decentralized substations of the Paris Saclay site in France.

These case studies provide the data foundation for the result assessment work and for the modelling and development activities taking place in different WPs in the project. They are described in detail in MAGNITUDE Deliverables D1.1 [1] and D1.2 [2]. Their main characteristics are nevertheless summarized below.

As shown in Table 3, the 7 case studies cover four main categories of MES and/or combinations of such MES, namely: industrial sites, large commercial and/or public sites, district heating/cooling systems, and small distributed units at consumers' premises.

The main technologies and the energy vectors involved in each case study are then shown in Table 4.

Table 3 – Main business/activity of the case studies and main MES categories

Case study Country	Main business/activity	MES categories			
		Industries	Large commercial and/or public sites	District heating and/or cooling	Distributed units at consumers'
Mälarenergi Sweden	District heating and cooling			Heating and cooling	
Paper mill Austria	Integrated pulp and paper mill				
HOFOR Denmark	Distributed units + district heating			Heating	
ACS Italy	Milan district heating			Heating	
Neath Port Talbot, UK	Industrial MES sites and large RES				

Case study Country	Main business/activity	MES categories			
		Industries	Large commercial and/or public sites	District heating and/or cooling	Distributed units at consumers'
EMUASA Spain	Waste water treatment plant				
Paris Saclay France	District heating & cooling + distributed units			Heating and cooling	

Table 4 - Main technologies and energy vectors involved in the case studies

Case Study	Technologies										Energy vectors			
	Bio-mass boiler	Gas boiler	Steam turbine	Gas turbine	Gas engine	Chiller	Heat pump	Electric boiler	(Bio)-Gas storage	Thermal Energy Storage	Heat	Cold	Gas	Electricity
Mälar-energi														
Paper Mill														
HOFOR														
ACS														
Neath Port Talbot														
EMUASA		Bio gas												
Paris Saclay														

For each of the case study, two types of configurations will be investigated, namely the existing configuration and configurations implementing technological options and/or operation strategies to improve the provision of flexibility to the electricity system. Such improvement options and strategies were discussed with the case study owners and/or the MAGNITUDE project partners in charge of the interface with the case study. The options/strategies identified are described detail in MAGNITUDE Deliverables D1.1 [1] and D1.2 [2].

Further discussions allowed to select the options and strategies, shown in Table 5, which appeared as the most relevant both for the project goals and from the technical feasibility of investigation in the project (e.g. availability of data). The main flexibility levers that can be activated are:

- fuel shifting between energy sectors through the operation of the technologies in the case study,
- storage capability,
- load shifting or demand response at consumers'.

Table 5 – Improvement options and/or strategies selected for investigation in the project

Case study	Improvement options or strategies
Mälarenergi Sweden	• Investigate the benefits of the integration of thermal (heat/cooling) storage tanks and of an increase of the electricity generation from the CHP (Combined Heat and Power) plant.
Paper mill Austria	• Investigate the benefits of the installation of a new steam accumulator in the facility, with respect to the following impacts: reduction of steam blow-off, and as a consequence increased energy efficiency, reduction of effort to prepare fresh boiler feed water, increased flexibility of the steam turbines for providing frequency control services, and reduced fuel demand for steam generators. • Investigate the optimized operation of the facility considering peak grid tariffs of gas and electricity.
HOFOR Denmark	• Integration of appropriate control and communication interfaces to allow aggregation and provide services through heat load shifting in multi-storey buildings and single row houses.
ACS Italy	• Improvement of the electrical network which will allow to provide Frequency Containment Reserve (see Section 3.3). • Investigate the benefits of increasing the thermal storage capacity • Investigate new heat pricing models for day/night tariffs to implement heat demand response
Neath Port Talbot, UK	• Investigate how gas-fired generators using fuel from high-pressure gas distribution networks could provide flexibility (within-pipe storage capability of high pressure gas distribution network is crucial).
EMUASA Spain	• Increase of the gas storage to exploit flexibility coming from gas production line • Integration of a heat storage
Paris Saclay France	• Integration of heat pumps and thermal storage in buildings and substations • Integration of PV production on the site (e.g. on building rooftops).

For ACS and EMUASA case studies, other improvement options or strategies are still being discussed and might be considered in a second step depending on the results of these discussions, namely for:

- ACS: introduction of a predictive model for thermal load forecast to allow to forecast the electrical production bi-weekly ahead and consequently better plan the participation in the service procurement markets.
- EMUASA: integration of a chiller for cold generation (tri-generation).

Both the existing configurations of the case studies and configurations integrating the selected improvements options and strategies will be investigated in the project.

3.3 Selected services to be provided to the electricity system

Starting from the analysis of the main needs of the electricity system, as well as of the services that can be procured/provided to meet them, the most relevant services to be provided by MESs have been selected in Deliverable D3.1 [3] using the following criteria, namely selection of services:

- that allow to increase the share of Renewable Energy Sources (RES) and enhance security of supply,
- for which the enhancement of the synergies between electricity, heating/cooling and gas systems provide real opportunities,
- for which the first elements already collected by the project (technical, regulatory, market design) show a potential value for the provision by MES.

The resulting list of selected services is given in Table 6.

Table 6 - Selected electricity system needs and services (from MAGNITUDE Deliverable D3.1 [3])

Needs	Services
Balancing and frequency control	Provision of reserves for Transmission System Operators (TSOs) • Frequency Containment Reserve (FCR) • Automatic Frequency Restoration Reserve(aFRR) • Manual Frequency Restoration Reserve (mFRR) and Replacement Reserve (RR) + dedicated additional balancing mechanisms which may exist in certain countries
Congestion management	Re-dispatching mechanisms or active power control at both transmission and distribution levels (ReD)
Energy trades - Reducing price risks & optimizing energy portfolios	Energy procurement mechanisms and markets: • Day ahead energy trades/market (DA) • Intraday energy trades/market (ID)
System adequacy	Capacity requirement mechanisms (Cap): • Capacity markets (together with other revenue streams) • Strategic reserves (without other revenue stream)

It should be noted that the enhancement of the synergies between electricity, gas and heating/cooling systems will mainly have an impact on “energy” or active power in the electricity system, whereas it is expected to have a low (or even no) impact on the reactive power control. Therefore, the most relevant services are those services linked to active power.

For this reason, voltage control as such does not appear in Table 6. Indeed, in most cases, voltage control is a mandatory service being carried out by acting on reactive power at the connection point and then it depends on the reactive power control capabilities of the equipment connected to the grid.

However, on the distribution networks, due to the technical characteristics of the medium voltage (MV) and low voltage (LV) lines, active and reactive powers are much more “coupled” than on the transmission networks, and active power control or re-dispatching can also be used to control the voltage at MV or LV levels, in combination with the management of power flow constraints. Indeed, the management of distribution grids generally involves a combined optimisation process of the active and reactive powers on the grid to deal with both the power flow and voltage constraints. Therefore active power control or re-dispatching is a flexibility service that could be offered to the Distribution System Operator (DSO) to meet its needs [10], [11], [12].

For the reserve services, two different aspects or phases must be distinguished: (i) the procurement of the power reserves in order to guarantee the availability of the flexible resources when they will be needed, and (ii) the activation of the service and the actual energy delivery. The procured reserves might indeed not be activated. This distinction may also apply to capacity services, as well as to some procurement mechanisms of local power capacities to be used for congestion management.

Other new flexibility services are presently being studied such as for instance ramping margin or provision of inertial response [13], [14]. However, they are not implemented yet in the MAGNITUDE case study countries. The characteristics of the products, the associated market mechanisms and remunerations still need to be clarified and no market data are available yet. So, they will not be further investigated in the project.

After the selection phase summarized above, the mechanisms existing in the 7 case study countries for the procurement of the services of Table 6 have been described in detail and compared in Deliverable D3.1 [3]. The results of this analysis will not be reported here.

3.4 Innovative multi-carrier market designs

Besides focusing on the existing services as introduced in the previous section, innovative multi-carrier market schemes were proposed in MAGNITUDE Deliverable D3.2 [4] with the objective to increase the synergies between the different energy carriers under consideration (electricity, gas, heat/cooling[1]), taking into account the potential coupling between their respective markets. This activity was specifically carried out for the design of day-ahead (DA) multi-carrier energy markets.

Five innovative market schemes were introduced, based on two main market dimensions, namely:

- **the multi-carrier market integration**, i.e. the combination of single and/or multi-carrier markets. As explained in [4], in a single carrier market the inter-dependencies (or linkages) between different carriers are not considered in the orders nor in the clearing process, while in a multi-carrier market, inter-dependencies (or linkages) between various carriers are explicitly considered in the orders and in the clearing process.
- **the locality of the markets**, i.e. the consideration of local and/or global markets [4]. A global market is defined as a market operated by a global market operator which manages energy trades at large regional-wide scale (e.g. national, supra-national) (mostly over high-voltage electricity network or high-pressure gas pipeline system). A local market is defined as a market operated by a local market operator which manages energy trades at smaller local geographical scales comprising for example one or multiple MV or LV electricity network(s), low pressure gas network(s) and/or heat network(s).

[1] In this section, no distinction is made between heat and cooling and the word “heat” is used to represent both.

The 5 considered market schemes are the following:

- **MS1 - Single carrier energy market scheme**, in which only separate (single carrier) day-ahead energy markets are organised for the different energy carriers (gas, heat, electricity);
- **MS2 - Mixed single and multi-carrier energy market scheme**, composed of multi-carrier markets for gas, heat and electricity at the local level, and of single carrier markets for electricity and gas at the global level;
- **MS3 - Coexisting global and local multi-carrier energy market scheme**, composed of a unique multi-carrier market for electricity and gas at the global level and of multiple local multi-carrier markets for heat, gas and electricity at the local level.
- **MS4 - Local multi-carrier energy market scheme**, only composed of local multi-carrier markets for heat, gas and electricity.
- **MS5 - Unified multi-carrier energy market scheme**, composed of one unique multi-carrier market for heat, gas and electricity at the global level.

They are illustrated in Figure 4 and are described in detail in Deliverable D3.2 [4] in terms of their scope, advantages and disadvantages. These results are not repeated here.

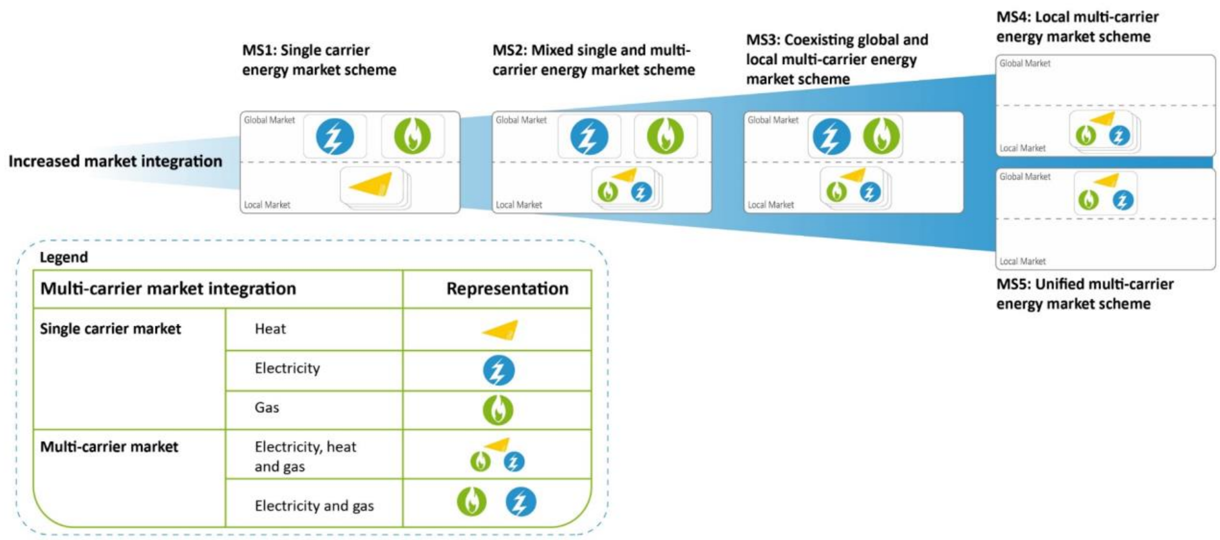


Figure 4 – Innovative schemes for multi-carrier markets

Among the 5 market schemes introduced in Deliverable D3.2, MS1 and MS5 were selected for further investigation and four market designs (MD) have been defined for these schemes. They are listed below:

- For MS1 - Single carrier energy market scheme:
    - **MD1.1 – decoupled multi-carrier market design with decentralised clearing**, where the separated markets for electricity, gas and heat are cleared in a decentralised way, i.e. by their respective market operators. No explicit links exist between the three carrier markets and the impacts that the clearing results of the different carrier markets have on each other are fully internalised by the market participants in their positioning on the different markets.
- For MS5 - Unified multi-carrier energy market scheme:
    - **MD5.1 - Integrated multi-carrier market design with centralised clearing**, where there is one unique integrated multi-carrier market for heat, gas and electricity at the global level

operated by a single multi-carrier market operator. All single carrier and multi-carrier orders are cleared centrally and simultaneously by this multi-carrier market operator.

- **MD5.2 - Integrated multi-carrier market design with decentralised clearing with auxiliary variables linking the conversion orders**, which preserves the current organisational structure with separate market operators for each carrier, while explicitly ensuring the coordination between the different market operators through the exchange of appropriate information and the inclusions of dedicated (auxiliary) variables in their optimisation functions during the clearing process.
- **MD5.3** - **Integrated multi-carrier market design with decentralised clearing with an auxiliary agent processing the conversion orders,** which is a variant of MD5.2 where, instead of dedicated variables in the optimisation process, a new market operator role or agent is introduced to ensure the coordination between the three carrier market operators.

These four innovative market designs are described in detail in MAGNITUDE Deliverable D3.3 [13], where a first qualitative comparative analysis is presented, along with the mathematical formulation of the orders, constraints, and market clearing processes.

3.5 Project high level simplified business use cases

Based on the different dimensions presented in the previous Sections 3.2, 3.3 and 3.4, the project high level simplified business use cases can now be defined.

First a distinction should be made between on the one hand the business use cases associated with the provision of services by the MESs considering the current service procurement mechanisms in the case study countries and on the other hand the business use cases associated with the simulation of the innovative market designs.

3.5.1 Services provided by the case studies with the current procurement mechanisms

Workshops organised with the case study owners and the project partners who ensure the interface with the case study (the "interface partners") first allowed to identify which of the services of Section 3.3 are already provided by the MESs in each of the 7 case studies [1]. They are indicated in Table 7 by a black cross in the first line (with white cells) of each case study. In a second step, the services that could be considered for the provision through the aggregation were identified. They are represented by the crosses in the second line (light blue and yellow cells) of each case study. Finally, further discussions with the case study owners and the interface partners led the selection of two or three services for each case study that will be investigated in detail in the project. They are indicated by red crosses in the yellow cells in Table 7.

Table 7 –Selected services for each case study

Case study	Main business/activity	Selected Services from Deliverable D3.1 [3]						
		FCR	aFRR	mFRR	ID	DA	ReD	Cap
Mälarenergi	District heating and cooling	-	-	-	X	X	-	-
		-	-	X (HP)	X	X	-	X
Paper Mill	Integrated pulp and paper mill	-	X[b]	X	-[a]	-[a]	-	-
		(X)	X	X	X	(X)	(X)	-
HOFOR	Distributed units + district heating	-	-	-	-	-	-	-
		-	(X)	(X)	X	X	X	-
ACS	Milan district heating	-	-	-	X	X	-	-
		X	X	X	X	X	X	(X)
Neath Port Talbot	Industrial MES sites and large RES	X	-	X	X	X	-	-
		X	-	X	X	X	X	X
EMUASA	Waste water treatment plant	-	-	-	-	-	-	-
		-	X	X	X	X	-	-
Paris Saclay	District heating & cooling + distributed units	-	-	-	-	-	-	-
		-	(X)	X	X	X	(X)	X

Services already provided by the MES in the case study	X= yes, - = no
Services that could be considered through aggregation	X= yes, - = no, (X) = possibly
Services to be investigated, selected among the services that could be considered through aggregation	X

[a] service indirectly provided through the supplier

[b] service provision started in 2019

The following main criteria led to this selection:

- As previously explained, the MAGNITUDE project relies on the 7 case studies for the application of the proposed solutions and validation of the results. In particular, the objective is to simulate and investigate the provision of the selected services for each case study in further Work Packages of the project. For this purpose, detailed data are necessary both on the case studies, such as for instance time series of measurements with the appropriate time steps, and on the service procurement markets/mechanisms in the case study countries, such as for instance historical market price time series with the appropriate granularity. In the absence of such necessary data, the corresponding services could not be selected.
- A second important criteria is the relevance of a given service provision according to the discussions with the case study owners, and the innovative aspect of this provision for the considered case study.

- Finally, the technical feasibility or difficulty of the actual implementation has also to be taken into account.

Discussions:

- Regarding the capacity requirement mechanisms, there is no such mechanisms in Austria, Denmark and Italy. No market data are therefore available and this service is not selected for these case studies. Considering the characteristics of the Paris Saclay case study, it appeared too constraining for this case study to participate in the capacity market as it is implemented in France. Due to the characteristics of the capacity payments in Spain, the participation of EMUASA does not seem possible.
- For the case studies of HOFOR, EMUASA and Paris Saclay, no services are presently provided. So the first step is to study their participation to the day ahead (DA) and intraday (ID) energy markets through the aggregation platform, which, in the discussions, appeared relevant for these three case studies considering the technologies involved and the actual implementation aspects. In particular, for EMUASA, the presently available measurement data would not allow to investigate the provision of aFRR, and, for HOFOR, provision of aFRR and mFRR would be very difficult to be actually implemented with the distributed units considered in the case study. For Paris Saclay, the possibility to study the participation in the French so-called balancing mechanism (part of mFRR) [3] is still under discussion and will depend on the data available and on the possibility to develop the appropriate models.
- For the Paper Mill, the most relevant services to study are aFRR, mFRR and ID. ID is not provided yet. Even if aFRR and mFRR are already provided by the plant (through an aggregator) the innovative aspect will result from the expected enhancement of the flexibility capability brought by the improvement strategy described in Table 5 (steam accumulator). The participation to FCR and DA would be too constraining for the plant and ReD does not seem relevant on this grid.
- For Mälarenergi, the presently available data would not allow to investigate the provision of mFRR. Even if DA and ID are already provided by the plant, the innovative aspect will result from the expected enhancement of the flexibility capability brought by the improvement strategy described in Table 5 (thermal storage and increased electricity generation from CHP).
- For ACS, the most relevant and innovative services are FCR, aFRR and mFRR. Indeed, DA and ID are already provided through aggregation and ReD does not seem relevant on this grid.
- For Neath Port Talbot, ReD and Cap will be studied. Indeed, aFRR is not used in Great Britain and all the other services are already provided. The main objective of this case study is to investigate the interactions between the gas and the electricity networks, and the grid constraints and congestion management, in particular resulting from the integration of large RES plants.

For each case study, the provision of the selected services will be investigated for:

- the current or reference configuration,
- the configuration(s) implementing the improvement strategies or options of Table 5, which for some case studies may lead to more than one configuration.

The specific scenarios and detailed configurations that will be studied will be defined later in another WP of the project.

Table 8 below summarizes the corresponding high level simplified business use cases that will be considered for the case studies with the current procurement mechanisms in their respective country.

Table 8 – High level simplified business use cases for the case studies with current procurement mechanisms

<table>
<tr><th colspan="2">Case study</th><th colspan="2">Business use cases</th></tr>
<tr><th>Name, Country</th><th>Main business/activity</th><th>Provision of the following services</th><th>In configurations</th></tr>
<tr><td>Mälarenergi, Sweden</td><td>District heating and cooling</td><td>Day-ahead (DA) and intraday (ID) energy markets.
Strategic reserves (Cap)</td><td rowspan="7">• Without improvement strategies
• With improvement strategies
(NB. for HOFOR, the services can be provided only in the configuration with improvement strategy)</td></tr>
<tr><td>Paper mill, Austria</td><td>Integrated pulp and paper mill</td><td>aFRR, mFRR, intraday energy market (ID)</td></tr>
<tr><td>HOFOR, Denmark</td><td>Distributed units + district heating</td><td>Day-ahead (DA) and intraday (ID) energy markets.
Congestion management service (ReD)</td></tr>
<tr><td>ACS, Italy</td><td>Milan district heating</td><td>FCR, aFRR, mFRR</td></tr>
<tr><td>Neath Port Talbot, UK</td><td>Industrial MES sites and large RES</td><td>Congestion management service (ReD)
Capacity market (Cap)</td></tr>
<tr><td>EMUASA, Spain</td><td>Waste water treatment plant</td><td>mFRR, day-ahead (DA) and intraday (ID) energy markets</td></tr>
<tr><td>Paris Saclay, France</td><td>District heating & cooling + distributed units</td><td>Day-ahead (DA) and intraday (ID) energy markets</td></tr>
</table>

3.5.2 Simulation of innovative market designs for the day-ahead energy markets

Among the four market designs proposed and described in detail in MAGNITUDE Deliverable D3.3 [5] (see Section 3.4), the following were selected for implementation in the market simulator:

- MD1.1 – decoupled multi-carrier market design with decentralised clearing,
- MD5.1 - Integrated multi-carrier market design with centralised clearing.

Multi-carrier market simulations will be performed for both market designs for the ACS case study, i.e. for the bidding zone of Italy North.

Market simulations for the other two market designs introduced in Section 3.4, namely MD5.2 and MD5.3, would lead to the same market outcomes as MD5.1 (if enough time is allowed for convergence). The difference with respect to MD5.1 lies in the institutional players or actors being involved, their respective role, and the fact that decentralization means that the global multi-carrier market clearing problem is solved by a decomposition method.

Concretely, MD5.1 has a single market operator while others involve multiple market operators (one for each carrier market, and for MD5.3, even an additional one to handle conversion orders). However, the coordinated operations of the different market operators in MD5.2 and MD5.3 converge to the outcome of MD5.1. This is why, as an implementation for market scheme MS5, only MD5.1 is considered in the market simulator.

Table 9 below summarizes the corresponding high level simplified business use cases that will be considered for the assessment of innovative multi-carrier market designs for the day-ahead energy markets.

Table 9 – High level simplified business use cases for the assessment of innovative multi-carrier market designs

Case study	Business use cases	
Name, Bidding zone	**Provision of the following service**	**with innovative market designs**
ACS, Bidding zone of Italy North	Day-ahead energy markets (**DA**)	MD1.1 - Decoupled multi-carrier market design with decentralised clearing.
		MD5.1 - Integrated multi-carrier market design with centralised clearing.

4 Current interactions between the multi-energy systems and the other stakeholders

This chapter is devoted to the description of the interactions inside the multi-energy systems and between the multi-energy systems and the other stakeholders in the current situation for the 7 case studies of the MAGNITUDE project. These interactions are described in terms of the roles involved and carried out by the different stakeholders (internal and/or external to the MES).

More specifically, a detailed analysis has then been conducted for each of the case studies. The roles currently involved have been identified and characterized for each of the energy sectors (electricity, gas, heat and cooling), as well as the main current interactions between them.

This analysis consisted of the following steps:

- Identification of the main stakeholders involved in the 4 considered energy sectors.
- Characterization of the roles they carry out. At this stage, a distinction is made between the so-called "internal" and "external" roles:
    - Internal roles are understood as roles which are existing within the multi-energy system and are general taken over by the same stakeholder that carries out the role of multi-energy system operator.
    - External roles refer both to roles external to the multi-energy system at a local, regional, national or even international level and roles of the MES who are in interaction with such external roles. So, on the one hand, external roles may be for instance the TSO/DSO, the heat consumers, the market operator, the supplier, etc., and on the other hand the MES operator role, the MES electricity producer (or consumer) role that injects (or consumes) electricity in (from) the grid, etc.

  NB. The meaning of this distinction becomes clearer from the tables of Chapter 9.
- Description of the main interactions between the roles in the forms of sequence diagrams, namely representing for each energy sector the sequence of the interactions between the roles involved, which are mainly relevant for the MAGNITUDE project goals. However the interactions between the purely internal roles, as well as the internal roles themselves which do not have any interaction with "external" roles, are not represented in the sequence diagrams (except in some very specific situations where it appeared important for the description of the whole process).

The results of this detailed analysis are given in the appendices of Chapter 9.

This Chapter is structured as follows. The concept of roles and role models is first introduced in Section 4.1 and the main roles involved in the electricity, gas, heat and cooling systems relevant for the MAGNITUDE project are described. Then Section 4.2 gives the roles currently identified in the 7 case studies for the 4 energy sectors. Finally Section 4.3 provides the main interactions between the identified roles in the current situation in the form of generic sequence diagrams.

4.1 Description of the roles in the electricity, gas and heat/cooling systems

Role models were first introduced and developed in the electricity system in order to facilitate the communication between the market participants from the different European countries, through the definition of common and unique names for the main roles and related objects involved in the European electricity market information exchange [15]. Since then, a role model for the gas system has also been proposed in [16], [17]. In addition to the roles as such, the role models also include the description of the main relationships and interactions between these roles. The objective of the role models is thus to allow all the stakeholders to have a common language and a better understanding of the organisation and structure of the energy systems.

Role models will be used in MAGNITUDE to describe the project technical and commercial functional architectures. For this purpose, the methodology proposed in [18] will be applied. This methodology was developed to analyse and characterize existing and potential future regulation and market designs, taking into account the specificities that can be met in different countries. The objective was to provide an integrated and coherent vision of the different roles in the energy systems and of their interactions, encompassing both the roles and interactions implied by the markets and those needed to ensure the secure and efficient operation of the networks.

The methodology proposed in [18] was first applied to some markets and service procurement mechanisms of the electricity systems in France, the UK and Germany in [19] and [20]. It was then used in [21] to characterize for the first time roles of the heat sector for three case studies in Germany, the UK and the USA.

In the MAGNITUDE project, the approach has been further developed and consolidated, and fully extended to the gas, heating and cooling sectors, in order to provide a comprehensive and coherent description of roles models for the three energy sectors of electricity, heating/cooling and gas.

The first step is to identify the main essential functions that have to be carried out in each of the three systems independently of their specific implementation in the different countries. These functions are listed in Table 10 and are mainly of two types:

- essential functions specific to the considered energy carrier,
- non-specific essential functions, even if they involve some specificities of implementation for the different energy carriers.

Table 10 clearly shows that the main essential functions in all three sectors are very similar, when taking into account appropriate adaptations. These adaptations result from the rather different characteristics of the electricity, gas and heat/cooling networks for instance in terms of time constants, inherent resilience and dynamic behaviours, and therefore from the associated operation needs and requirements which also differ considerably.

Table 10 – Main essential functions of the three energy systems

	Energy system		
	Electricity	**Heating/cooling**	**Gas**
Functions specific to energy carrier	Consume electricity Generate electricity Deliver electricity (transmission, distribution) • Control the voltage • Manage the congestions Balance generation and consumption of electricity • Control the frequency Restore the electricity network	Consume heat/cooling Generate heat/cooling Deliver heat/cooling • Control the temperature • Control the flow Balance generation & consumption of heat/cooling • Control the pressure/flow rate Restore the heat/cooling network	Consume gas "Generate/inject" gas Deliver gas (transmission, distribution) • Control the pressure • Control the flow Balance generation & consumption of gas • Control the pressure/flow rate Restore the gas network
Non-specific functions	• Measure and check • Coordinate and enable the different processes implied by the carrying out of the energy carrier specific functions		

Nevertheless, the similarities lead to the identification of very similar roles in the three sectors. Starting from the essential functions, the following main categories of roles can be found:

- Asset-related roles, i.e. roles associated with physical assets, such as consumption, generation, storage assets and even network assets,
- Operators of systems and markets,
- Market and service provision intermediaries,
- Operators of data and ICT infrastructures,
- Controllers and verifiers of the different processes and interactions.

Going into further detail and limiting to the roles needed for the description of the case studies and of the MAGNITUDE functional technical and commercial architectures, the main roles involved in the three energy sectors are identified and listed in Table 11. In this table, the names of the roles are generally given without reference to the energy sector. When they will be used later in the descriptions and whenever needed, the considered energy carrier will be identified by its first letter, namely E for electricity, H for Heat, C for cooling, G for gas. As an example, the term "E-consumer" will mean consumer of electricity.

Table 11 – Main roles involved in the electricity, heat/cooling and gas systems

Role	Description/comments
Consumer	Consumes electricity, heat/cooling or gas
Producer	Produces or injects electricity, heat/cooling or gas respectively in the

Role	Description/comments
	electricity, heat/cooling or gas network
Storage provider	Operates a storage system of electricity, heat/cooling or gas
Multi-Energy System (MES) operator	Operates a Multi-Energy System, i.e. the technologies and physical assets involved in the considered Multi-Energy System. This is a new dedicated cross-sector role between two or three of the considered energy sectors. The assets operated may be consumption, generation, or storage assets, or, depending on the situation, even network assets in the case of the heat/cooling networks. This role had to be introduced to take into account the cross sector operation and optimisation carried out in the MESs.
Transmission system operator (TSO) [22], [23], [24]	Operates, ensures the maintenance and, when necessary, develops the electrical transmission network or the gas transmission network in a given area as well as, where applicable, its interconnections with other systems. Ensures the long-term ability of the system to meet reasonable demands for the transmission of electricity or gas. Secures and manages in a continuous way the physical generation-consumption balance on a geographical perimeter and procures balancing services. This definition initially made for the electricity transmission system is extended here to the gas system. It can also be extended to the heat/cooling networks. *Comments*: • In the heat sector, the heat networks are mainly distribution networks. However, some transmission networks can also be found in some areas, like in the Copenhagen area in Denmark. Such heat transmission networks interconnect/supply several local distribution networks and are characterised by larger pipes. • This role may be further split in two roles, namely the roles of system operator and of the network provider [25], as for the electricity transmission systems in some regions in the USA and in the UK [26], [27]. However, in most European countries, both roles are carried out by the same player, so they will not be distinguished here.
Distribution system/network operator (DSO or DNO) [22], [23], [24]	Operates, ensures the maintenance and, when necessary, develops the electrical distribution network or the gas distribution network or the heat/cooling (distribution) network in a given area as well as, where applicable, its interconnections with other systems. Ensures the long-term ability of the system to meet reasonable demands for the distribution of electricity or gas or heat/cooling. This definition initially made for the electricity distribution system is extended here to the gas and heat/cooling systems. In the case of the heat/cooling system, when there is no transmission system (see above), this role also secures and manages in a continuous way the physical generation-consumption balance on its geographical perimeter. *Comments*: • As mentioned above, in the heat sector, the networks are mainly

Role	Description/comments
	distribution networks, except in some areas.
Market operator [23], [15]	Provides a service whereby the offers to sell electricity (respectively gas) are matched with bids to buy electricity (respectively gas), or in other words, organizes the trading between buyers and sellers (auctions, tendering process, continuous trading, etc.). This is usually carried out through an energy/power exchange or a market platform. In the sequel, this role may be further specified with the indication of the type of markets considered, for instance for the electricity system: • Balancing market operator, when the markets for balancing and frequency regulation products are considered, • Energy market operator, when the day-ahead and/or intraday energy markets are considered. *Comments*: • Presently, there is no market as such in the heat sector, even if some mechanisms implying a day ahead planning and intra-day adjustments can sometimes be found, like the integrated heat market mechanism implemented in the Greater Copenhagen area. The operator of such mechanisms can in some way be assimilated to a market operator.
Clearing and Settlement Responsible [28]	Ensures the clearing and the settlement of the concluded market transactions. It acts as a central counterparty between the sellers and the buyers and assumes the associated counterparty risk. It ensures the payment flows between the relevant market participants. *Comments*: • Depending on the market type, this role may be carried out by the same stakeholder who carries out the market operator role. • In the description of the case studies, this role will not necessarily be distinguished from the market operator role.
Broker	Facilitates transactions between sellers and buyers of electricity, gas or heat/cooling products.
Imbalance Settlement Agent [15], [24]	Is responsible for the financial settlement of the difference between the contracted quantities and the realised quantities of energy products for the Balance Responsible Parties in a defined area, or in other words is responsible for the mechanism for charging or paying Balance Responsible Parties for their imbalances. *Comment*: • This role is often carried out by the TSO.
Balance responsible party (BRP)	Ensures, for a given portfolio or group of players, the financial liability for imbalance between realized energy injection and consumption. Carries out the operational planning of imbalances within its perimeter (often called the balancing group).
Supplier (or retailer)	Supplies electricity, heat/cooling or gas to the consumers. On the electricity and gas sector, this may entail the purchase of electricity or gas on the wholesale markets and the subsequent resale to consumers.

Role	Description/comments
	Comments: • Since there is no unbundling in the heat sector, both the supplier role and the heat network operator role are often carried out by the same player, who can also be a heat producer.
Aggregator	In the specific context of the MAGNITUDE project, the aggregator may aggregate consumption, generation and/or storage resources, or the flexibility of such resources for the provision of services to the electricity markets. *Comments*: • The types of resources aggregated depend on the case study. They also depend on the regulation in the considered countries. For instance, in some countries, aggregation of demand is still not allowed or demand cannot be aggregated with generation resources [3].
Trader	Buys and sells products on wholesale markets.
Shipper	This a special role in the gas sector. The shipper buys gas, arranges for the transportation of gas through the gas networks, and sells is to the suppliers. For this purpose, the gas shippers enter into a contract with the gas operators to convey gas through the gas pipeline network.
Metering-related roles	Several roles may be identified corresponding to different activities such as: • installing and maintaining the meters, • providing, operating and maintaining the metering infrastructure, • operating the metering devices, collecting and processing the corresponding data, providing the metered data to the authorized users. However, they will not be distinguished in this report.
ICT-related roles (ICT=information and communication technology)	Provides and operates the ICT infrastructure (other than metering), processes the associated data. Again, several roles can be identified but they will not be distinguished in this report.
Regulator	Regulates the electricity, heat, cooling or gas sector

Some other specific roles that are not listed in the above table can also be found in some case studies. They are described in the next section.

4.2 Roles currently identified in 7 real-life case studies

Using the roles described in the previous section, the following tables give the roles currently identified in the seven case studies respectively for the electricity sector (Table 12), the gas sector (Table 13), the heat sector (Table 14) and the cooling sector (Table 15). Abbreviations are used for the case studies in the column headers, namely:

- **ME** for Mälarenergi,
- **APM** for the Austrian paper mill,
- **HO** for HOFOR,

- **ACS** for A2A Calore e Servizi,
- **NPT** for Neath Port Talbot,
- **EM** for EMUASA,
- **PS** for Paris Saclay.

As already shown in Table 4,

- the electricity sector is present in all the seven case studies,
- the gas sector is present in all case studies, except the Mälarenergi and HOFOR case studies,
- the heat sector is involved in all the case studies but for NPT and EMUASA, it is associated with purely internal processes of the MES technologies (that's why it does appear in Table 4),
- the cooling sector is involved only in Mälarenergi and Paris Saclay case studies.

Table 12 – Roles identified for the electricity sector in the case studies

Role	ME	APM	HO	ACS	NPT	EM	PS
Consumer	X	X	X	X	X	X	X
Producer	X	X		X	X	X	
Storage provider							
MES operator	X	X	X	X	X	X	X
TSO	X	X	X	X	X	X	X
DSO	X	X	X	X	X	X	X
Market operator: • Energy market operator • Balancing market operator	X	X X	X	X	X X	X	X
Clearing and Settlement Responsible							
Broker							
Imbalance Settlement Agent	X	X	X	X	X	X	X
BRP	X	X	X	X	X	X	X
Supplier	X	X	X	X	X	X	X
Aggregator		X		X	X		
Trader	X						
Metering-related roles	X	X	X	X	X	X	X
ICT-related roles: • Data hub operator			X				
Regulator	X	X	X	X	X	X	X

From the above table, we can observe that

- All case studies involve the electricity consumer role, 5 of them also have the electricity producer role and there is no storage system on the electricity "side". These roles are of course directly related to the type of processes involved in the case study and the associated technologies. A more detailed analysis indicating whether these roles are internal and/or external and the stakeholders who carry them out is given in Chapter 9.

- The MES operator role is of course present in all the case studies.
- The following roles are also found in all the case studies: DSO, TSO, Supplier, BRP, Imbalance Settlement Agent, metering-related roles, energy market operator and the regulator.
- The role of balancing market operator appears in only two case studies, namely the Austrian paper mill and NPT, since these are the only case studies where balancing and frequency regulation services are currently provided (see Table 7).
- In the same way the aggregator role currently appears in 3 case studies, namely the Austrian paper mill for the provision of aFRR and mFRR, ACS for the participation in the day-ahead and intraday energy markets and NPT for the provision of balancing services.
- The trader role appears only for Malärenergy but it can also be assimilated to an aggregator role since it collects and trades all the electricity needs of Malärenergy, which are larger than the needs of the MES (since for instance Malärenergy is also an electricity supplier). In the same way, the aggregator role for the ACS case study is also in some way a trader role. In both cases (Malärenergi and ACS), these trader and aggregator roles can probably be merged with the BRP role, too.
- As already mentioned in Table 11, the role of Clearing and Settlement Responsible has not been distinguished from the market operator role that’s why it does not appear in the case studies.
- The broker does not appear either, but this does not necessarily mean that transactions are not carried out through brokers. The analysis indeed focussed mainly on “organised” market mechanisms.
- Finally, the role of Data hub operator appears only for HOFOR due to the special role carried out by Energinet, who operates the Danish Data Hub. The Data Hub automates the execution of the market processes and the business transactions in the Danish retail electricity market. For this purpose, it receives all the meter readings and all other relevant data, and provide access to those authorised market participants who need them [29], [30], [31].

It should also be noted that for the Mälarenergi case study, the additional specific role of “Waste supplier” has also been considered in the appendices of Chapter 9 to take into account the particular type of fuel used by the CHP plant, namely waste. In the same way, in the Paris Saclay case study, the specific role of MES owner has been introduced in Chapter 9 to take into account that the owner and the operator of the MES are different stakeholders, linked by a contract.

Table 13 - Roles identified for the gas sector in the case studies

Role	APM	ACS	NPT	EM	PS
Consumer	X	X	X	X	X
Producer			X	X	
Storage provider				X	
MES operator	X	X	X	X	X
TSO		X	X		
DSO	X	X	X		X
Market operator		X	X		

Role	APM	ACS	NPT	EM	PS
Clearing and Settlement Responsible					
Broker					
Imbalance Settlement Agent			X		
BRP			X		
Supplier	X	X	X		X
Aggregator					
Trader					
Shipper			X		
Metering-related roles	X	X	X		X
Regulator	X	X	X		X

From the above table for the gas sector, we can observe that:

- All 5 case studies involve the gas consumer role, 2 of them also have the gas producer role and there is a gas storage only in the EMUASA case study. These roles are of course directly related to the type of processes involved in the case study and the associated technologies. Like for the electricity sector, a more detailed analysis indicating whether these roles are internal and/or external and the stakeholders who carry them out is given in Chapter 9.
- The MES operator role is of course present in all the case studies.
- In the EMUASA case study, the gas is produced, stored and consumed in the plant itself, and therefore the gas sector is associated with purely internal processes of the MES technologies. So, the roles identified in the case study are the consumer, producer, storage provider and MES operator roles. All the other roles are not involved in this case study.

The following comments apply only to the other 4 case studies (APM, ACS, NPT and PS):

- The following roles are found in all the 4 case studies: DSO, Supplier, metering-related roles, and regulator.
- This does not mean that the other roles are not present in the gas sector in the considered countries. Indeed, the gas system has a lot of similarities with the electricity system in terms of the roles involved. However, their representation in the description of the case studies was not needed since the focus of the MAGNITUDE project is on the provision of flexibility to the electricity system.
- The only exception is the NPT case study where a more detailed description of the gas system is required in order to be able to properly investigate the interactions between the gas system and the electricity system, since this is an important objective of this case study. So, in the NPT case study, all the other roles are present, except the roles of Clearing and Settlement Responsible, Broker, Aggregator and Trader, which are further discussed below.
- Like previously for electricity sector, the role of Clearing and Settlement Responsible has not been distinguished from the market operator role that's why it does not appear in the case studies. The broker does not appear either, but this does not necessarily mean that transactions are not carried out through brokers. The analysis indeed focussed mainly on "organised" market mechanisms.
- Aggregator and trader roles do not appear either in the considered scope of the case studies.

- It should be noted that the roles of TSO and Market operator have also been identified in ACS case study due to the specificities of the A2A group and the specific quality activity of SNAM (see Section 9.4.3).

Finally, like for the electricity sector, in the appendices of Chapter 9, the specific role of MES owner is introduced for the Paris Saclay case study to take into account that the owner and the operator of the MES are different stakeholders.

Table 14 - Roles identified for the heat sector in the case studies

Role	ME	APM	HO	ACS	NPT	EM	PS
Consumer	X	X	X	X	X	X	X
Producer	X	X	X	X	X	X	X
Storage provider	X	X	X	X	X		
MES operator	X	X	X	X	X	X	X
TSO			X				
DSO	X	X	X	X			X
Market operator			X				
Clearing and Settlement Responsible							
Broker							
Imbalance Settlement Agent							
BRP							
Supplier	X	X	X	X			X
Aggregator							
Trader							
Metering-related roles	X	X	X	X			X
Regulator	X		X	X			X

From the above table for the heat sector, we can observe that:

- All case studies involve the roles of heat consumer and heat producer and 5 of them also have a heat storage. Like for the previous sectors, these roles are directly related to the type of processes involved in the case study and the associated technologies. A more detailed analysis indicating whether the roles are internal and/or external and the stakeholders who carry them out is given in Chapter 9.
- The MES operator role is of course present in all the case studies.
- As previously mentioned, for NPT and EMUASA, the heat sector is associated with purely internal processes of the MES technologies, namely heat or steam is produced and consumed on the plant itself. So only the roles of heat consumer, producer, MES operator (and heat storage provider for NPT) are present.

- The other 5 case studies involve a district heating system, directly in the scope of the case study for Mälärenergi, ACS, HOFOR and Paris Saclay or indirectly for the Austrian paper mill, which is a heat producer and injects heat in the district heating of the city nearby.
- For these 5 case studies, the following roles are therefore also found: heat DSO, supplier, metering-related roles, and regulator (except for the Austrian paper mill for which the regulator role is out of the scope of the case study since the focus is not on the district heating activities).
- Since there is no market as such in the heat sector, the following roles are not found: market operator (except for HOFOR – see below), Clearing and Settlement Responsible, Broker, Aggregator and trader.
- In the same way, even if there is a need for balancing the generation and consumption of heat. The associated activities are carried out by the system operator (DSO/TSO) and there are no roles of BRP and Imbalance Settlement Agent, unlike in the electricity and gas sectors.
- For HOFOR, even if it is out of the scope of the case study as such, it was deemed interesting to represent the integrated heat market mechanism in place in the Greater Copenhagen area, which includes a day ahead planning and intra-day adjustments. The operator of this mechanism can be assimilated in some way to a market operator. This detailed representation also needed to include the heat TSO role, which is not present in the other case studies.

Finally, it should also be noted that specific additional roles were introduced in two case studies in the appendices of Chapter 9, namely:

- The role of “Ground owner” for the ACS case study to take into account the relationship between ACS (MES operator) and the Municipality who is the ground owner and receives a yearly rent from the heat network operator (ACS) for the usage of the ground.
- The role of “MES owner” for the Paris Saclay case study, as already mentioned, to take into account the relationship between IDEX, who is the MES operator, and EPAPS, who owns the whole district heating and cooling systems: heating and cooling networks, as well as heat and cooling generating plants (geothermal heat plant, gas boiler, thermo-refrigerating pumps located in sub-stations).

Table 15 - Roles identified for the cooling sector in the case studies

Role	ME	PS
Consumer	X	X
Producer	X	X
Storage provider	X	
MES operator	X	X
TSO		
DSO	X	X
Market operator		
Clearing and Settlement Responsible		
Broker		
Imbalance Settlement Agent		

Role	ME	PS
BRP		
Supplier	X	X
Aggregator		
Trader		
Metering-related roles	X	X
Regulator	X	X

The cooling sector is involved only in the Maläreneri and Paris Saclay case studies. Most of comments made for the heat sector can be made here too, namely:

- Both case studies involve the roles of cooling consumer and cooling producer, and Malärenergi also has a heat storage.
- The MES operator role is of course present.
- Since both case studies include a district cooling system, the following roles are also found: cooling DSO, supplier, metering-related roles, and regulator.
- There is no cooling transmission network and therefore no TSO role involved.
- Since there is no market as such in the cooling sector, the following roles are not found: market operator, Clearing and Settlement Responsible, Broker, Aggregator and trader.
- In the same way, even if there is a need for balancing the generation and consumption of cooling. The associated activities are carried out by the system operator (DSO) and there are no roles of BRP and Imbalance Settlement Agent, unlike in the electricity and gas sectors.

Finally, like previously, the additional specific role of MES owner is introduced in Chapter 9 for the Paris Saclay case study to take into account the relationship between IDEX (MES operator) and EPAPS (MES owner).

4.3 Main current interactions between the identified roles – Generic sequence diagrams

Based on the detailed analysis reported in the appendices of Chapter 9, a comparison of the current role models (roles and main interactions) of the case studies has then been conducted in order to build generic sequence diagrams. This will allow to address the issue of the replicability of the MAGNITUDE case studies and to anticipate potential evolutions of the roles.

The sequence diagrams are structured according to the following three main phases of the service provision process [3]:

4. **Procurement and negotiation**: corresponding to the planning and product procurement phase, including the players' optimisation process, identification of needs, formulation and submission of requests and/or bids, the market clearing or OTC negotiation, contract conclusion, etc. This phase may also require a prequalification of players to be able to participate in certain markets or to propose services.

5. **Technical delivery**: corresponding to the product delivery phase, including activation mechanisms depending on the service, the physical delivery of the products, possibly real-time monitoring and real-time measurement/metering, etc.
6. **Settlement**: corresponding to the settlement or post-delivery phase, including exchanges of metered data, financial settlement, billing and payments, cost recovery, possible penalties, etc.

These three phases are shown in Figure 5.

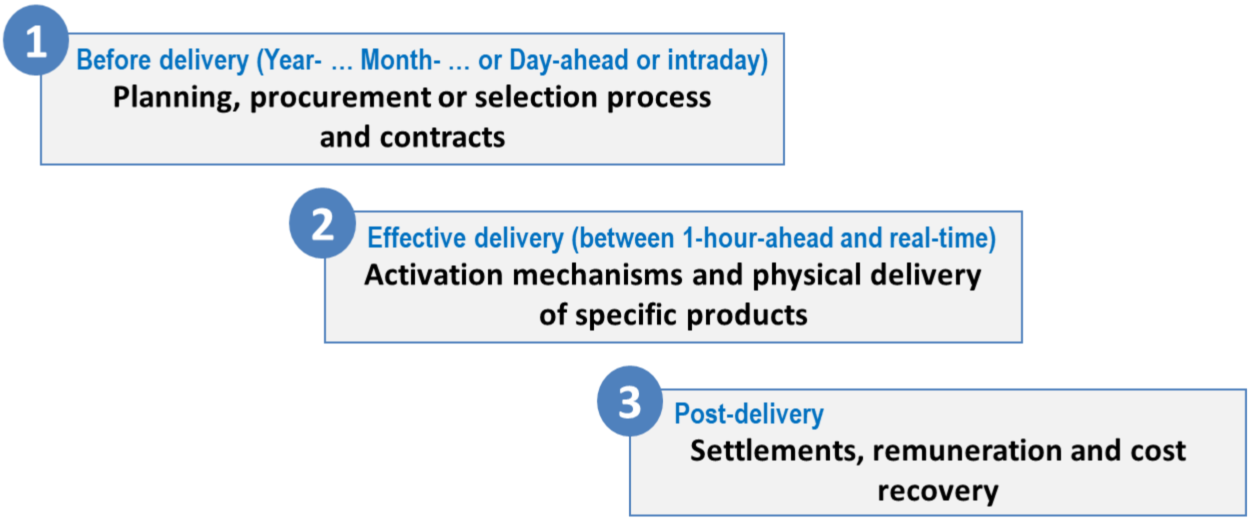


Figure 5 – The three main phases of the service provision process from [3]

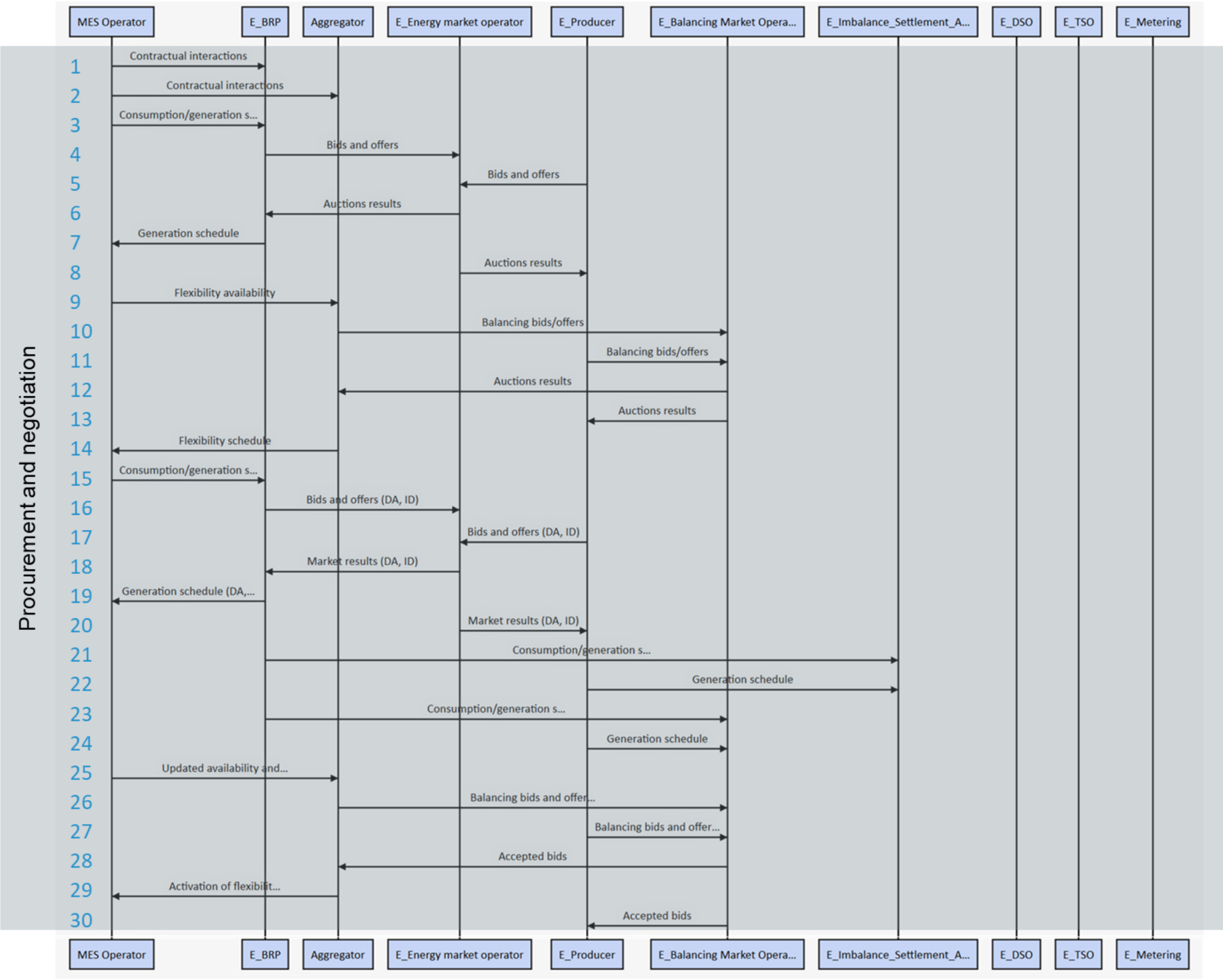
The figures below provide the generic sequence diagrams obtained respectively for the electricity, gas, heating and cooling sectors.

Figure 6 shows the interactions between the identified roles and provides the generic sequence diagram for the electricity system. In this figure, for simplicity and in order to highlight the main relevant interactions,

- the interactions with the Regulator are not represented,
- for the case studies where they have been identified, the roles of supplier and trader are merged with the BRP role,
- the aggregator role appears only for the trading of flexibility,
- the roles of consumer and producer of the MES are merged with the MES operator role, except for the case of NPT, where the CCGT only produces electricity and is connected to the transmission system,
- to properly take the NPT case study into account, the role of producer is used in the figure and the roles of MES operator and BRP of the Baglan Bay CCGT are merged with the producer role.
- Even if in most European countries the roles of TSO and Balancing Market Operator are carried out by the same stakeholder, they are kept separated here since this is not the case in the UK and might change in the future for some balancing services in other countries,
- the metering-related roles are kept separated from the DSO role even if in most European countries (but not necessarily in the UK) they are carried out by the DSO for the users connected to the distribution system.

It should be noted that in some countries even for some balancing service procurement mechanisms, the market participants must now be a BRP or be part of a BRP's portfolio. However, this is not represented here since there is still a large diversity between countries on this topic.

Additionally, the aggregator role can be carried out, and is very often carried out, by stakeholders who are the suppliers and/or traders, and not necessarily by separate players. In particular, this situation is found in the case studies, where the aggregator role is indeed ensured by the supplier and/or the trader.


MES Operator
E_BRP
Aggregator
E_Energy market operator
E_Producer
E_Balancing Market Opera...
E_Imbalance_Settlement_A...
E_DSO
E_TSO
E_Metering
Procurement and negotiation
1 Contractual interactions
2 Contractual interactions
3 Consumption/generation s...
4 Bids and offers
5 Bids and offers
6 Auctions results
7 Generation schedule
8 Auctions results
9 Flexibility availability
10 Balancing bids/offers
11 Balancing bids/offers
12 Auctions results
13 Auctions results
14 Flexibility schedule
15 Consumption/generation s...
16 Bids and offers (DA, ID)
17 Bids and offers (DA, ID)
18 Market results (DA, ID)
19 Generation schedule (DA,...
20 Market results (DA, ID)
21 Consumption/generation s...
22 Generation schedule
23 Consumption/generation s...
24 Generation schedule
25 Updated availability and...
26 Balancing bids and offer...
27 Balancing bids and offer...
28 Accepted bids
29 Activation of flexibilit...
30 Accepted bids

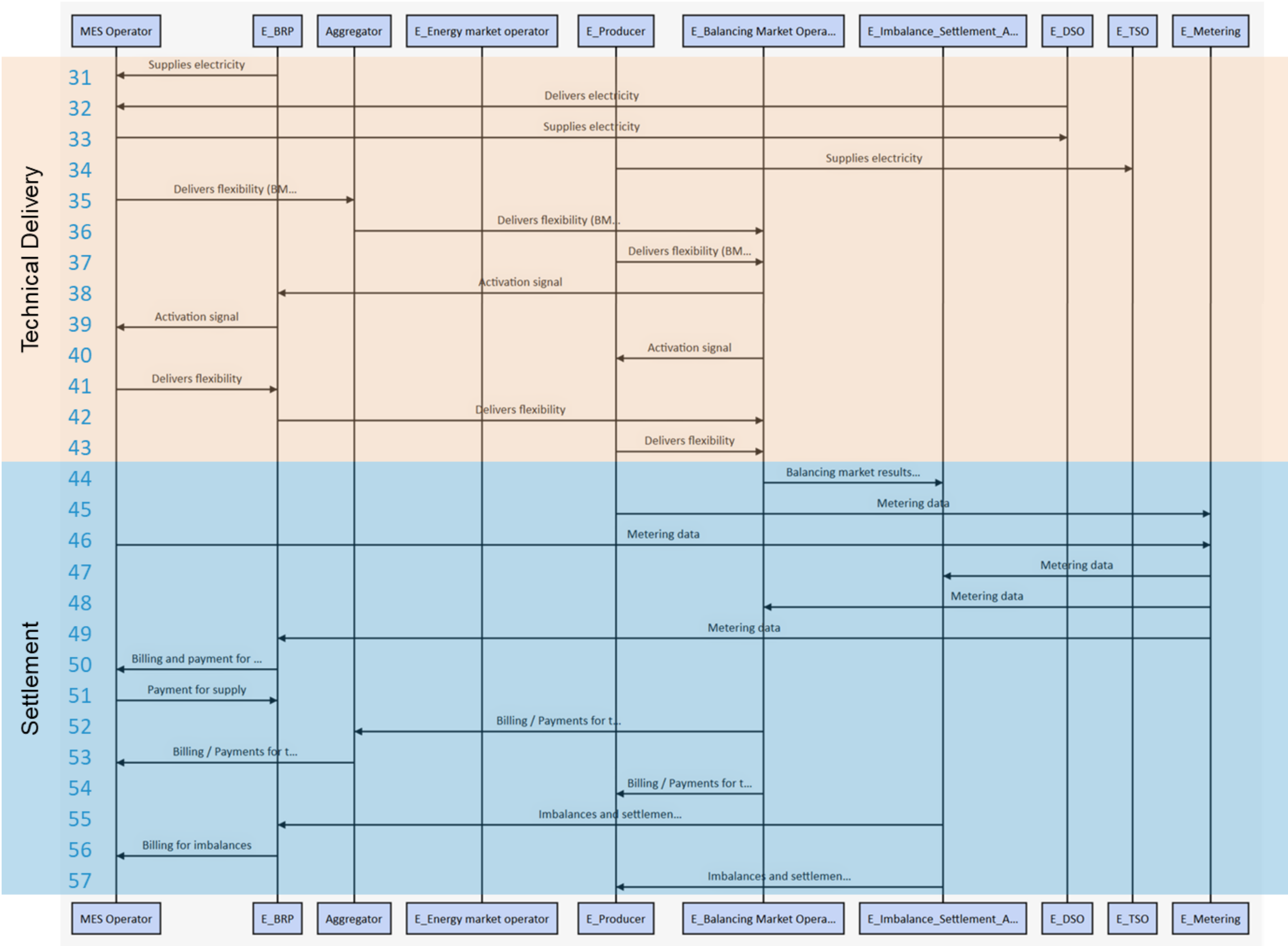


Figure 6 – Generic sequence diagram for the electricity system

The interactions shown in the figure are further detailed below for the three main phases of the service provision process.

Procurement and negotiation phase

1. The MES Operator establishes a contract with the BRP for the participation in the energy markets.
2. The MES Operator establishes a contract with the Aggregator for the participation in the balancing and frequency regulation markets.
3. For longer term trading than day ahead, the MES Operator communicates its consumption and/or generation schedule to the BRP who is also the supplier of electricity for the MES consumption and/or the trader for the MES electricity generation. Depending on the type of MES, several situations may arise: the MES may consume electricity, produce electricity, produce and self-consume a part or all the electricity locally produced. As a result, the MES may be
    a) a net consumer with electricity provided by a supplier
    b) a net producer with the generated electricity traded by a trader or an aggregator merged here with the BRP,
    c) both a producer and a consumer at the same time if self-consumption is not taken into account, which might depend on the regulation in the country and/or on the contracts with the supplier and the trader.
4. The BRP engages in long term trading and therefore submits bids/offers to the Energy Market Operator.
5. The Producer engages in long term trading and submits bids/offers to the Energy Market Operator.
6. The Energy Market Operator communicates the auction results to the BRP.
7. The BRP communicates the results in terms of generation schedule traded on the market to the MES Operator (for cases b and c above).
8. The Energy Market Operator communicates the auction results to the Producer.
9. The MES Operator sends flexibility availability information to the Aggregator.
10. The Aggregator offers the flexibility of its pool of resources in the frequency regulation and reserve markets and submits bids/offers to the Balancing Market operator.
11. The Producer markets its own flexibility in the frequency regulation and reserve markets and submits bids/offers to the Balancing Market Operator.
12. The Balancing Market Operator informs the Aggregator about the auction results (contracted flexibility).
13. The Balancing Market Operator informs the Producer about the auction results (contracted flexibility).
14. The Aggregator informs the MES Operator about the auction results and the flexibility to be reserved and associated prices.
15. If it is part of the contract between them, for day ahead and intraday trades, the MES Operator communicates its planned consumption and/or generation schedule to the BRP.
16. The BRP engages in trade in the day-ahead and intraday markets and submits bids/offers to the Energy Market Operator. NB: of course, intraday trades occur after day ahead trades (see the remarks below for more details).
17. The Producer engages in trade in the day-ahead and intraday markets and submits bids/offers to the Energy Market Operator.
18. The Energy Market Operator communicates the results of the markets clearing to the BRP.

19. The BRP communicates the results in terms of generation schedule traded on the markets to the MES Operator (for cases b and c described in step 1).
20. The Energy Market Operator communicates the results of the markets clearing to the Producer.
21. After the closure of the day-ahead and intraday markets, the BRP sends the final consumption and/or generation schedule to the Imbalance Settlement Agent.
22. After the closure of the day-ahead and intraday markets, the Producer sends the final generation schedule to the Imbalance Settlement Agent.
23. After the closure of the day-ahead and intraday markets, the BRP sends the physical notifications of the final consumption and/or generation schedule to the Balancing Market Operator.
24. After the closure of the day-ahead and intraday markets, the Producer sends the physical notifications of the final generation schedule to the Balancing Market Operator.
25. In some countries a balancing mechanism may also exist in intraday after the intraday trades. For the participation in such a mechanism, the MES Operator communicates its updated available flexibility and associated costs to the Aggregator.
26. In the framework of this balancing mechanism, the Aggregator sends bids/offers to the Balancing Market Operator, namely how much it is willing to pay or be paid to increase or decrease the consumption or generation of its pool of resources by given amounts.
27. In the framework of this balancing mechanism, the Producer sends bids/offers to the Balancing Market Operator, namely how much it is willing to pay or be paid to decrease or increase its generation by a given amount.
28. The Balancing Market Operator sends the results of the accepted bids and offers to the Aggregator.
29. The Aggregator sends the MES Operator the information for the activation of its flexibilities in the framework of the balancing mechanism.
30. The Balancing Market Operator sends the Producer the results of the accepted bids and offers in the framework of the balancing mechanism.

Remarks:

- It should be highlighted that a large part of the energy trading is still carried out through OTC trading. Representing this situation in the figure can be done by replacing the interactions between the BRP, the Producer and the Energy Market Operator steps 2, 3, 4, 6, 14, 15, 16 and 18) by OTC trading.
- The objective of the figure is to show the main principles of the whole process and to be as generic as possible. Actually, the whole process is much more complex and depends on the specificities of the market mechanisms implemented in the considered countries. Several subsets of steps could be repeated and/or moved along the chronological line. For instance (and not limited to):
    - Steps 7 to 12 could be repeated for the different frequency reserve markets (FCR, aFRR, mFRR).
    - Steps 13 to 18 should be split between the day-ahead energy trading and the intraday energy trading, and then repeated several times for the intraday depending on the number of auctions implemented in some countries or to represent the continuous intraday trading implemented in other countries [3].
    - In the same way, steps 23 to 28, related to the intraday balancing mechanism that can be found in some countries, could also be repeated several time during the day, in accordance with the country specific implementation rules.

    - In some countries the gate closure for some frequency reserve market is after the day-ahead energy market gate closure meaning that the corresponding steps should be moved accordingly.
- As shown in [3], there is a large diversity of situations, market mechanisms and rules that can be found in the considered countries, despite some harmonisation initiatives that have been carried out and/or are on-going. Additionally, this is a very fast evolving field: namely some rules or mechanisms can change from one year to the other, or sometimes even faster, which means that any fully detailed sequence diagram can soon become obsolete.

Technical delivery

31. From the transactional perspective, the BRP "supplies" electricity to the MES Operator when it is a consumer (see step 1).
32. But the physical delivery of electricity to the MES Operator is carried out by the distribution network or the DSO.
33. If the MES is a producer, as in the cases b and c of step, the MES Operator generates and supplies electricity to the distribution network and therefore the DSO.
34. The Producer generates and supplies electricity to the transmission system and therefore the TSO.
35. The MES Operator delivers to the Aggregator the flexibility requested in the framework of the balancing mechanism (in place in some countries).
36. The Aggregator in turn delivers the flexibility of its pool to the Balancing Market operator, in accordance with the accepted bids of the balancing mechanism.
37. The Producer delivers flexibility to the Balancing Market operator in accordance with the accepted bids of the balancing mechanism.
38. If it is needed for the compensation of imbalances, the Balancing Market operator sends an activation signal to the Aggregator to activate the delivery of services and reserves procured in advance on the frequency regulation and reserve markets.
39. The Aggregator dispatches the resources in its pool and accordingly sends an activation signal to the MES Operator.
40. At the same time as step 36, if needed for the compensation of imbalances, the Balancing Market operator sends an activation signal to the Producer to activate the delivery of services and reserves procured in advance on the frequency regulation and reserve markets.
41. The MES Operator delivers the requested flexibility to the Aggregator.
42. The Aggregator in turn delivers the requested flexibility of its pool to the Balancing Market operator.
43. The Producer delivers the requested flexibility to the Balancing Market operator.

Remark: the steps of the "Technical delivery" phase are of course repeated as many times as needed during the day and are "interlaced" with steps of the "Procurement and negotiation" phase, namely during the day there are a succession of "Procurement" phases for the products traded in intraday, followed by "Technical delivery" phases. However, to keep the figure as simple and as readable as possible, this has not been represented here.

Settlement

44. The Balancing Market operator sends the results of the balancing mechanism (accepted bids and offers) and of the balancing adjustment actions taken outside the balancing mechanism to the Imbalance Settlement Agent.
45. The Producer makes the metering data available to its metering company, who collects them.
46. The MES Operator makes the metering data available to its metering company, who collects them.
47. The metering companies send the metering data to the Imbalance Settlement Agent for it to perform imbalance settlement.
48. The metering companies send metering data to the Balancing Market Operator.
49. The metering companies send the BRP the metering data relevant to its portfolio.
50. The BRP (who is also the supplier/trader) sends the MES Operator the billing information for the electricity consumed and/or generated by the MES. In case of generation, the BRP remunerated the MES Operator according to the contract between them.
51. In case of consumption, the MES Operator pays the BRP for the consumed electricity according to the contract between them.
52. The Balancing Market Operator provides the billing for the payments/penalties of the flexibility provision by the Aggregator, according to the bids/offers accepted on the balancing mechanism, and to the procurement conditions, activation and provision performance of the frequency regulation services.
53. The Aggregator provides the payments for the provided flexibility services to the MES Operator.
54. The Balancing Market Operator provides the billing for the payments/penalties of the flexibility provision by the Producer, according to the bids/offers accepted on the balancing mechanism, and to the procurement conditions, activation, and provision performance of the frequency regulation services.
55. The Imbalance Settlement Agency provides the billing for the payments/penalties related to the imbalances and ensures the payment flows with the BRP.
56. If it is included in the contract between them, the BRP may settle payments or penalties related to the imbalances with the MES Operator.
57. The Imbalance Settlement Agency provides the billing for the payments/penalties related to the imbalances and ensures the payment flows with the Producer.

Remarks:

- The settlement phase involves some additional steps that are not represented in the above sequence diagram, for instance the interactions linked to the invoice and payment of the grid tariffs. There might be different situations or rules depending on the country and/or on the “size” of the consumers, for instance, they may be:
    - Either included in the Supplier’s bill. In this case, the DSO then provides the billing information for the grid tariffs so that they are included in the bill sent to the consumer. The Supplier collects the associated payments from the consumers and then, in turn, pays the DSO.
    - Or included in a DSO’s bill sent to the consumer separately. In this case, the DSO invoices directly the consumer for the grid tariff and collects the associated payment.
- There might be additional interactions related to imbalance settlement, for instance to avoid penalties for the BRP when resources of its portfolio participate to the provision of balancing and frequency regulation services. This particularly applies when the aggregator is not the supplier or the

BRP. Since the rules are still very different from one country to the other, there are not represented in this generic sequence diagram.

- Depending on the contract between them, the payment of penalties might be considered between the MES Operator and the Aggregator, in case of failure of the MES to deliver the contracted flexibility.
- The possible role of the Imbalance Settlement Agent in the payment/penalties associated with the provision of balancing and frequency regulation services is not clear in the different countries and is presently changing.
- Since the objective of Figure 6 is to give the main principles of the settlement process. The number and the order of the steps may be different depending on the country specificities and on the contracts between the stakeholders. It is not possible to represent all the situations here. Additionally, as mentioned above, this is a fast evolving field.

Figure 7 provides a detailed generic sequence diagram for the gas system. The structure of the whole gas system and the interactions between the stakeholders for the day ahead gas market and longer term trading are rather similar to the ones of the electricity system. The sequence diagram shown in the figure is derived from the description obtained for the NPT case study where such a detailed description is needed. Differences and/or specificities may be found depending on the considered countries. The objective here is to illustrate the main types of interactions between the roles.

It should be noted that a much simplified description can also be used since the focus is mainly on the provision of services to the electricity system. Such a simplified generic sequence diagram is presented later in Figure 8.

Remarks: in Figure 7, for simplicity and in order to highlight the main relevant interactions,

- the interactions with the regulator are not represented,
- the role of consumer of the MES is merged with the MES operator role,
- the role of producer appearing in the NPT case study is not represented since it is a purely internal role,
- the role of BRP is merged with the shipper role,
- the role of Imbalance Settlement Agent is merged with the TSO role, since both roles are most often carried out by the same stakeholder.

OTC trading between the market participants is not represented in this sequence diagram. OTC trades can be carried out through a broker or an informal agreement made directly between two parties. They are then accounted for in the system through the nominations.

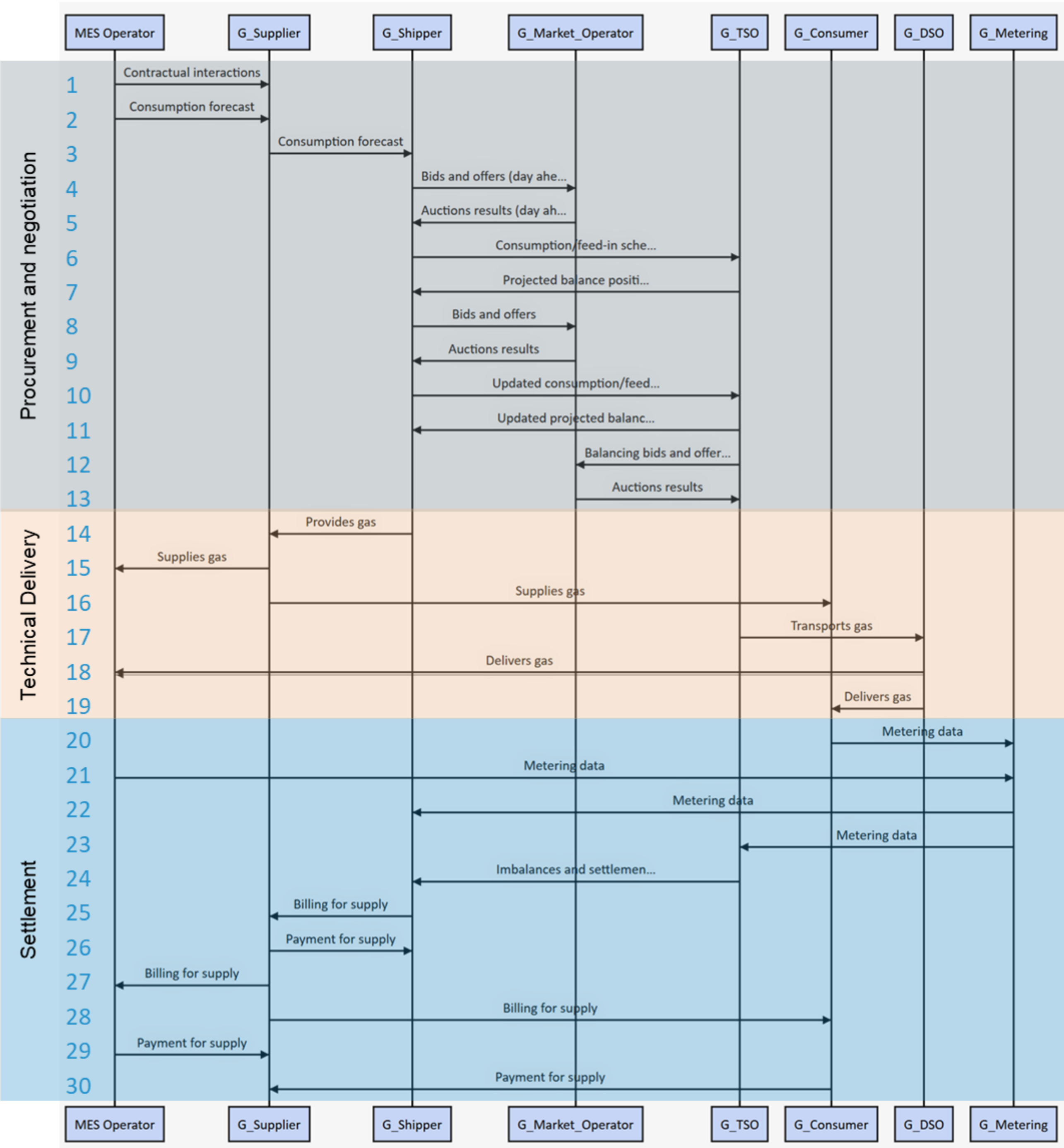


Figure 7 – Generic sequence diagram for the gas system

The interactions are further detailed below for the three main phases of the service provision process.

Procurement and negotiation

1. The MES Operator signs a contract with the gas Supplier for the procurement of gas.
2. The MES Operator communicates its expected consumption to the gas Supplier.
3. The gas Supplier, in turn, communicates the expected consumption (expected sales) to the gas Shipper.
4. Before the Gas Day, the gas Shipper trades in various kinds of markets in different time frames, and in particular in the day ahead gas market, operated by the gas Market Operator.
5. For the day ahead trade, the Market Operator communicates the market results to the gas Shipper.

6. The gas Shipper communicates its gas flow nominations and notified trades to the TSO.
7. The TSO communicates different types of information, such as the projected gas consumption, gas flow, linepack, gas system status, that allow the gas Shipper to assess its projected end-of-day balance position.
8. On the Gas Day, the gas Shipper can trade on the gas market to balance its schedule and submits bids and offers to the gas Market Operator.
9. The gas Market Operator communicates the market results to the gas Shipper.
10. The gas Shipper communicates the update of its gas flow nominations and notified trades to the TSO.
11. The TSO communicates updated information to allow the gas Shipper to update projected end-of-day balance position.
12. If needed to reduce imbalances, the TSO, as residual balance responsible, can carry out market-balancing actions on gas market and therefore submits bids and offers to the gas Market Operator.
13. The gas Market Operator communicates the market results to the TSO.

Steps 8 to 13 can be repeated several times during the Gas Day.

Technical delivery

14. From the transactional perspective, the gas Shipper provides gas to the gas Supplier.
15. In the same way, from the transactional perspective, the gas Supplier supplies gas to the MES operator.
16. And the gas Supplier supplies gas to its other gas Consumers.
17. But from the physical point of view, the TSO ensures the transport of gas through the gas transmission system and delivers it to the gas distribution network or to the DSO.
18. The physical delivery of gas to the MES Operator is ensured by the distribution network or the DSO.
19. In the same way, the physical delivery of gas to the other gas consumers is also ensured by the distribution network or the DSO.

Settlement

20. The gas Consumers make the metering data available to their respective metering company.
21. The MES operator makes metering data available to its metering company.
22. The metering companies send metering data to the gas Shipper.
23. The metering companies send metering data to the TSO.
24. The TSO provides the billing for the payments/penalties related to the imbalances and ensures the payment flows with the gas Shipper.
25. The gas Shipper invoices the gas Supplier for the gas provision.
26. The gas Supplier pays the gas Shipper for the gas provided.
27. The gas Supplier invoices the MES operator for the gas supply.
28. The gas Supplier invoices its other gas consumers for the gas supply.
29. The MES Operator pays the gas Supplier for the gas supplied.
30. The other gas consumers pay the gas Supplier for the gas supplied.

The settlement phase involves some additional steps that are not represented in the above sequence diagram, namely the interactions linked to the invoice and payment of the grid tariffs. For instance, depending on the country and/or on the "size" of the consumers, they may be:

- included in the Supplier's bill. In this case, the DSO then provides the billing information for the grid tariffs so that they are included it in the bill sent to the consumer. The Supplier collects the associated payments from the consumers and then, in turn, pays the DSO.
- Or included in a DSO's bill sent to the consumer separately. In this case, the DSO invoices directly the consumer for the grid tariff and collects the associated payment.

As previously mentioned, a much simplified description can also be used when limiting the scope to the main interactions with the MES. Such a simplified generic sequence diagram is given in Figure 8.

Remarks: in the figure, for simplicity and in order to highlight the main relevant interactions,

- the interactions with the Regulator are not represented,
- the role of gas consumer is merged with the MES operator role,
- the metering-related roles are merged with the DSO role since in most European countries they are carried out by same stakeholder.
- The role of gas supplier and gas shipper are merged.

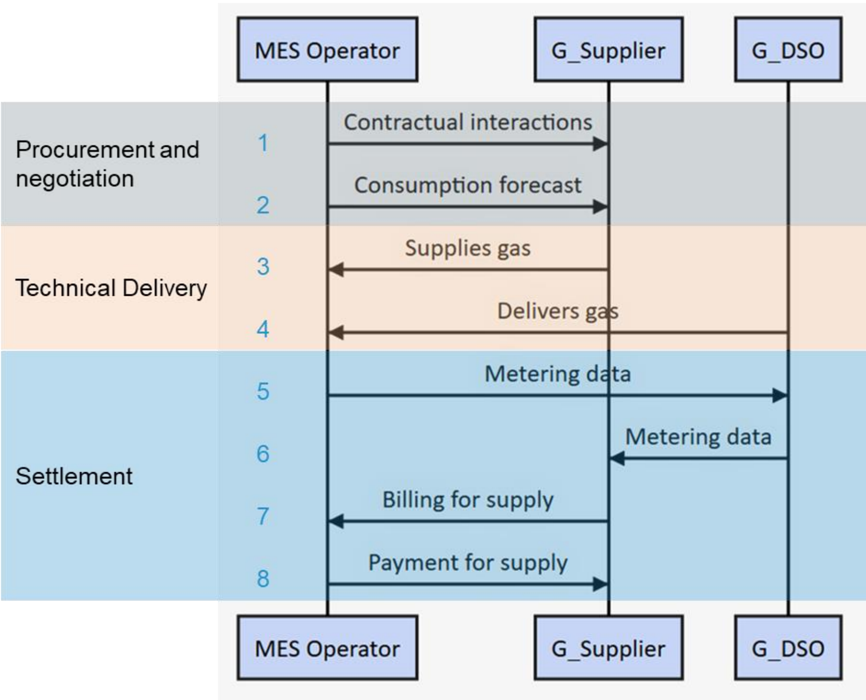


Figure 8 - Simplified generic sequence diagram for the gas system

The interactions are further detailed below for the three main phases of the service provision process.

Procurement and negotiation

1. The MES Operator signs a contract with the gas Supplier for the procurement of gas.
2. The MES Operator sends its gas consumption forecast to the gas Supplier.

Technical delivery

3. From the transactional perspective, the gas Supplier supplies gas to the MES Operator.
4. But the physical delivery of gas to the MES Operator is carried out through the gas network or the gas DSO.

Settlement

5. The MES operator makes metering data available to DSO.
6. The gas DSO sends metering data to the gas Supplier.
7. The gas Supplier invoices the MES Operator for the gas supply.
8. The MES Operator pays the gas Supplier for the gas supplied.

Like previously, the settlement phase involves additional steps, not represented in the above sequence diagram, and linked to the invoice and payment of the grid tariffs. As mentioned above, depending on the country and/or on the “size” of the consumers, they may be either included in the Supplier’s bill, or included in a DSO’s bill sent to the consumers separately.

Figure 9 shows provides the generic sequence diagram for the heat system for the case studies involving a district heating system, namely Malärenergi, ACS, HOFOR and Paris Saclay.

Remarks: in the figure, for simplicity and in order to highlight the main relevant interactions,

- the interactions with the regulator, the ground owner and the DHC owner are not represented,
- the role of storage provider is merged with the producer role,
- the heat supplier role is merged with the MES operator role,
- the metering-related roles are merged with the DSO role.

Generally in current district heating networks, the roles of heat supplier, MES operator, DSO (and metering-related roles), and also heat producer (as well as storage provider) are carried-out by the same stakeholder, however it was deemed important to keep some of them separated in the sequence diagram to show their main interactions. It also allows to show the interactions when there are third party heat producers (like in the ACS case study).

When there is no third party heat producer, step 10 probably does not exist. In the same way, depending on the contractual relationship between the heat producer and the MES operator, step 2 might not exist either.

This sequence diagram can also be used for the Austrian paper mill case study, with some modifications. Indeed, the Austrian paper mill is a third party heat producer with respect to the district heating system. When the focus is on the Austrian paper mill, the MES Operator role of the figure should be replaced by the heat supplier role and the heat producer role should be associated with the MES operator role.

It should be noted that the additional processes linked to the day ahead planning and intra-day adjustments in place in the Greater Copenhagen area, are not included in the figure here, since this is specific to one case study. They are represented in Appendix 9.3.2 (Figure 22).

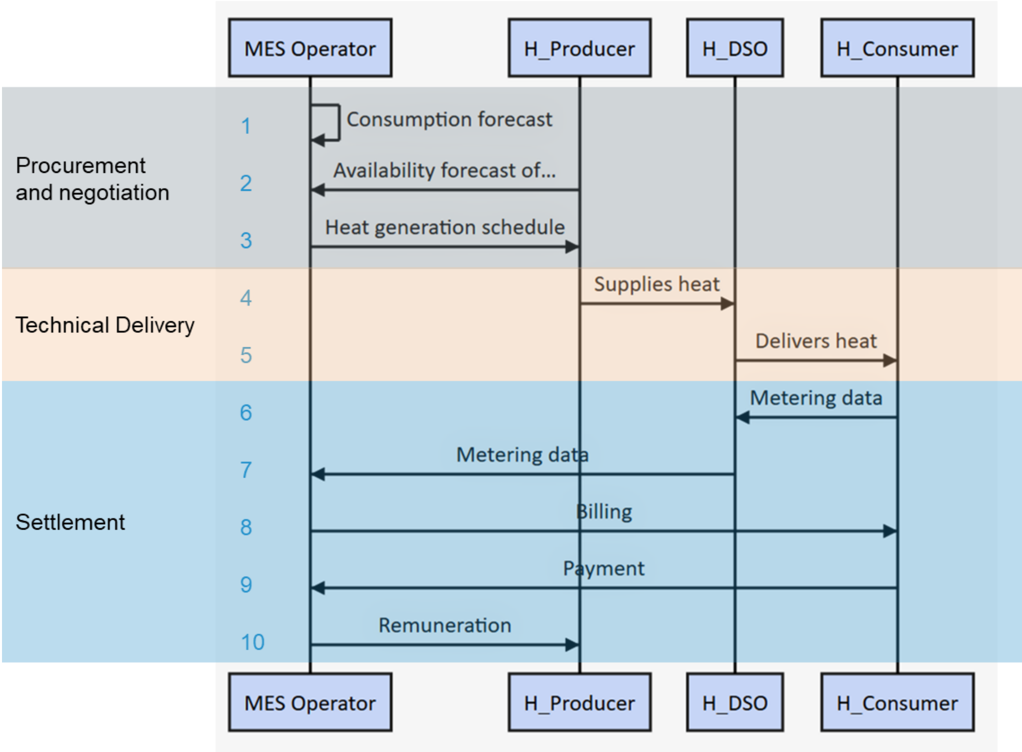


Figure 9 – Generic sequence diagram for the heat system for district heating case studies

The interactions in Figure 9 are further detailed below for the three main phases of the service provision process.

Procurement and negotiation

1. The MES Operator assesses the expected thermal load or heat demand of the heat consumers.
2. Depending on the contractual relationship, the heat producers may send their heat generation availability forecast to the MES Operator.
3. Based on the forecasts, the MES Operator computes and sends the heat generation schedule to the heat producers.

Technical delivery

4. The heat producers generate and provide heat to the heat DSO.
5. The heat DSO delivers heat to the consumers.

Settlement

6. The heat consumers make the metering data available to the heat DSO, who collects them.
7. The heat DSO sends metering data on the actual consumption to the MES Operator.
8. The MES Operator invoices the heat consumers.
9. The heat consumers pay the MES Operator for the heat consumed.
10. The MES Operator remunerates the third-party heat producers for the heat fed into the heat network.

Figure 10 provides the generic sequence diagram for the cooling system for the case studies involving a district cooling system, namely Malärenergi and Paris Saclay.

Remarks: in the figure, for simplicity and in order to highlight the main relevant interactions,

- the interactions with the regulator and the DHC owner are not represented,
- the role of storage provider is merged with the producer role,
- the supplier role is merged with the MES operator role,
- the metering-related roles are merged with the DSO role.

Like for district heating, generally in current district cooling networks, the roles of cooling supplier, MES operator, DSO (and metering-related roles), and cooling producer (as well as storage provider) are carried-out by the same stakeholder, however it was deemed important to keep some of them separated in the sequence diagram to show their main interactions. It also allows to show the interactions in case there would be third party cooling producers. Again, when there is no third party producer, step 10 probably does not exist. In the same way, depending on the relationship between the producer and the MES operator, step 2 might not exist either.

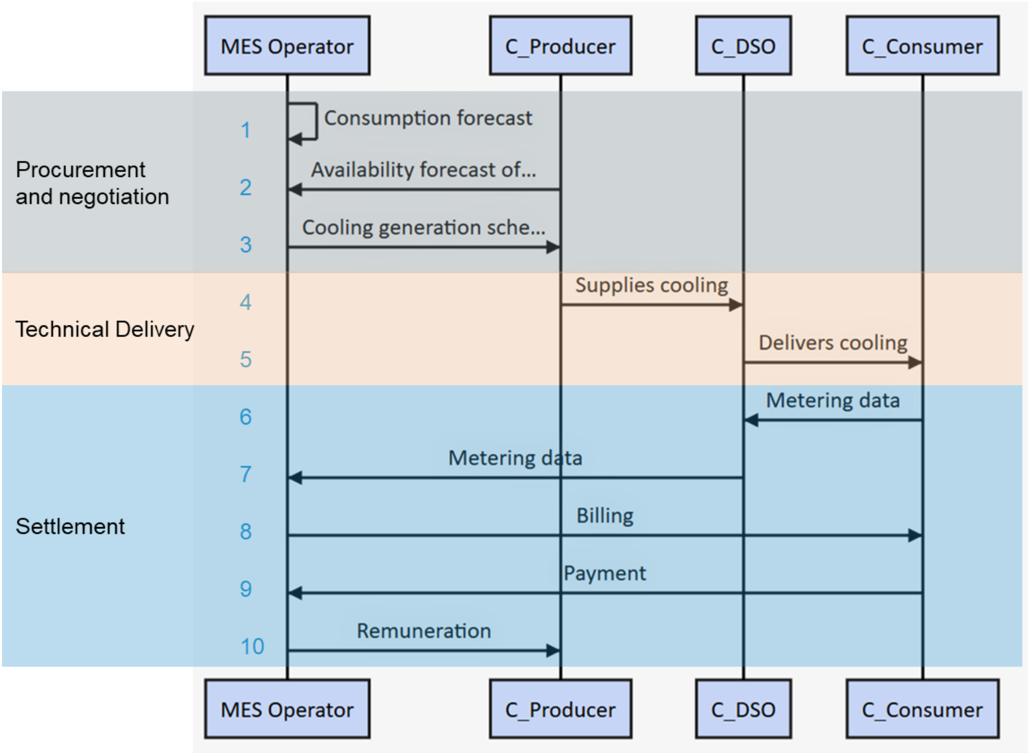


Figure 10 – Generic sequence diagram for the cooling system

The interactions are further detailed below for the three main phases of the service provision process.

Procurement and negotiation

1. The MES Operator assesses the expected thermal load or cooling demand of the consumers.
2. Depending on the contractual relationship, the cooling producers may send their cooling generation availability forecast to the MES Operator.
3. Based on the forecasts, the MES Operator computes and sends the cooling generation schedule to the producers.

Technical delivery

4. The cooling producers generate and provide cooling to the cooling DSO.
5. The DSO delivers cooling to the consumers.

Settlement

6. The consumers make the metering data available to the DSO, who collects them.
7. The DSO sends metering data on the actual consumption to the MES Operator.
8. The MES Operator invoices the cooling consumers.
9. The consumers pay the MES Operator for the cooling consumed.
10. The MES Operator remunerates the third-party cooling producers for the cooling fed into the network.

5 Interactions between the aggregation platform and the multi-energy systems

This chapter describes the proposed interactions between the aggregation platform and the multi-energy systems (MES) for the provision of flexibility to the electricity systems.

Starting from the generic sequence diagram of Figure 6 in Section 4.3 and after bringing the required adaptations, Figure 11 and Figure 12 show the main interactions and provide the associated sequence diagram for the electricity system.

In this figure, in order to highlight the main relevant interactions,

- two roles appear for the aggregation platform:
    - the BRP role since the aggregator must either be a BRP or be part of a BRP's portfolio to participate in the day-ahead and intraday energy markets,
    - the aggregator role like in Figure 6 for the trading of flexibility on the balancing and frequency regulation markets.

  It should be noted that in some countries even for some balancing service procurement mechanisms, the market participants must now be a BRP or be part of a BRP's portfolio. But this has not been represented here since there is still a large diversity between countries on this topic.
  Additionally, it should be reminded that the aggregator role can be carried out, and is very often carried out, by stakeholders who are the suppliers and/or traders, and not necessarily by separate players. In particular, this situation is found in the case studies, where the aggregator role is indeed ensured by the supplier and/or the trader.
- the roles of consumer and producer of the MES are merged with the MES operator role,
- the role of Clearing and Settlement responsible is merged with the Energy Market Operator,
- the role of TSO is merged with Balancing Market Operator role,
- the metering-related roles are kept separated from the DSO role even if in most European countries (but not necessarily in the UK) they are carried out by the DSO for the users connected to the distribution system,
- the interactions with the regulator are not represented.

The interactions are further detailed below for the three main phases of the service provision process.

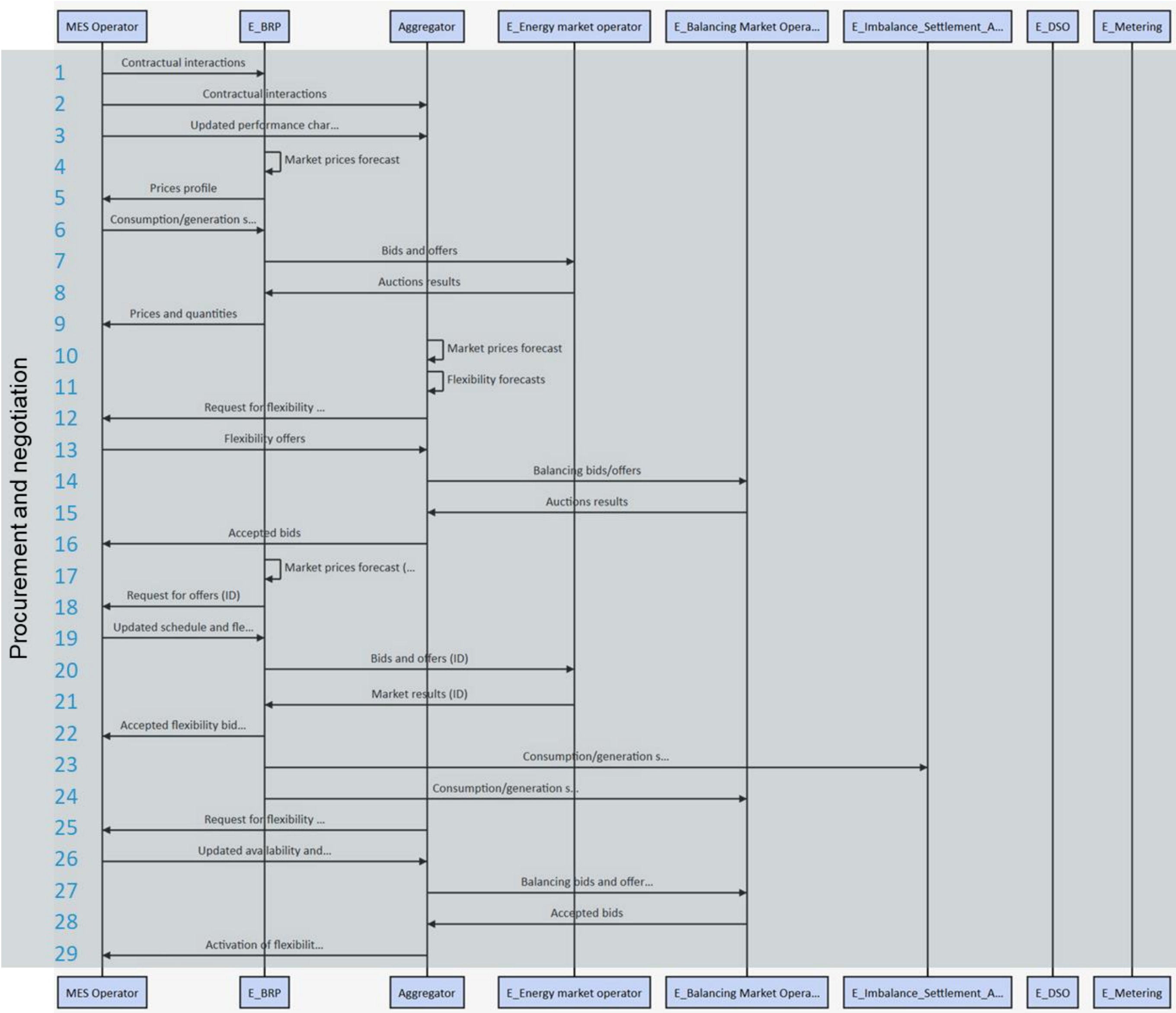


Figure 11 - Sequence diagram of the interactions between the aggregator role and the MES operator role – Procurement and negotiation phase

Procurement and negotiation phase

1. The MES Operator establishes a contract with the BRP for the participation in the energy markets.
2. The MES Operator establishes a contract with the Aggregator for the participation in the balancing and frequency regulation markets.
3. The MES Operator also communicates the flexibility performance characteristics of its system to the Aggregator, namely (but not limited to):
   - maximum positive and negative flexibility,
   - maximum duration of service provision (activation),
   - minimum recovery time between 2 activations,
   - number of activations per period of time (e.g. day, week, etc.),

- estimated availability factor (annual average of flexible energy which can be provided in the real case compared to the planned flexibility), necessary to consider the risk of technical outages or underperformance.

   These characteristics can be updated if the MES process experiences major changes, for instance with the season for DHC networks. They are then sent again to Aggregator on a season, month or even a weekly basis, but too frequent changes should be avoided.

4. For longer term and day ahead trading, the BRP performs a forecasting of the market prices for the considered periods of time.
5. The BRP sends forecasted prices profiles to the MES Operator. These profiles are based on the forecasted market prices but also include additional components associated to the BRP's costs and remuneration.
6. The MES carries out its optimisation process and communicates its consumption and/or generation schedule to the BRP. Like previously (see Section 4.3), depending on the type of MES, the MES may consume electricity from the grid, produce and inject electricity in the grid, or be both a consumer and a producer depending on the country regulation and contractual conditions.
7. The BRP engages in long term and/or day ahead energy trading and therefore submits bids/offers to the Energy Market Operator.
8. The Energy Market Operator communicates the auction results to the BRP.
9. The BRP communicates the final results in terms of prices and possibly generation schedule to the MES Operator.
10. The Aggregator performs a forecasting of the market prices for the considered markets and periods of time.
11. The Aggregator performs a forecasting of the flexibility of the resources in its portfolio for the considered periods of time.
12. The Aggregator sends the MES Operator a request for flexibility offers for specified periods of time. It may also specify the type of markets considered, along with information on the forecasted price levels.
13. The MES Operator carries out its optimisation and sends the Aggregator flexibility offers in the forms of time series including for each time step, the amounts and types of flexibility (positive and/or negative) and the associated prices. It may also provide several time series for different types of markets.
14. The Aggregator carries out optimizations at portfolio level aggregating the flexibility of the MES and of the other resources in its portfolio, prepares bids and offers for the frequency regulation and reserve markets, and submits bids/offers to the Balancing Market operator.
15. The Balancing Market Operator informs the Aggregator about the auction results (contracted flexibility).
16. The Aggregator carries out optimizations, dispatches between the MES and the other resources in its portfolio, and informs the MES Operator about its accepted flexibility bids and therefore the flexibility to be reserved and associated prices.
17. For intraday energy trading, the BRP performs a forecasting of the market prices for the considered periods of time.
18. The BRP sends the MES Operator a request for offers for intraday trading. It may also send forecasted price levels.

19. The MES carries out its optimisation process and communicates its updated consumption and/or generation schedule to the BRP, possibly along with flexibility offers for intraday trading (for each time step positive and/or negative flexibility with respect to the updated schedule and the associated prices).
20. The BRP engages in trade in intraday energy market and submits bids/offers to the Energy Market Operator.
21. The Energy Market Operator communicates the results of the market clearing to the BRP.
22. The BRP informs the MES Operator about its accepted flexibility bids and the resulting consumption/generation schedule.
23. After the closure of the day-ahead and intraday markets, the BRP sends the final consumption and/or generation schedule to the Imbalance Settlement Agent.
24. After the closure of the day-ahead and intraday markets, the BRP sends the physical notifications of the final consumption and/or generation schedule to the Balancing Market Operator.
25. As previously mentioned, a dedicated balancing mechanism also exists in some countries in intraday after the intraday trades. For participation in such a mechanism, the aggregator sends a request for flexibility offers to the MES Operator.
26. The MES Operator communicates its remaining available flexibility and associated costs to the Aggregator.
27. In the framework of this balancing mechanism, the Aggregator sends bids/offers to the Balancing Market Operator, namely how much it is willing to pay or be paid to increase or decrease the consumption or generation of its pool of resources by given amounts.
28. The Balancing Market Operator sends the results of the accepted bids and offers to the Aggregator.
29. The Aggregator sends the MES Operator the information on its accepted flexibility in the framework of the balancing mechanism.

Remarks:

- As previously mentioned, it should be highlighted that a large part of the energy trading is still carried out through OTC trading. Representing this situation in the figure can be done by replacing the interactions between the BRP and the Energy Market Operator by OTC trading.
- The objective of the figure is to show the main principles of the whole process and to be as generic as possible. Actually, the whole process is much more complex and also depends on the specificities of the market mechanisms implemented in the considered countries. Several subsets of steps could be repeated and/or moved along the chronological line. For instance (and not limited to):
  - Steps 14 and 15 should be repeated for the different frequency reserve markets (FCR, aFRR, mFRR).
  - Steps 18 to 22 for the intraday energy trading could be repeated several times depending on the number of auctions implemented in some countries or to represent the continuous intraday trading implemented in other countries [3].
  - In the same way, steps 25 to 29, related to the intraday balancing mechanism that can be found in some countries, could also be repeated several time during the day, in accordance with the country specific implementation rules.
  - In some countries the gate closure for some frequency reserve markets is after the day-ahead energy market gate closure meaning that the corresponding steps should be moved accordingly.

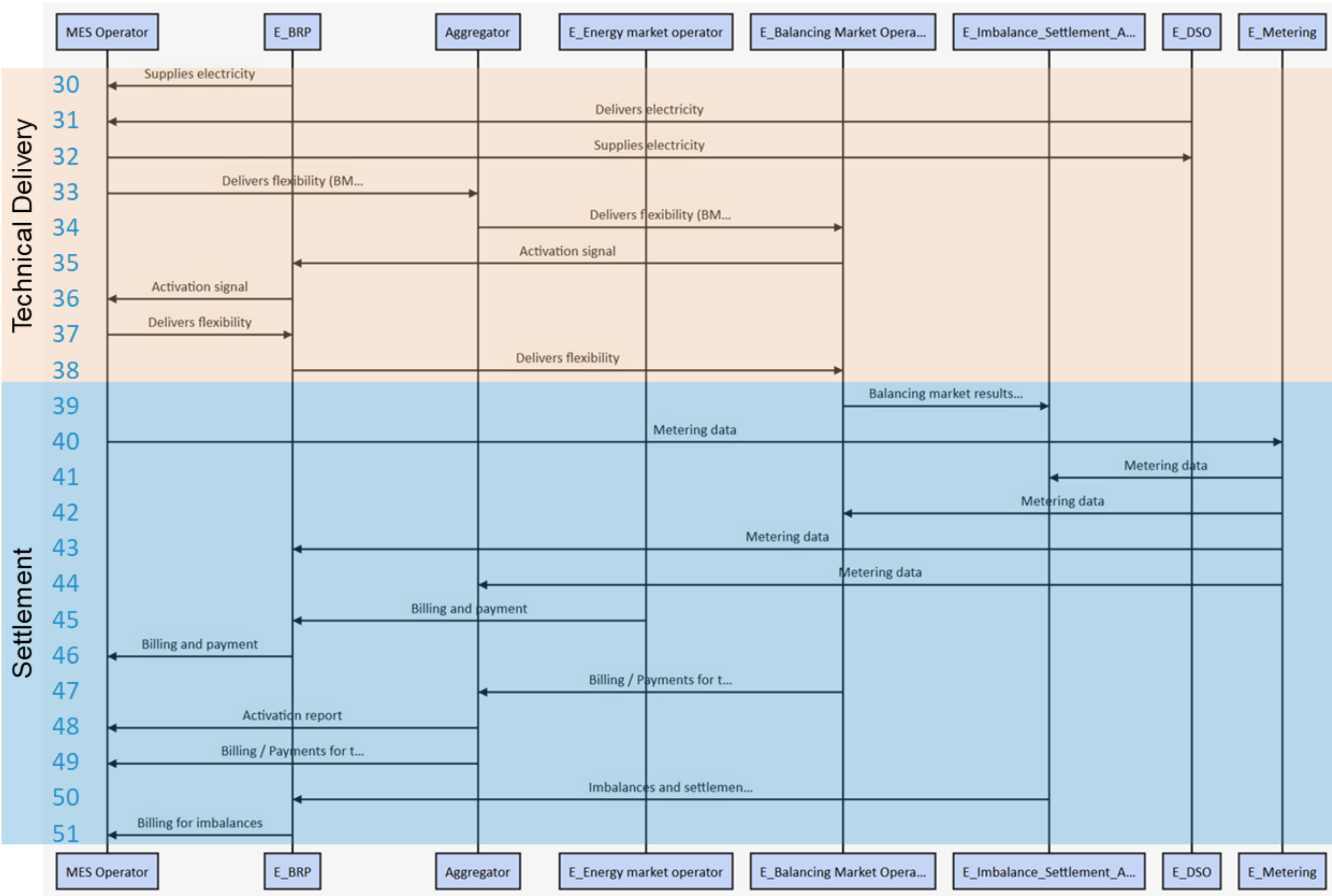


Figure 12 - Sequence diagram of the interactions between the aggregator role and the MES operator role – Technical delivery and settlement phases

Technical delivery

30. From the transactional perspective, the BRP "supplies" electricity to the MES Operator when it is a consumer.
31. But the physical delivery of electricity to the MES Operator is carried out by the distribution network or the DSO.
32. If the MES is a producer, the MES Operator generates and supplies electricity to the distribution network and therefore the DSO.
33. The MES Operator delivers to the Aggregator the flexibility requested in the framework of the balancing mechanism (implemented in some countries).
34. The Aggregator in turn delivers the flexibility of its pool to the Balancing Market operator, in accordance with the accepted bids of the balancing mechanism.
35. If it is needed for the compensation of imbalances, the Balancing Market operator sends an activation signal to the Aggregator to activate the delivery of services and reserves procured in advance on the frequency regulation and reserve markets.
36. The Aggregator dispatches the resources in its pool and accordingly sends an activation signal to the MES Operator.
37. The MES Operator delivers the requested flexibility to the Aggregator.

38. The Aggregator in turn delivers the requested flexibility of its pool to the Balancing Market operator.

Remark: the steps of the "Technical delivery" phase are of course repeated as many times as needed during the day and are "interlaced" with steps of the "Procurement and negotiation" phase, namely during the day there are a succession of "Procurement" phases for the products traded in intraday, followed by "Technical delivery" phases. However, to keep the figure as simple and as readable as possible, this has not been represented here.

Settlement

39. The Balancing Market operator sends the results of the balancing mechanism (accepted bids and offers) and of the balancing adjustment actions taken outside the balancing mechanism to the Imbalance Settlement Agent.
40. The MES Operator makes the metering data available to its metering company, who collects them.
41. The metering companies send the metering data to the Imbalance Settlement Agent for it to perform imbalance settlement.
42. The metering company sends metering data to the Balancing Market Operator.
43. The metering company sends the BRP the metering data relevant to its portfolio.
44. The metering company sends the Aggregator the metering data relevant to its portfolio.
45. The Energy Market Operator provides with the billing to the BRP and settles the payments, according to the bids/offers accepted on the energy markets.
46. The BRP sends the MES Operator the billing information and settles the payments for the electricity consumed and/or generated by the MES, as well as for the flexibility provided on the intraday energy market according to the accepted flexibility bids/offers.
47. The Balancing Market Operator provides the billing for the payments/penalties of the flexibility provision by the Aggregator, according to the bids/offers accepted on the balancing mechanism, and according to the procurement conditions, activation and provision performance of the frequency regulation services.
48. The Aggregator sends the report of the flexibility activations.
49. The Aggregator provides the billing information to the MES Operator and settles the payments for the provided flexibility services.
50. The Imbalance Settlement Agency provides the billing for the payments/penalties related to the imbalances and ensures the payment flows with the BRP.
51. If it is included in the contract between them, the BRP may settle payments or penalties related to the imbalances with the MES Operator.

Remarks:

- The settlement phase involves some additional steps that are not represented in the above sequence diagram, for instance the interactions linked to the invoice and payment of the grid tariffs. As previously mentioned, there might be different situations/rules depending on the country and/or on the "size" of the consumers, for instance, the grid tariffs may be:
    - Included in the Supplier's bill. In this case, the DSO then provides the billing information for the grid tariffs so that they are included in the bill sent to the consumer. The Supplier collects the associated payments from the consumers and then, in turn, pays the DSO.

  - Or included in a DSO's bill sent to the consumer separately. In this case, the DSO invoices directly the consumer for the grid tariff and collects the associated payment.
- There might additional interactions related to imbalance settlement, for instance to avoid penalties for the BRP when resources of its portfolio participate to the provision of balancing and frequency regulation services. Since the rules are still very different from one country to the other, there are not represented here in this generic sequence diagram.
- Depending on the contract between them, the payment of penalties might be considered between the MES Operator and the Aggregator, in case of failure of the MES to deliver the contracted flexibility.
- The number and the order of the steps involved in the settlement phase may be different depending on the country specificities and on the contracts between the stakeholders.

The objective of Figure 11 and Figure 12 is to provide generic sequence diagrams able to show the principles of the whole process and in particular the main roles and interactions involved. However, as already explained in Section 4.3, there is a large diversity of situations, market mechanisms and rules that can be found in the considered countries, despite some harmonisation initiatives that have been and/or are being carried out. It is not possible to represent here all the situations in detail. Additionally, this is a very fast evolving field: some rules or mechanisms can change from one year to the other, or sometimes even faster, which means that any fully detailed sequence diagram can soon become obsolete.

6 Innovative market designs for multi-carrier market integration: roles and interactions

6.1 Description of the roles in multi-carrier markets

The main roles involved in the three energy sectors[2] (gas, heat and electricity) have already been identified in Table 11 (see Section 4.1). In this table, the names of the roles are given without reference to the energy sector. Some of the considered roles would have to change in a multi-carrier market context.

The role of the market operator was introduced in Table 11. In our study on innovative market designs, we anticipate – next to the already existing day-ahead electricity and gas markets - the evolution towards day-ahead heat markets and day-ahead multi-carrier markets. This means that, depending on the considered multi-carrier market design, four different types of market operators can be distinguished as explained in MAGNITUDE Deliverable D3.2 [4]:

- Electricity market operator,
- Heat market operator,
- Gas market operator,
- Multi-carrier market operator.

The generic definition provided in Table 11 still applies, i.e. the market operator provides a service whereby the offers to sell energy (of a certain carrier or multiple carriers) are matched with bids to buy energy (of a certain carrier or multiple carriers). In the context of the proposed multi-carrier markets, we specifically focus on day-ahead auctions. In addition, a call market is assumed where energy orders are traded at a specific time. These market operators are all of the type "Energy market operator" as introduced in Section 4.1.

When evolving towards more liquid day-head gas markets, we would also expect that the gas BRP would more and more need to balance its portfolio during the day (while presently this might still be mainly done on a daily basis), similarly as the current practice of BRPs in the electricity sector. A BRP, as indicated in Table 11, has to bear the responsibility for imbalance between realized energy injection and consumption for a given portfolio or group of players. For heat we did not add this role, as here the local context is still very important. Here we assume that the MES operator would bid directly into the day-ahead heat market. Depending on the size of the heat networks and related markets, such a role could however become important for large heat networks. Also, for the market design which considers an integrated multi-carrier market, we would expect current BRPs to evolve towards BRPs which would be responsible for imbalances in their portfolio across multiple carriers. They are called multi-carrier BRPs in the next section. A detailed analysis of the BRP role in the context of multi-carrier markets is however out of scope of the MAGNITUDE project.

[2] In this Chapter, no distinction is made between heat and cooling and the word "heat" is used to represent both.

6.2 Roles identified in the multi-carrier markets business use cases

All the different roles defined in Section 4.1 are expected to be relevant in the context of multi-carrier markets as well. However for the selected business use cases (see Section3.5.2), we focus on the day-ahead time frame and on the first phase of the service provision process, i.e. the procurement and negotiation phase, as we expect the most impact in this phase. Moreover, the exact evolution of the roles and responsibilities in the context of different multi-carrier markets, would require a more detailed study, regulatory discussions and inter-sectoral negotiations, which is beyond the scope of the MAGNITUDE project.

Table 16 below summarizes the roles which are considered in the sequence diagram for the two selected business use cases, i.e. for MD1.1 Decoupled multi-carrier market design with decentralised clearing and MD5.1 Integrated multi-carrier market design with centralised clearing. We based ourselves on the assumptions made for the sequence diagram representing the future interactions during the procurement and negotiation phase for electricity as presented in Figure 11, but only focusing on the day-ahead timeframe. We then considered the existence of organised day-ahead markets for gas and heat next to the current electricity markets in the case of MD1.1, and the integration of the different day-ahead markets into one single multi-carrier market in MD5.1.

Table 16 – Roles identified for the assessment of innovative multi-carrier market designs

Role	MD1.1	MD5.1
MES operator	X	X
Heat Market operator	X	
Electricity Market operator	X	
Gas Market operator	X	
Multi-carrier Market operator		X
Electricity BRP	X	
Gas BRP	X	
Multi-carrier BRP		X

The table shows that in MD1.1 (Decoupled multi-carrier market design with decentralised clearing), three different market operators are identified for each of the different carriers. Balance responsibility for electricity and gas is taken up by separate roles as is currently also the case, while we assume that balancing responsibility for heat is internalised in the role of the MES operator as explained above.

In contrast, in the case of MD5.1 (Integrated multi-carrier market design with centralised clearing), there is one single market operator, the so-called multi-carrier market operator, and one BRP, the multi-carrier BRP.

It should be noted that this is just an example of the potential evolutions of roles in a multi-carrier market context. Other set-ups could also be envisioned.

6.3 Main future interactions

In the context of multi-carrier markets, large MES operators can have direct access to single or multi-carrier markets whereas smaller multi-energy systems and other consumers/prosumers of different carriers might be represented by an intermediary. Here, we base ourselves on the assumptions taken in Chapter 5 where in the case of electricity day-ahead trading, the MES operator would share generation and consumption schedules with the BRP based on price forecasts received via the BRP. We also extend this approach to gas and to the multi-carrier market of MD5.1. In the latter case (i.e. MD5.1), the MES operator would also share underlying information from its portfolio (e.g. conversion efficiency, OPEX...) so that the BRP can prepare multi-carrier orders on their behalf. Other set-ups are also possible within this market design (e.g. where the MES operator prepares bids and offers and forwards them to the BRP or even to the Market operator directly).

In MD1.1 (Decoupled multi-carrier market design with decentralised clearing), separate day-ahead energy markets are organised for the different energy carriers (i.e. electricity, heat and gas). By choosing adequate gate closure times, clearing times and the times for publishing the results for the different markets, these markets can in effect be sequential, thereby allowing market participants to readjust their position for the next market(s) taking into account the clearing outcome of the previous market(s) as explained in MAGNITUDE Deliverable D3.2 [4]. This situation is the one considered in the business use case and shown in the sequence diagram in Figure 13 below.

In this sequence diagram, we assumed the following sequence of market clearing per carrier: first heat, secondly electricity and then gas. Other sequences are also possible. In the same way, in terms of interactions between the different roles, other implementations are possible too.

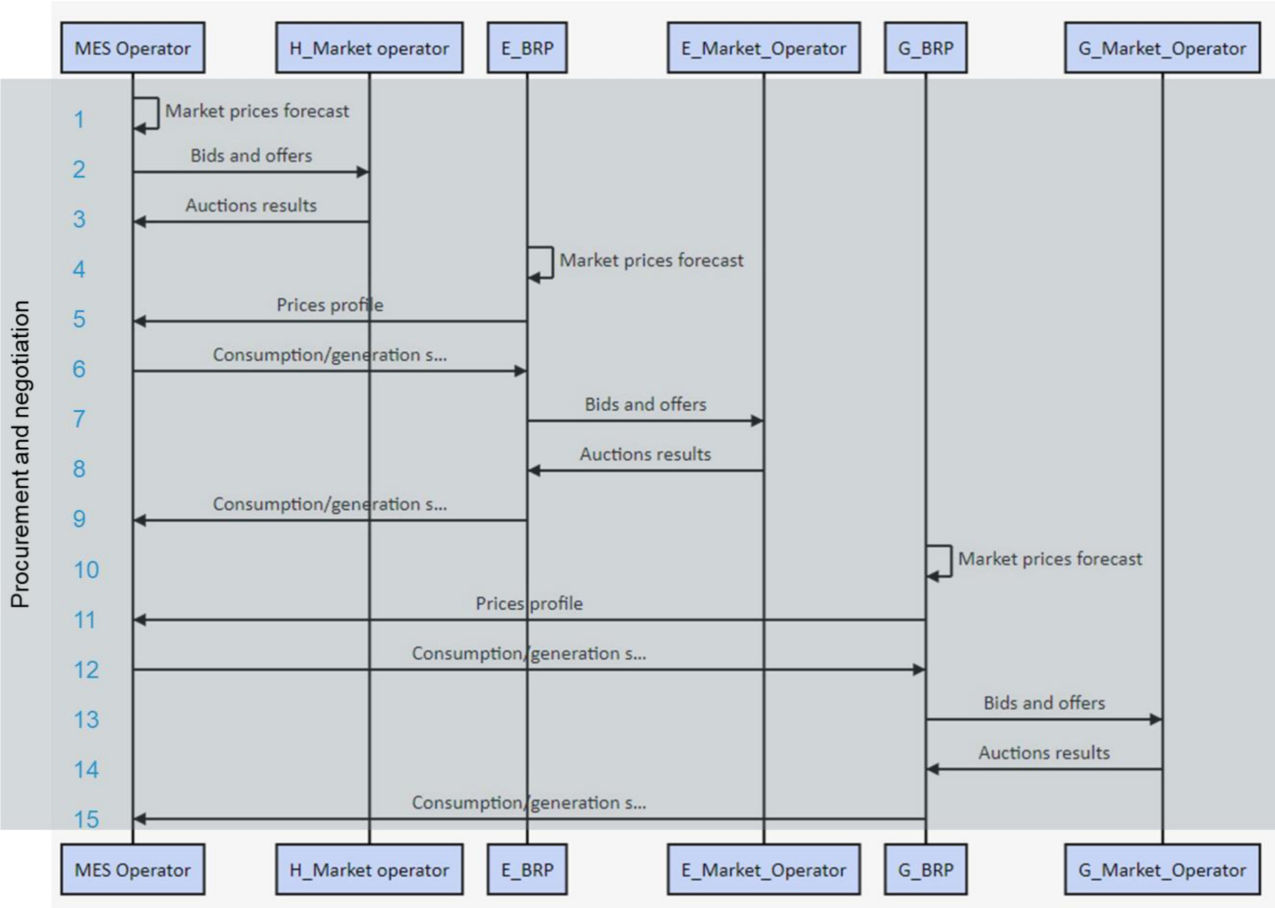


Figure 13 - A possible sequence diagram of the interactions for the business use case related to MD1.1 and for the procurement and negotiation phase

The main interactions of MD1.1 business use case shown in the figure are explained below.

1. The MES operator performs its own price forecast for heat and its own optimisation process[3].
2. The MES operator engages in day ahead heat trading and therefore submits bids/offers to the Heat Market Operator.
3. The Heat Market Operator communicates the auction results to the MES operator.
4. The BRP for electricity or Electricity BRP performs a forecasting of the market prices for the considered periods of time.
5. The Electricity BRP sends forecasted prices profiles to the MES Operator. These profiles are based on the forecasted market prices but also include additional components associated to the BRP's costs and remuneration.
6. The MES operator carries out its optimisation process and communicates its consumption and/or generation schedule for electricity to the Electricity BRP. Like previously (see Section 4.3), depending

[3] Price forecasts for a certain carrier are depicted each time as a first step before the submission of bids and offers for heat or for generation and consumption schedules for the other carriers. It should however be noted that price forecasts of the different carriers would happen at different times (e.g. electrticity price forecasts would already be considered before the heat bids and offers would need to be prepared) and would be updated regularly based on incremental information until the gate closure for a certain market.

on the type of MES, the MES may consume electricity from the grid, produce and inject electricity in the grid, or be both, consuming and producing energy.

7. The Electricity BRP engages in day ahead electricity trading and therefore submits bids/offers to the Electricity Market Operator.
8. The Electricity Market Operator communicates the auction results to the Electricity BRP.
9. The Electricity BRP communicates the final results in terms of prices and possibly generation/consumption schedule to the MES Operator.
10. The BRP for gas or Gas BRP performs a forecasting of the market prices for the considered periods of time
11. The Gas BRP sends forecasted prices profiles to the MES Operator. These profiles are based on the forecasted market prices but also include additional components associated to the BRP's costs and remuneration.
12. The MES carries out its optimisation process and communicates its consumption and/or generation schedule for gas to the Gas BRP. Like previously (see Section 4.3), depending on the type of MES, the MES may consume gas from the grid, produce and inject gas in the grid, or be both a consumer and a producer.
13. The Gas BRP engages in day ahead gas trading and therefore submits bids/offers to the Gas Market Operator.
14. The Gas Market Operator communicates the auction results to the Gas BRP.
15. The Gas BRP communicates the final results in terms of prices and possibly generation/consumption schedule to the MES Operator.

In MD5.1 (Integrated multi-carrier market design with centralised clearing), there is only one unified multi-carrier market, operated by a unique Multi-carrier Market Operator that processes all orders. This is shown in the sequence diagram of Figure 14.

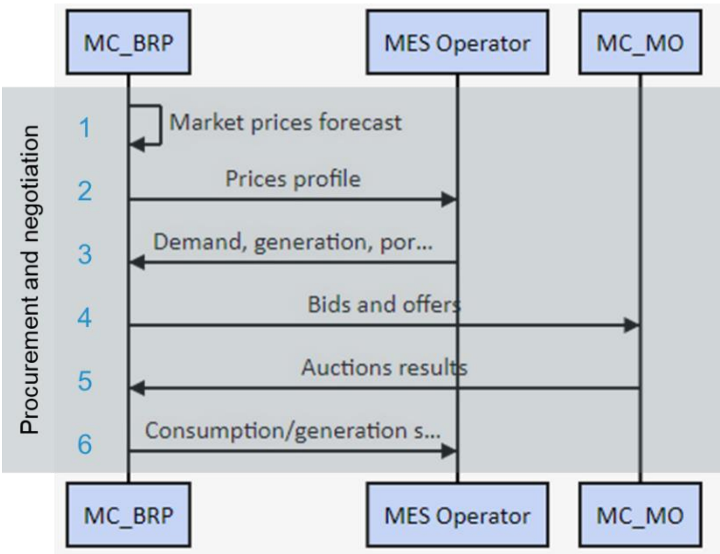


Figure 14 - A possible sequence diagram of the interactions for the business use case related to MD5.1 and for the procurement and negotiation phase

The main interactions of MD5.1 business use case shown in the figure are explained below.

1. The Multi-carrier BRP (MC BRP) sends forecasted prices profiles to the MES Operator. These profiles are based on the forecasted market prices but also include additional components associated to the BRP's costs and remuneration.
2. The MES operator carries out its optimisation process and communicates its consumption and/or generation schedule for the different carriers together with additional information related to its underlying portfolio (e.g. conversion efficiency, OPEX…) to the multi-carrier BRP. Like previously (see Section 4.3), depending on the type of MES, the MES may be a consumer and/or producer of the different energy carriers.
3. The Multi-carrier BRP engages in day ahead trading for the different carriers and therefore submits a combination of single- and multi-carrier bids and/or offers to the Multi-carrier Market Operator (MC_MO).
4. The Multi-Carrier Market Operator (MC_MO) communicates the auction results to the Multi-carrier BRP (MC_BRP).

7 Conclusions

In this report, the MAGNITUDE main concepts and high level conceptual architecture are first introduced.

Then the high level (simplified) business use cases investigated in the project are described both

- for the services provided by the MES in the case studies with the current procurement mechanisms in the considered countries, and
- for the assessment of innovative markets designs for enhanced multi-carrier integration.

An integrated and coherent definition of the roles involved in the 4 energy sectors (electricity, gas, heating and cooling) is proposed and applied to characterize the role models of the case studies.

The results of the detailed analysis conducted for the 7 real-life case studies in the current situation for the 4 energy sectors are given in the appendices and provide for each case study and each energy sector:

- the main stakeholders involved,
- the roles they carry out,
- the main interactions between these roles in the form of sequence diagrams.

A comparative cross analysis of the roles identified in the case studies is then presented and allows to highlight the similarities between the case studies and to elaborate generic sequence diagrams of the main interactions between the identified roles for the 4 energy sectors.

The proposed interactions between the aggregation platform and the multi-energy systems for the provision of flexibility to the electricity system are described and integrated in the generic sequence diagram for the electricity system.

Finally, the roles involved in the innovative market designs for multi-carrier market integration are identified and the proposed interactions between these roles are presented in the form of sequence diagrams.

These generic sequence diagrams thus formalize the conceptual technical and commercial architectures of MAGNITUDE on the one hand for the provision of services by the case studies with the current procurement mechanisms and on the other hand for the innovative market designs developed in the project for the enhancement of multi-carrier synergies at market level.

In the next phases of the project, some evolutions of these architectures will be investigated in particular with respect to the data exchange process. Indeed, the concept of data hubs has been developing since several years now, along with new roles associated with data management and data hub operation. An example is provided by the Danish case study (HOFOR) where Energinet carries out the role data hub operator in the electricity system, not only for metering data but also for data related to market processes and business transactions. Multi-energy data hubs will be investigated in the next phases of the project and the associated results will be reported in future deliverables.

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9 Appendices: roles involved in the case studies and their interactions – current situation

The appendices in this chapter provide, for each of 7 real-life case studies of the MAGNITUDE project, the results of the detailed analysis carried out on the current situation for the 4 energy sectors considered (electricity, gas, heat and cooling), regarding:

- the stakeholders involved in the case study,
- the roles they carry out,
- the main interactions between these roles.

For each energy sector, the results are presented in the following way:

- A table mapping the actual stakeholders involved with the roles they carry out and the type of roles. By type of roles, it is meant “internal” or “external” roles:
    - Internal roles are understood as roles which are existing within the multi-energy system and are generally taken over by the same stakeholder that carries out the role of multi-energy system operator.
    - External roles refer both to roles external to the multi-energy system at a local, regional, national or even international level and roles of the MES who are in interaction with such external roles. External roles may be for instance the TSO/DSO, the heat consumers, the market operator, the supplier, etc. but also the MES operator, the MES electricity producer (or consumer) role that injects (or consumes) electricity in (from) the grid.

  The meaning will become clearer from the tables given in the sequel for each case study.
- Sequence diagrams presenting the sequences of the interactions between the roles involved, which are mainly relevant for the MAGNITUDE project goals. It should be noted that the interactions between the internal roles, as well as the roles that are purely internal, are not represented in these sequence diagrams, except in some very specific cases where it appeared important for the description of the whole process.

The sequence diagrams are structured according to the three main phases of the service provision process [3] introduced in Section 4.3 and shown in Figure 5, namely:

1. **Procurement and negotiation**: corresponding to the planning and product procurement phase, including the players’ optimisation process, identification of needs, formulation and submission of requests and/or bids, the market clearing or OTC negotiation, contract conclusion, etc. This phase may also require a prequalification of players to be able to participate in certain markets or to propose services.
2. **Technical delivery**: corresponding to the product delivery phase, including activation mechanisms depending on the service, the physical delivery of the products, possibly real-time monitoring and real-time measurement/metering, etc.
3. **Settlement**: corresponding to the settlement or post-delivery phase, including exchanges of metered data, financial settlement, billing and payments, cost recovery, possible penalties, etc.

9.1 Mälarenergi

The following sections provide the results of the detailed analysis of the current situation for the Mälarenergi case study for the electricity, heat and cooling sectors. The gas sector is not involved in this case study.

9.1.1 Electricity sector

Table 17 provides the stakeholders identified for the electricity system, along with the roles they carry out.

Table 17 – Mälarenergi: stakeholders and roles for the electricity system

Stakeholder	Role	Type of role	Comment
Mälarenergi AB (Västerås CHP plant)	Producer	Internal/external	CHP plant owned by Mälarenergi AB
Mälarenergi AB	Trader	Internal/external	Mälarenergi AB trades electricity directly on the energy market
Mälarenergi AB	BRP	Internal/External	
Mälarenergi AB	MES operator	Internal/External	
Mälarenergi AB	Supplier	Internal	Supplies electricity to the heat pumps and electric boilers.
Mälarenergi AB	Consumer	Internal	Heat pumps, electric boilers consume electricity.
Nordpool	Market operator	External	Nordpool also ensures the role of clearing and settlement responsible for the energy markets.
eSett	Imbalance settlement Agent	External	In Sweden, the collection of imbalance payments is not performed by the TSO but by a dedicated player.
Svenska Kraftnät	TSO	External	
Fortum	Distribution System Operator	External	The generation plant is connected to Fortum's network.
Fortum	Metering-related roles	External	
Miljödomstolen (environmental court)	Regulator	External	Gives permission for continued operation of CHP, permission of using waste, etc.
Länsstyrelsen Västmanland (county administrative board)	Regulator	External	Gives permission to release carbon dioxide, supervises that Mälarenergi AB follows the environmental law (release of substances, noise, smell, etc.).

Stakeholder	Role	Type of role	Comment
Naturvårdsverket (Swedish environmental protection agency)	Regulator	External	Gives permission for import of waste and also keeps track of emissions from the CHP.
Waste suppliers	*Waste supplier*	*External*	*Provide "fuels", namely waste, for the CHP plant*

In the above table, the roles of supplier and consumer of Mälarenergi in the case study are internal to the MES system since they are linked to the consumption of electricity by the heat pumps and electric boilers on the Mälarenergi site. The roles of producer, trader, BRP and MES operator of Mälarenergi appear as both internal and external since they have interactions both with purely internal roles in the MES (such as electricity consumer and supplier) and roles external to the MES (e.g. Market operator, DSO, etc.).

A special role ("Waste supplier") has been added in the table to take into account the particular type of fuel used by the CHP plant, namely waste. However, it will not be further considered nor represented in the sequence diagram.

Figure 15 shows the main relevant interactions between the identified roles and provides the sequence diagram for the electricity system.

Remarks: in the figure, for simplicity and in order to highlight the main relevant interactions,

- the interactions with the Regulator are not represented,
- the trader and BRP roles are merged in one role (BRP),
- the Mälarenergi roles of producer, consumer, supplier are merged with the MES operator role,
- the metering-related roles are merged with the DSO role since they are indeed carried out by the DSO.

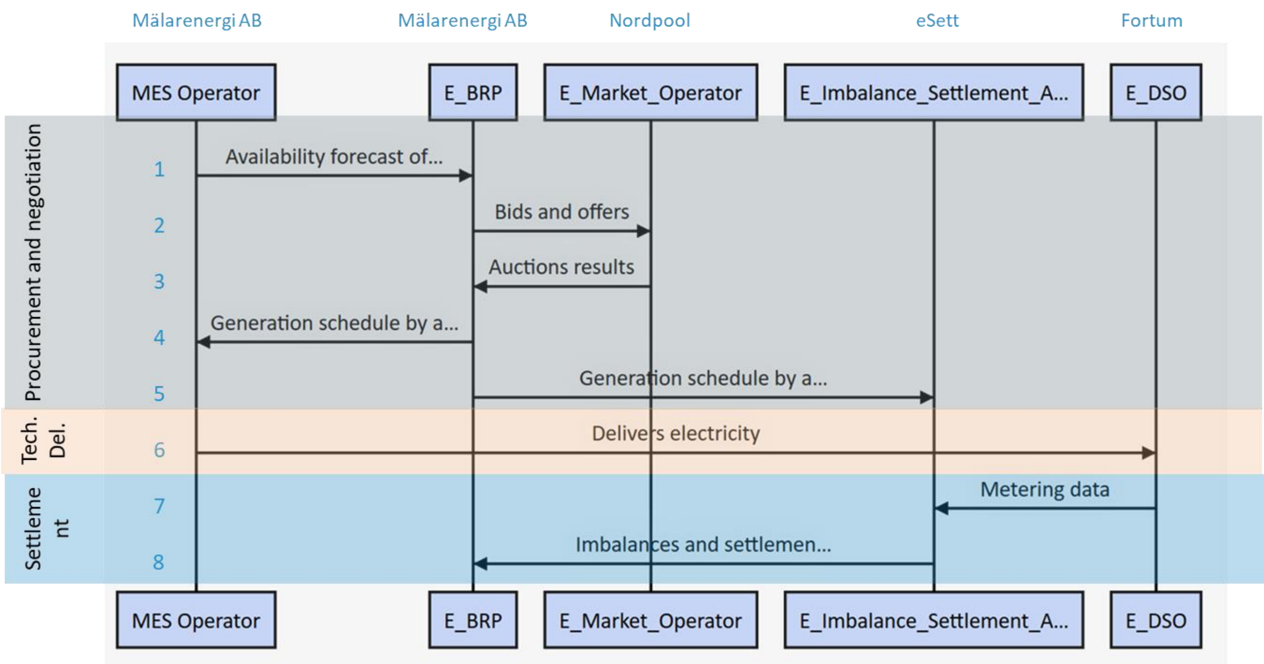


Figure 15 – Mälarenergi: sequence diagram for the electricity system

The interactions are further detailed below for the three main phases of the service provision process.

Procurement and negotiation phase

1. The MES Operator (Mälarenergi AB) communicates the schedule of electricity generation (if the CHP is in heat driven operation) to the BRP (Mälarenergi AB).
2. The BRP (Mälarenergi AB) engages in trade in the day-ahead and intraday markets and therefore submits bids/offers to the market operator (Nordpool).
3. The market operator (Nordpool) communicates the auction results (day-ahead and intraday) to the BRP (Mälarenergi AB).
4. The BRP (Mälarenergi AB) confirms the final generation schedule to the MES Operator (Mälarenergi AB).
5. After the closure of the markets, the BRP (Mälarenergi AB) submits the final consumption/generation schedule to the Imbalance Settlement Agent (eSett).

Technical delivery

6. The MES (MES Operator - Mälarenergi AB) produces and injects the electricity on the distribution grid (E_DSO - Fortum).

Settlement

7. The DSO (Fortum) sends metering data to the Imbalance Settlement Agent (eSett).
8. The Imbalance Settlement Agent (eSett) ensures the billing and the payment flows of the imbalances with the BRP (Mälarenergi AB).

9.1.2 Heat sector

Table 18 provides the stakeholders identified for the heat system, along with the roles they carry out.

Table 18 – Mälarenergi: stakeholders and roles for the heat system

Stakeholder	Role	Type of role	Comment
Mälarenergi AB (Västerås CHP plant)	Producer	Internal/external	Owned by Mälarenergi AB
Mälarenergi AB	Distribution System Operator	Internal/external	Owns the district heating network
Mälarenergi AB	MES operator	Internal/external	
Mälarenergi AB	Storage provider	Internal/external	Hot water storage tanks
Mälarenergi AB	Supplier	Internal/External	
Mälarenergi AB	Metering-related roles	Internal/External	
Heat customers	Consumers	External	Private and industrial consumers

Miljödomstolen (environmental court)	Regulator	External	Gives permission for continued operation of CHP, permission of using waste, etc.
Länsstyrelsen Västmanland (county administrative board)	Regulator	External	Gives permission to release carbon dioxide, supervises that the Mälarenergi follows the environmental law (including release of substances, noise, smell, etc.)
Naturvårdsverket (Swedish environmental protection agency)	Regulator	External	Gives permission for import of waste and also keeps track of emissions from the CHP

Figure 16 shows the main relevant interactions between the identified roles and provides the sequence diagram for the heat system.

Remarks: in the figure, for simplicity and in order to highlight the main relevant interactions,

- the interactions with the different types of regulatory bodies are not represented,
- the Mälarenergi role of storage provider has been merged with the heat producer role,
- the Mälarenergi role of supplier is merged with the MES operator role,
- the metering-related roles are merged with the DSO role since they are indeed carried out by the heat network operator.

The interactions are further detailed below for the three main phases of the service provision process.

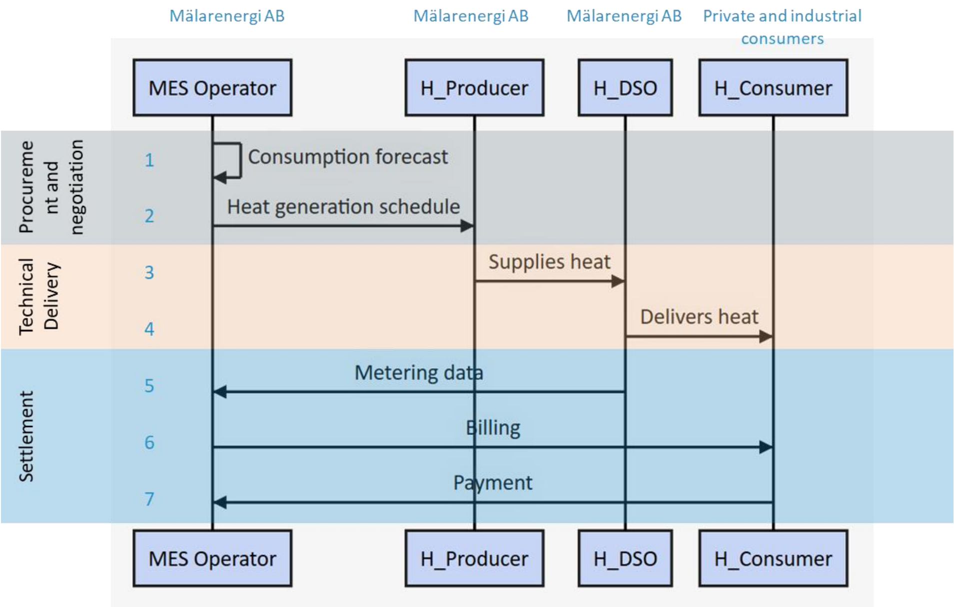


Figure 16 – Mälarenergi: sequence diagram for the heat system

Procurement and negotiation

1. The MES Operator (Mälarenergi AB) forecasts the heat demand.

2. The MES Operator (Mälarenergi AB) communicates the heat generation schedule to the heat Producer (Mälarenergi AB).

Technical delivery

3. The heat Producer (Mälarenergi AB) supplies heat to the heat DSO (Mälarenergi AB).
4. The heat DSO (Mälarenergi AB) delivers heat to the heat consumers (private and industrial consumers).

Settlement

5. The heat DSO (Mälarenergi AB) sends metering data to the MES Operator (Mälarenergi AB).
6. The MES operator (Mälarenergi AB) invoices the heat supply to the heat consumers (private and industrial consumers).
7. The heat consumers (private and industrial consumers) pay the bill to the MES operator (Mälarenergi AB).

9.1.3 Cooling sector

Table 19 provides the stakeholders identified for the cooling system, along with the roles they carry out.

Table 19 - Mälarenergi: stakeholders and roles for the cooling system

Stakeholder	Role	Type of role	Comment
Mälarenergi AB	Producer	Internal/external	Generates cooling through absorption chillers.
Mälarenergi AB	Distribution System Operator	Internal/external	Owns the cooling network. The cooling network is different from the heat network.
Mälarenergi AB	MES operator	Internal/external	
Mälarenergi AB	Supplier	Internal/external	
Mälarenergi AB	Metering-related roles	Internal/external	
Cooling customers	Consumers	External	Only industrial customers, who do not have to be also heat customers.
Miljödomstolen (environmental court)	Regulator	External	Gives permission for continued operation of CHP, permission of using waste, etc.
Länsstyrelsen Västmanland (county adminstrative board)	Regulator	External	Gives permission to release carbon dioxide, supervises that the Mälarenergi follows the environmental law (including release of substances, noise, smell, etc.)

Naturvårdsverket (Swedish environmental protection agency)	Regulator	External	Gives permission for import of waste and also keeps track of emissions from the CHP.

Figure 17 shows the main relevant interactions between the identified roles and provides the sequence diagram for the cooling system.

Remarks: in the figure, for simplicity and in order to highlight the main relevant interactions,

- the interactions with the different types of regulatory bodies are not represented,
- the Mälarenergi role of supplier is merged with the MES operator role,
- the metering-related roles are merged with the DSO role since they are indeed carried out by the cooling network operator.

The interactions are further detailed below for the three main phases of the service provision process.

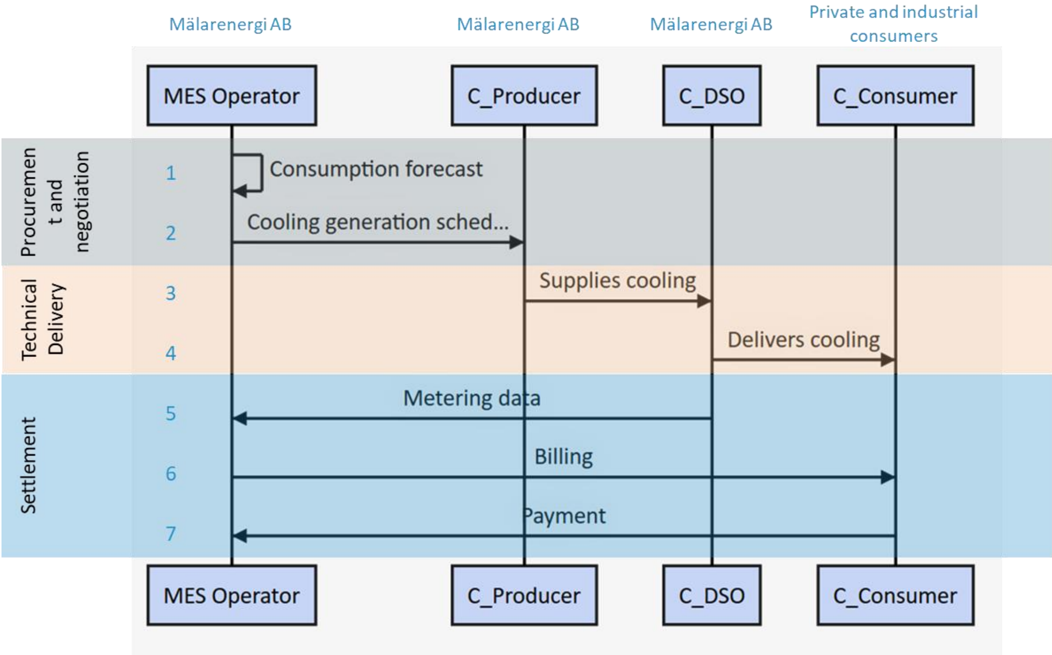


Figure 17 - Mälarenergi: sequence diagram for the cooling system

Procurement and negotiation

1. The MES Operator (Mälarenergi AB) forecasts the cooling demand.
2. The MES Operator (Mälarenergi AB) communicates the cooling generation schedule to the cooling Producer (Mälarenergi AB).

Technical delivery

3. The cooling Producer (Mälarenergi AB) supplies cooling to the cooling DSO (Mälarenergi AB).
4. The cooling DSO (Mälarenergi AB) delivers cooling to the cooling consumers (private and industrial consumers).

Settlement

5. The cooling DSO (Mälarenergi AB) sends metering data to the MES Operator (Mälarenergi AB).
6. The MES operator (Mälarenergi AB) invoices the cooling energy supply to the cooling consumers (private and industrial consumers).
7. The cooling consumers (private and industrial consumers) pay the bill to the MES operator (Mälarenergi AB).

9.2 Austrian Paper Mill

The following sections provide the results of the detailed analysis of the Austrian Paper Mill case study for the electricity, heat and gas sectors.

9.2.1 Electricity sector

Table 20 provides the stakeholders identified for the electricity system, along with the roles they carry out. For confidentiality reasons, some names of stakeholders cannot be given. Then only the type of stakeholder is mentioned.

Table 20 - Austrian paper mill: stakeholders and roles for the electricity system

Stakeholder	Role	Type of role	Comment
Paper mill	Consumer	Internal/external	With respect to the distribution grid, the paper mill is a net consumer of electricity. It self-consumes electricity produced on site and consumes the remaining part from the grid.
Paper mill	Producer	Internal	In average, 60% of the electricity of the paper mill is produced by the CHP (steam turbines) on site.
Paper mill	MES operator	Internal/external	
Paper mill	Distribution system operator	Internal	The paper mill operates an industrial (private) electrical grid with different voltage levels.
Paper mill	Metering-related roles	Internal	The paper mill has a system that monitors the whole production line including steam turbine operation.
Supplier	Supplier	External	Supplies electricity to the paper mill. The paper mill submits its consumption schedule to the supplier.
Supplier	Balance Responsible Party	External	In this case study, the supplier is also the BRP.
Flexibility aggregator	Aggregator	External	The site provides mFRR and aFRR to the Austrian TSO. The flexibility is

Stakeholder	Role	Type of role	Comment
			provided through an aggregator.
Netz Niederösterreich	Distribution system operator	External	DSO of the public grid that delivers electricity to the paper mill.
Netz Niederösterreich	Metering-related roles	External	In Austria, the DSO is also the meter operator.
EPEX SPOT	Energy market operator	External	Operates the main day ahead and intraday energy markets
EXAA	Energy market operator	External	Operates day-ahead energy market for the areas of Germany and Austria, in parallel to EPEX SPOT.
EEX or other stakeholder	Energy market operator	External	Long term trading
Austrian Power Grid (APG)	Transmission system operator	External	Sends activation signals to the aggregator for mFRR and aFRR
APG	Balancing market operator	External	Operates the balancing market, in particular the FCR, aFRR and mFRR procurement mechanisms. Receives flexibility offers.
APCS	Imbalance settlement agent	External	This role is carried out by a player different from the TSO.
E-Control	Regulator	External	Regulator for the electricity and natural gas markets in Austria

Figure 18 shows the main relevant interactions between the identified roles and provides the sequence diagram for the electricity system for the participation in long term trading, aFRR/mFRR daily auctions and day ahead energy market.

Remarks: in the figure, for simplicity and in order to highlight the main relevant interactions,

- the interactions with the Regulator are not represented,
- the supplier and BRP roles are merged in one role, namely the BRP role,
- the TSO role is merged with the role of Balancing Market Operator, since they are both carried out by the same player (APG),
- the metering-related roles are merged with the DSO role since they are indeed carried out by the DSO.

In addition, it should be highlighted that a large part of the long term and day ahead trading is still carried out through OTC trading. Representing this situation in Figure 18 can be done by replacing the interactions between the Supplier/BRP and the Energy Market Operator (steps 2, 3, 9 and 10) by OTC trading.

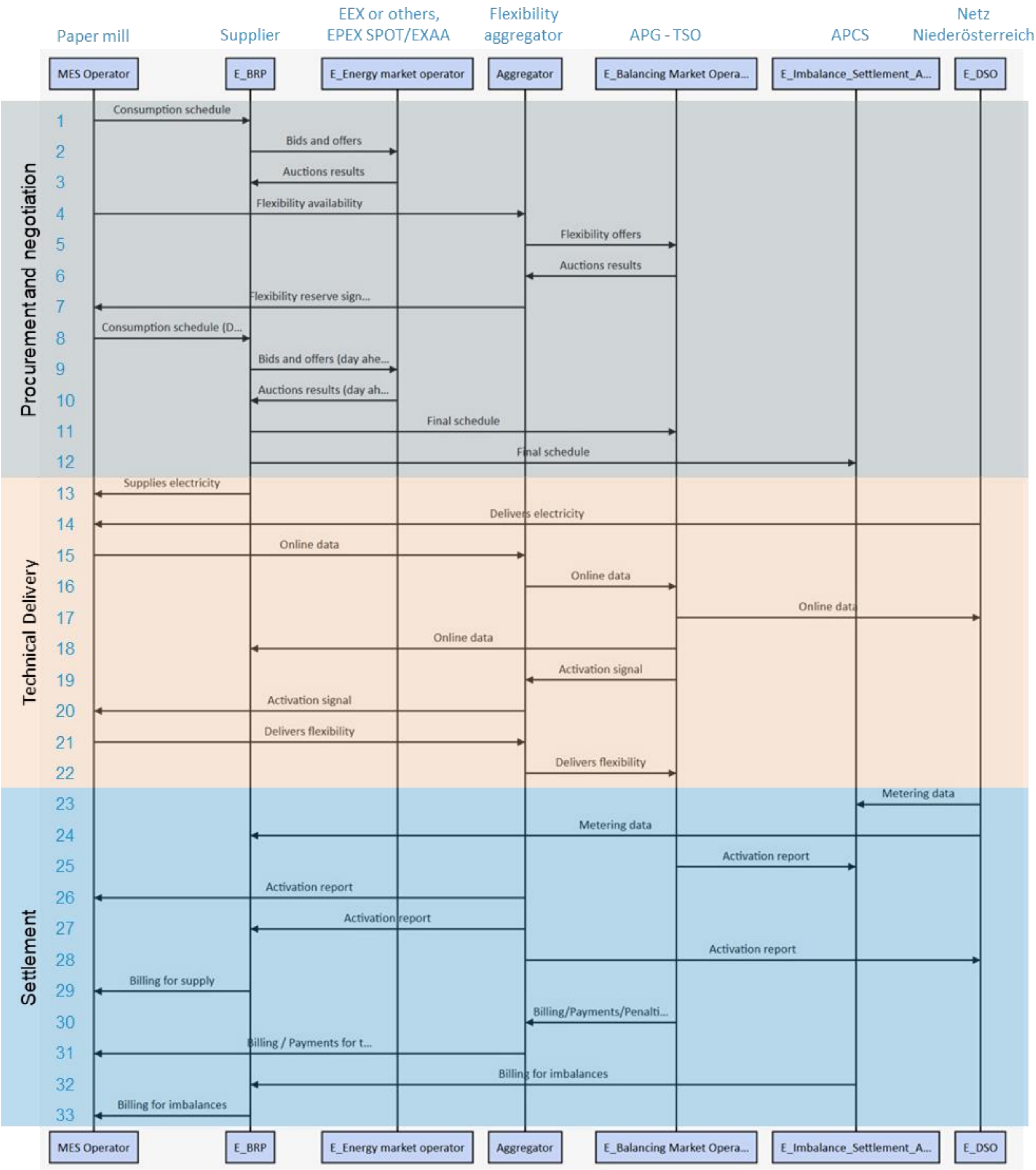


Figure 18 – Austrian paper mill: sequence diagram for the electricity system

The interactions are further detailed below for the three main phases of the service provision process.

Procurement and negotiation phase

1. For longer term trading than day ahead, the MES Operator (Paper mill) communicates the indicative consumption schedule to the supplier who is also the BRP (Supplier).

2. The BRP (Supplier) engages in long term trading and therefore submits bids/offers to the energy market operator (EEX or other).
3. The energy market operator (EEX or other) communicates the auction results to the BRP (Supplier).
4. The MES Operator (Paper mill) sends flexibility availability schedules to the Aggregator (Aggregator).
5. The Aggregator (Aggregator) offers the flexibility of the pool and submits bids for mFRR/aFRR to the Balancing Market operator (APG, TSO).
6. The Balancing Market operator (APG, TSO) informs the Aggregator (Aggregator) about the auction results (contracted flexibility).
7. The Aggregator (Aggregator) informs the MES Operator (Paper mill) about flexibility to be reserved and related prices
8. The MES Operator (Paper mill) communicates the day ahead consumption schedule to the supplier who is also the BRP (Supplier).
9. The BRP (Supplier) engages in trade in the day-ahead market and therefore submits bids/offers to the energy market operator (EPEX SPOT/EXAA).
10. The energy market operator (EPEX SPOT/EXAA) communicates the auction results to the BRP (Supplier).
11. After the gate closure of the day-ahead and intraday markets, the BRP (Supplier) sends the final consumption schedule to the TSO/Balancing Market operator (APG, TSO).
12. After the gate closure of the day-ahead and intraday markets, the BRP (Supplier) sends the final consumption schedule to the Imbalance Settlement Agent (APCS).

Technical delivery

13. From the transactional perspective, the BRP (Supplier) "supplies" electricity to the MES Operator (Paper mill),
14. whereas the physical delivery of electricity to the MES Operator (Paper mill) is carried out by the Distribution network or the DSO (Netz Niederösterreich).
15. The MES Operator (Paper mill) sends online data (active power measurements, availability, activation…) to the Aggregator (Aggregator).
16. The Aggregator (Aggregator) sends online data of the pool to the TSO, who is also the Balancing Market operator (APG, TSO).
17. The Balancing Market operator (APG, TSO) sends aggregated online data of all the units of the distribution area to the DSO (Netz Niederösterreich).
18. The Balancing Market operator (APG, TSO) sends the BRP (Supplier) aggregated online data (activation of aFRR and mFRR) of all the units of the BRP portfolio.
19. If it is needed for the control of the frequency, the TSO/Balancing Market operator (APG, TSO) sends activation signals to the Aggregator (Aggregator).
20. The Aggregator (Aggregator) dispatches the resources in its pool and accordingly sends an activation signal to the MES Operator (Paper mill).
21. The MES Operator (Paper mill) delivers the requested flexibility to the Aggregator (Aggregator).
22. The Aggregator (Aggregator) in turn delivers the requested flexibility of its pool to the TSO/Balancing Market operator (APG, TSO).

Settlement

23. The DSO (Netz Niederösterreich) sends metering data to the Imbalance Settlement Agent (APCS)

24. The DSO (Netz Niederösterreich) sends metering data to the BRP (Supplier).
25. The TSO/Balancing Market operator (APG, TSO) sends the report on the activations to the Imbalance Settlement Agent (APCS).
26. The Aggregator (Aggregator) sends the report on the MES activations (including time series, revenues) to the MES Operator (Paper mill).
27. The Aggregator (Aggregator) sends the report on the activations of the relevant resources in its pool to the BRP (Supplier) for correction of schedules.
28. The Aggregator (Aggregator) sends the report on the activations of the relevant resources in its pool to the DSO (Netz Niederösterreich) for grid tariff calculation (ancillary services are treated under special network tariff schemes).
29. The BRP (Supplier) invoices the MES Operator (Paper mill) for the electricity supply.
30. The Balancing Market operator (APG, TSO) provides the billing for the payments/penalties to the Aggregator (Aggregator) according to framework contract, accepted bids and activation performance.
31. The Aggregator (Aggregator) provides contractual payments to MES Operator (Paper mill).
32. The Imbalance Settlement Agent (APCS) provides the billing for the payments/penalties related to the imbalances to the BRP (Supplier).
33. The BRP (Supplier) invoices imbalances to the MES Operator (Paper mill).

Additional steps not represented in Figure 18, consists of the billing of the grid tariff by the DSO (Netz Niederösterreich) and the associated payment made by the MES Operator (Paper mill).

9.2.2 Heat sector

Table 21 provides the stakeholders identified for the heat system, along with the roles they carry out.

Table 21 - Austrian paper mill: stakeholders and roles for the heat system

Stakeholder	Role	Type of role	Comment
Paper mill	Consumer	Internal	Consumes heat generated on site.
Paper mill	Producer	Internal/external	Three gas-fired and one biomass-fired steam generators. Steam is consumed internally, and a small amount of heat is fed to the public district heating network upon request from the heat network operator. Additionally, the paper mill provides a supply backup service for the main heat generator of the heating network operator.
Paper mill	Storage provider	Internal	Steam accumulator on site
Paper mill	Network operator	Internal	Operates the steam network on site
Paper mill	Metering-related roles	Internal	The paper mill has a system that monitors the whole production line including steam turbine operation

Stakeholder	Role	Type of role	Comment
Paper mill	MES operator	Internal/external	
BAW – Biowärme Amstetten West GmbH	Heat DSO	External	The public district heating network operator. As shown below, the heat network operator is also the heat supplier and a heat producer.
BAW – Biowärme Amstetten West GmbH	Supplier	External	
BAW – Biowärme Amstetten West GmbH	Producer	External	
BAW – Biowärme Amstetten West GmbH	Metering-related roles	External	

Figure 19 shows the main relevant interactions between the identified roles and provides the sequence diagram for the heat system.

Remarks: in the figure, for simplicity and in order to highlight the main relevant interactions,

- the Paper mill roles of heat producer and storage provider are merged with the MES operator role,
- the heat producer role and supplier role of BAW – Biowärme Amstetten West GmbH are merged with the DSO role which is also carried out by this stakeholder,
- in the same way, the metering-related roles for the district heating network are merged with the DSO role since they are carried out by the district heating network operator.

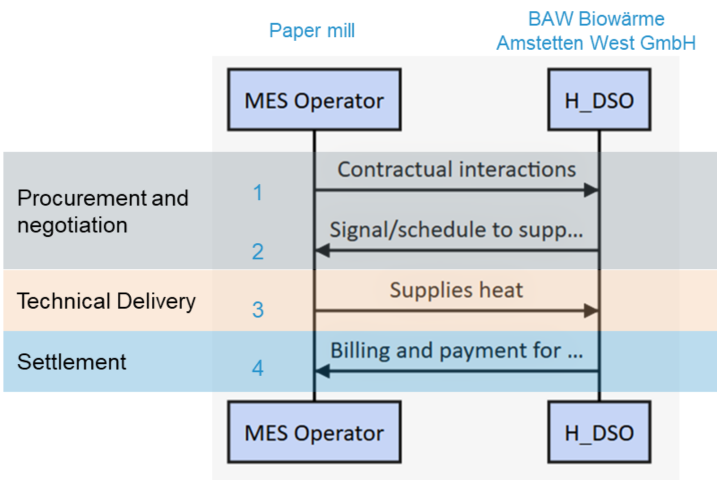


Figure 19 - Austrian paper mill: sequence diagram for the heat system

This case study focusses on the paper mill. So, since its core business is to produce paper and that only a small amount of heat is injected in the district heating network, the relevant interactions for the heat sector are very limited. Anyway, they are further detailed below for the three main phases of the service provision process.

Procurement and negotiation

1. The MES Operator (Paper Mill) establishes a contract with the heat DSO (BAW – Biowärme Amstetten West GmbH) for the heat provision to the district heating network.
2. When needed, the heat DSO (BAW – Biowärme Amstetten West GmbH) sends a signal and the schedule to supply heat to the MES Operator (Paper Mill).

Technical delivery

3. The MES Operator (Paper Mill) supplies heat to the heat DSO (BAW – Biowärme Amstetten West GmbH).

Settlement

4. The heat DSO (BAW – Biowärme Amstetten West GmbH) provides the contractual payments to the MES Operator (Paper mill).

9.2.3 Gas sector

Table 22 provides the stakeholders identified for the gas system, along with the roles they carry out. For confidentiality reasons, some names of stakeholders cannot be given. Then only the type of stakeholder is mentioned.

Table 22 - Austrian paper mill: stakeholders and roles for the gas system

Stakeholder	Role	Type of role	Comment
Paper mill	Consumer	Internal/external	The paper mill consumes gas for the steam generators.
Paper mill	MES operator	Internal/external	
Gas supplier	Supplier	External	Provides gas to the paper mill.
Netz Niederösterreich	Gas DSO	External	Natural gas is provided from the public grid.
Netz Niederösterreich	Metering-related roles	External	
E-Control	Regulator	External	Regulator for the electricity and gas markets in Austria

It should be noted that this table only shows the stakeholders and roles which directly interact with the MES. Further stakeholders and roles, like the gas shipper and BRP, gas TSO, gas market operator, gas imbalance settlement agent, etc. are not represented in this section since there is no direct impact on the MES, which is a sole gas consumer. The gas supplier and the gas DSO fulfil the main interactions with the other roles and integrate any related costs into the invoices to the MES. Indeed, the structure of the whole gas system and the interactions between the stakeholders for the day ahead gas market and longer-term trading are rather similar to the ones of the electricity system. In the same way, balancing mechanisms are also implemented. The organisation of the gas system is described in detail in Section 4.3 and a specific example is given for the NPT case study (Section 9.5.3).

Figure 20 shows the main relevant interactions between the identified roles and provides the sequence diagram for the gas system. In the Austrian case study, the MES is only a gas consumer, so the relevant interactions for the gas sector are very limited. As explained above, the interactions between the gas supplier or the gas DSO and the other roles not directly communicating with the MES are not represented.

Remarks: in the figure, for simplicity and in order to highlight the main relevant interactions,

- the interactions with the Regulator are not represented,
- the Paper mill role of gas consumer is merged with the MES operator role,
- the metering-related roles are merged with the DSO role since they are carried out by the gas network operator.

The interactions are further detailed below for the three main phases of the service provision process.

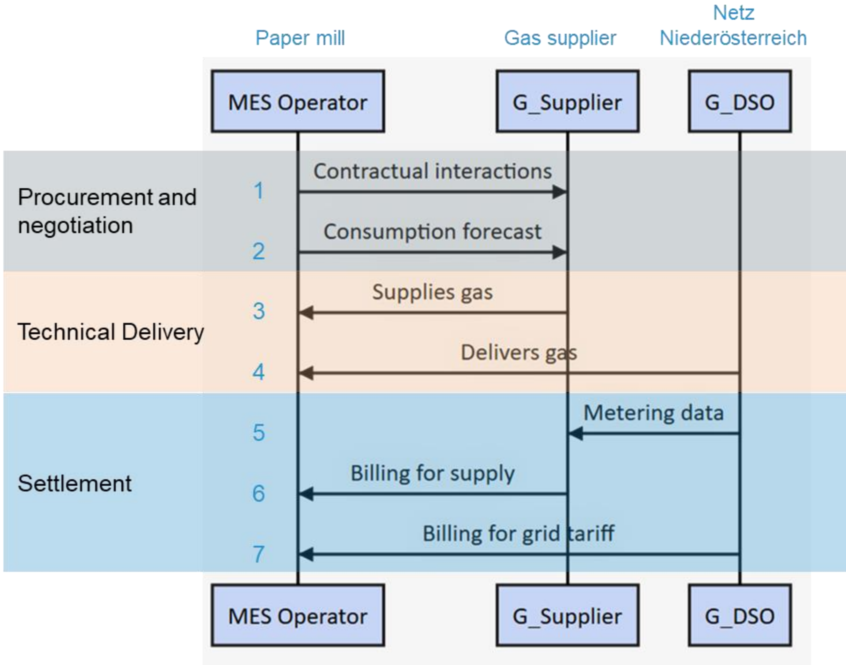


Figure 20 - Austrian paper mill: sequence diagram for the gas system

Procurement and negotiation

1. The MES Operator (Paper Mill) signs a contract with the gas supplier (Gas Supplier) for the procurement of gas.
2. The MES Operator (Paper Mill) send its gas consumption forecast to the gas supplier (Gas Supplier).

Technical delivery

3. From the transactional perspective, the gas supplier (Gas Supplier) "supplies" gas to the MES Operator (Paper mill);
4. But the physical delivery of gas to the MES Operator (Paper mill) is carried out through the gas network of the gas DSO (Netz Niederösterreich).

Settlement

5. The gas DSO (Netz Niederösterreich) sends metering data to the gas supplier (Gas Supplier).
6. The gas supplier (Gas Supplier) invoices the MES Operator (Paper Mill) for the gas supplied.
7. The gas DSO (Netz Niederösterreich) invoices the MES Operator (Paper Mill) for the payment of grid tariffs.

9.3 HOFOR

The following sections provide the results of the detailed analysis of the HOFOR case study for the electricity and heat sectors. The gas and cooling sectors are not involved in this case study.

9.3.1 Electricity sector

Table 23 provides the stakeholders identified for the electricity system, along with the roles they carry out.

Table 23 - HOFOR: stakeholders and roles for the electricity system

Stakeholder	Role	Type of role	Comment
HOFOR	MES operator	External	
HOFOR	Consumer	External	Electric consumption of • the heat pumps and thermal storages in multi-storey multi-family buildings, • the electric boosters and thermal storages in row houses.
Supplier	Supplier	External	The supplier(s) of the heat network consumers may be different from HOFOR's supplier
Supplier	BRP	External	It is assumed here that the supplier(s), namely HOFOR's supplier and/or the supplier(s) of the heat consumers, are also BRPs. But the BRPs may also be different players.
Consumers	Consumers	External	Multi-storey multi-family buildings and row houses.
Radius	Distribution System Operator	External	
Radius	Metering-related roles	External	
Energinet	Transmission System Operator	External	
Energinet	Imbalance settlement Agent	External	

Energinet	*Data Hub operator* (ICT-related role)	External	New role introduced here due to the specificities of the Danish system. It is part of the “ICT-related roles” of Table 11.
Nordpool	Energy market operator	External	
Danish Utility Regulator (DUR)	Regulator	External	Supervision of the utility sectors: electricity, natural gas and district heating.

Figure 21 shows the main relevant interactions between the identified roles and provides the sequence diagram for the electricity system.

Remarks: in the figure, for simplicity and in order to highlight the main relevant interactions,

- the interactions with the Regulator are not represented,
- the HOFOR role of consumer is merged with the MES operator role,
- as explained in Table 23, the suppliers involved in the case study are assumed to be BRP too,
- The role of supplier appears only once even different stakeholders may be the suppliers for HOFOR and the heat consumers (this is in accordance with the usual practice in sequence diagrams where one role is represented only once),
- the roles of imbalance settlement agent and data hub operator are merged with the TSO role, since all three are carried out by Energinet,
- the metering-related roles are merged with the DSO role since both are carried out by Radius.

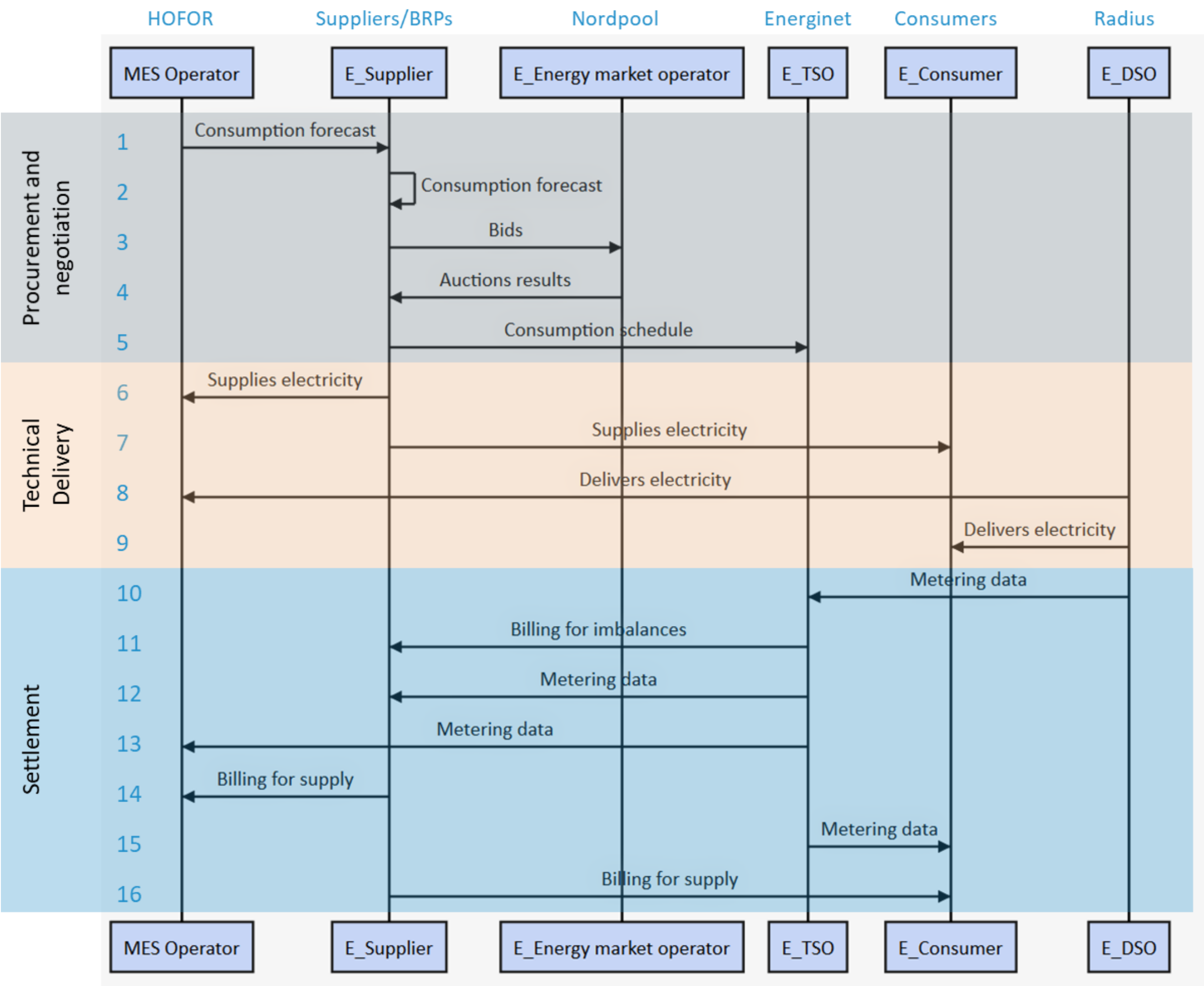


Figure 21 - HOFOR: sequence diagram for the electricity system

The interactions are further detailed below for the three main phases of the service provision process.

Procurement and negotiation phase

1. The MES Operator (HOFOR) communicates its consumption forecast to its supplier who is also a BRP (Suppliers/BRPs).
2. The suppliers (Suppliers/BRPs) forecast the consumption of all the consumers in their portfolios.
3. The suppliers (Suppliers/BRPs) submit bids to the energy market operator (Nordpool).
4. The energy market operator (Nordpool) communicates the auction results to the suppliers (Suppliers/BRPs).
5. The suppliers (Suppliers/BRPs) send the consumption schedule to the TSO who is also the Imbalance Settlement Agent (Energinet).

Technical delivery

6. From the transactional perspective, HOFOR's supplier (Suppliers/BRPs) "supplies" electricity to the MES Operator (HOFOR).

7. In the same way, the consumers' suppliers (Suppliers/BRPs) "supply" electricity to the consumers (Consumers) in their portfolio.
8. But the physical delivery of electricity to the MES Operator (HOFOR) is ensured by the distribution network or the DSO (Radius).
9. In the same way, the DSO (Radius) ensures the physical delivery of electricity to the consumers (Consumers).

Settlement

10. The DSO (Radius) sends metering data to the TSO (Energinet), who is the Imbalance Settlement Agent and also the data hub operator.
11. The Imbalance Settlement Agent (Energinet) provides the billing for the imbalances to the BRPs, who are also the suppliers (Suppliers/BRPs).
12. The TSO (Energinet), as part of its role of data hub operator, sends metering data to the suppliers (Suppliers/BRPs).
13. The MES operator (HOFOR) can get its metering data from the data hub operated by the TSO (Energinet).
14. HOFOR's supplier (Suppliers/BRPs) invoices the MES operator (HOFOR) for the electricity supply.
15. The consumers (consumers) can get their metering data from the data hub operated by the TSO (Energinet).
16. The suppliers (Suppliers/BRPs) invoice the consumers (consumers) for the electricity supply.

9.3.2 Heat sector

The HOFOR case study mainly focuses on distributed units for domestic hot water preparation at consumers' connected to the district heating network, namely heat pumps and thermal accumulator tanks in multi-storey buildings, and electric boosters and thermal storages in row houses. Considering only this scope, the number of roles is rather limited, as well as their interactions.

However it appears relevant to describe the more general framework of the integrated heat market implemented in the Greater Copenhagen area, which includes a day ahead planning and intra-day adjustments [32]. This integrated system is particularly interesting for the MAGNITUDE's goals.

Table 24 provides the stakeholders identified for the heat system, along with the roles they carry out.

Table 24 - HOFOR: stakeholders and roles for the heat system

Stakeholder	Role	Type of role	Comment
HOFOR	Producer	Internal/External	• CHP, heat pumps for the district heating network. • Heat pumps in multi-storey multi-family buildings and electric boosters in row houses.
HOFOR	Storage provider	Internal/External	• Thermal storage. • Hot water accumulation tanks with an integrated heat exchanger for

Stakeholder	Role	Type of role	Comment
			connecting to district heating are installed in all buildings.
HOFOR	MES operator	Internal/External	
HOFOR	Supplier	Internal/External	
HOFOR	Distribution System Operator	Internal/External	District heating system is owned and operated by HOFOR.
HOFOR	Metering-related roles	Internal/External	The main heat meter measures water flow, temperature and pressure in supply pipe and return pipe.
CTR	Transmission system operator	External	
Heat consumers	Consumer	External	
Varmelast	Market Operator	External	Even if it is not a market like in the electricity sector, Varmelast is responsible for the daily planning and the dispatch of the heat production based on the bids made by the producers, which can be assimilated to some extent to a market operator role. Both a day ahead mechanism and intraday adjustments are involved.
Municipality	Regulator	External	
Danish Utility Regulator (DUR)	Regulator	External	Supervision of the utility sectors: electricity, natural gas and district heating
Energy Appeal Board	Regulator	External	Deals with appeals against decisions of public authorities and interpretation of laws and regulations.

Figure 22 shows the main relevant interactions between the identified roles and provides the sequence diagram for the heat system.

Remarks: in the figure, for simplicity and in order to highlight the main relevant interactions,

- the interactions with the different types of regulatory bodies are not represented,
- the HOFOR role of storage provider is merged with the heat producer role,
- the HOFOR roles of heat supplier and MES operator are merged with the heat DSO role, as well as the metering-related roles, since they are all carried out by the same player, the heat network operator (HOFOR).

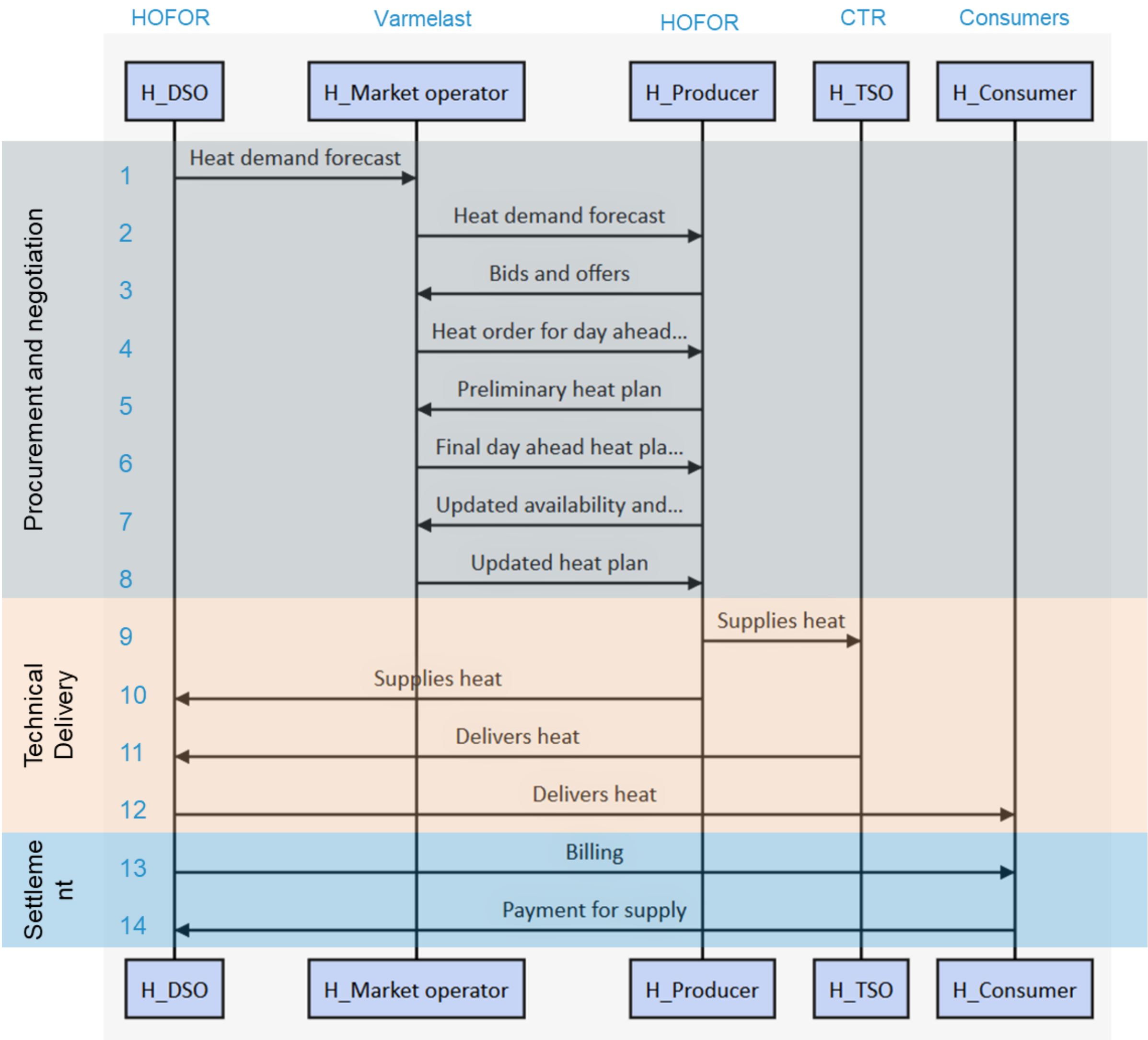


Figure 22 – HOFOR: sequence diagram for the heat system

The interactions are further detailed below for the three main phases of the service provision process.

Procurement and negotiation phase [32]

1. In day ahead, the district heating network operator or heat DSO (HOFOR) and the other heat DSOs (not represented) communicate their heat demand forecast to the market operator (Varmelast).
2. The market operator (Varmelast) aggregates the heat demand forecasts received from the heat DSOs and sends the heat load forecast to the producer (HOFOR) and to the other heat producers (not represented).
3. The producer (HOFOR) and the other heat producers submit their bids (combinations of heat generation and prices for all their units) to the market operator (Varmelast).
4. The market operator (Varmelast) sends heat order for day ahead production for each unit of the producer (HOFOR) and the other heat producers.
5. The producer (HOFOR) and the other heat producers send their preliminary heat generation plan to the market operator (Varmelast).

6. The market operator (Varmelast) corrects the preliminary plans according to heat load profile and the most important bottlenecks in the heat system and sends the final heat generation plans to the producer (HOFOR) and the other heat producers.
7. In intraday, at five specific times during the day, the producer (HOFOR) and the other heat producers have the possibility to send an updated heat generation plan (updated availability and marginal cost of changing the heat load for each unit) to the market operator (Varmelast).
8. The market operator (Varmelast) then sends the updated heat plans to the producer (HOFOR) and the other heat producers.

Technical delivery

9. The producer (HOFOR) generates and provides heat to the heat TSO (CTR).
10. For small units connected directly to the district heating system, the producer (HOFOR) generates and provides heat to the heat DSO (HOFOR). In the same way but only from a transactional perspective, for the units directly installed at the consumers', the producer (HOFOR) generates and provides heat to the heat DSO (HOFOR).
11. The heat TSO (CTR) delivers heat to the heat DSO (HOFOR).
12. The heat DSO (HOFOR) delivers heat to the consumers (Consumers).

Settlement

13. The heat DSO (HOFOR) collects and processes the metered data and invoices the consumers (Consumers) for the heat supply.
14. The consumers (Consumers) pay for the heat supply.

9.4 ACS

The following sections provide the results of the detailed analysis of the ACS case study for the electricity, heat and gas sectors.

9.4.1 Electricity sector

Table 25 provides the stakeholders identified for the electricity system, along with the roles they carry out.

Table 25 - ACS: stakeholders and roles for the electricity system

Stakeholder	Role	Type of Role	Comment
ACS	Producer	Internal/external	CHPs
ACS	Consumer	Internal/external	Heat pumps, electric boiler
ACS	MES Operator	Internal/External	
A2A	Aggregator	External	Aggregates ACS generation and submits bids to the day ahead and intraday energy markets

Stakeholder	Role	Type of Role	Comment
A2A	Balance Responsible Party	External	
A2A Energia	Supplier	External	Supplies electricity to ACS
UNARETI	DSO	External	
UNARETI	Metering-related roles	External	
Terna	TSO	External	
Terna	Imbalance settlement Agent	External	
Consumers	Consumer	External	Other electricity consumers
Gestore Mercati Energetici (GME)	Market Operator	External	
Autorità di Regolazione per Energia Reti e Ambiente (ARERA)	Regulator	External	Italian regulator for energy, networks and environment. Carries out regulatory and supervisory activities in the sectors of electricity, natural gas, water services, waste cycle and district heating.
Gestore Servizi Energetici (GSE)	Regulator	External	Manages incentive mechanisms Pays for green certificates due for the power produced by the CHPs. Pays for green certificates due for the power produced by natural gas.

Figure 23 shows the main relevant interactions between the identified roles and provides the sequence diagram for the electricity system.

Remarks: in the figure, for simplicity and in order to highlight the main relevant interactions,

- the interactions with the different types of regulatory bodies are not represented,
- the ACS roles of producer and consumer are merged with the MES operator role,
- the aggregator role of A2A is merged with its BRP role,
- the TSO role of Terna is merged with its role of Imbalance settlement Agent,
- the metering-related roles of UNARETI are merged with its DSO role.

The interactions are further detailed below for the three main phases of the service provision process.

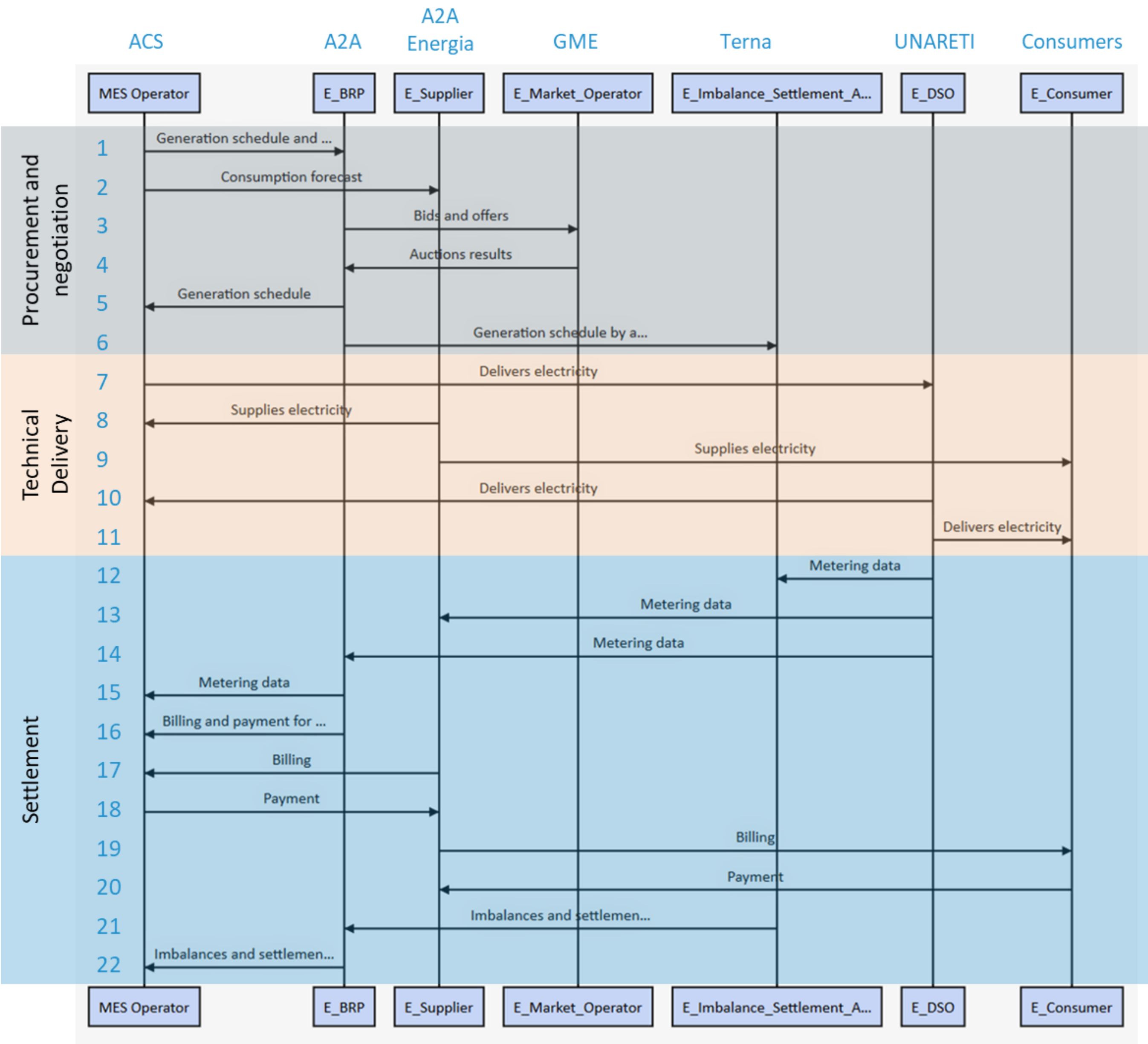


Figure 23 - ACS: sequence diagram for the electricity system

Procurement and negotiation

1. The MES Operator (ACS) communicates the schedule of electricity generation to the aggregator who is also the BRP (A2A).
2. The MES Operator (ACS) communicates the consumption forecast to the supplier (A2A Energia).
3. The BRP (A2A) engages in trade in the day-ahead and intraday markets and therefore submits bids/offers to the market operator (GME).
4. The market operator (GME) communicates the auction results (day-ahead and intraday) to the BRP (A2A).
5. The BRP (A2A) confirms the final generation schedule to the MES Operator (ACS).
6. The BRP (A2A) sends the final consumption/generation schedule of the assets in its portfolio to the TSO who is also the Imbalance Settlement Agent (Terna) after the closure of the markets.

Technical delivery

7. The MES Operator (ACS) physically delivers the electricity generated to the distribution grid or the DSO (UNARETI).
8. From the transactional perspective, the Supplier (A2A Energia) "supplies" electricity to the MES Operator (ACS).
9. From the transactional perspective, the Supplier (A2A Energia) "supplies" electricity to the other consumers (Consumers).
10. But the physical delivery of electricity to the MES Operator (ACS) is ensured by the distribution network or the DSO (UNARETI).
11. In the same way, the physical delivery of electricity to the other consumers (Consumers) is ensured by the distribution network or the DSO (UNARETI).

Settlement

12. The DSO (UNARETI) sends the metering data to the Imbalance Settlement Agent (Terna).
13. The DSO (UNARETI) sends the metering data to the supplier (A2A Energia) for the consumers in its portfolio.
14. The DSO (UNARETI) sends the metering data to the aggregator-BRP (A2A) for the assets in its portfolio.
15. The aggregator-BRP (A2A) sends the relevant metering data to the MES Operator (ACS), which will be used for the payment of the green certificates by GSE (see below).
16. The aggregator-BRP (A2A) provides the contractual payments to the MES Operator (ACS) for the electricity generated.
17. The electricity supplier (A2A Energia) invoices the MES Operator (ACS Canavese) for the supply of electricity.
18. The MES Operator (ACS) pays the supplier (A2A Energia) for the electricity supplied.
19. The electricity supplier (A2A Energia) invoices the other consumers (Consumers) for the supply of electricity.
20. The other consumers (Consumers) pay the supplier (A2A Energia) for the electricity supplied.
21. The Imbalance Settlement Agency (Terna) provides the billing for the payments/penalties related to the imbalances and ensures the payment flows with the BRP (A2A).
22. The BRP (A2A) settles payments or penalties related to the imbalances with the MES Operator (ACS)

The whole process involves some additional steps that are not represented in the above sequence diagram, namely:

- The interactions between the MES Operator (ACS) and the regulator (GSE) for the payments by GSE of green certificates earned for the electricity generated by the CHPs of ACS.
- The interactions between the supplier (A2A Energia) and other roles for the energy procurement: for instance with the market operator (GME), with a trader, a BRP or with a producer in case of OTC, as well as the interactions between the supplier role and the BRP role for the settlement of imbalances.

9.4.2 Heat sector

Table 26 provides the stakeholders identified for the heat system, along with the roles they carry out.

Table 26 - ACS: stakeholders and roles for the heat system

Stakeholder	Role	Type of Role	Comment
ACS	Producer	Internal/external	CHPs, heat pumps, electric and gas boilers
ACS	Storage provider	Internal/external	Thermal storage – Installed capacity 22 MWt
ACS	MES Operator	Internal/external	
ACS	Distribution System Operator	Internal/external	Owns and manages the East Milan district heating
ACS	Metering-related roles	Internal/external	
ACS	Supplier	Internal/external	
SEA Energia Linate	Producer	External	CHP plants
Municipality, residential, tertiary…	Consumer	External	
Municipality	*Ground owner*	*External*	*(30 years) concession to host the District Heating (DH) network: receives a yearly rent for the DH network.* *ACS pays the Municipality a DH network fee for the usage of the ground.*
Autorità di Regolazione per Energia Reti e Ambiente (ARERA)	Regulator	External	Italian regulator for energy, networks and environment. Carries out regulatory and supervisory activities in the sectors of electricity, natural gas, water services, waste cycle and district heating.

In the table, a special role has been added to take into account the relationship between ACS and the Municipality who is the ground owner and receives a yearly rent from the heat network operator. Even if this role and the associated interactions are important for the district heating business model, this ground owner role is not represented in the sequence diagram below.

Figure 24 shows the main relevant interactions between the identified roles and provides the sequence diagram for the heat system.

Remarks: in the figure, for simplicity and in order to highlight the main relevant interactions,

- the interactions with the regulator and the ground owner are not represented,
- the ACS role of storage provider is merged with the producer role,
- the ACS supplier role is merged with its MES operator role,

- the metering-related roles of ACS are merged with its DSO role.

The interactions are further detailed below for the three main phases of the service provision process.

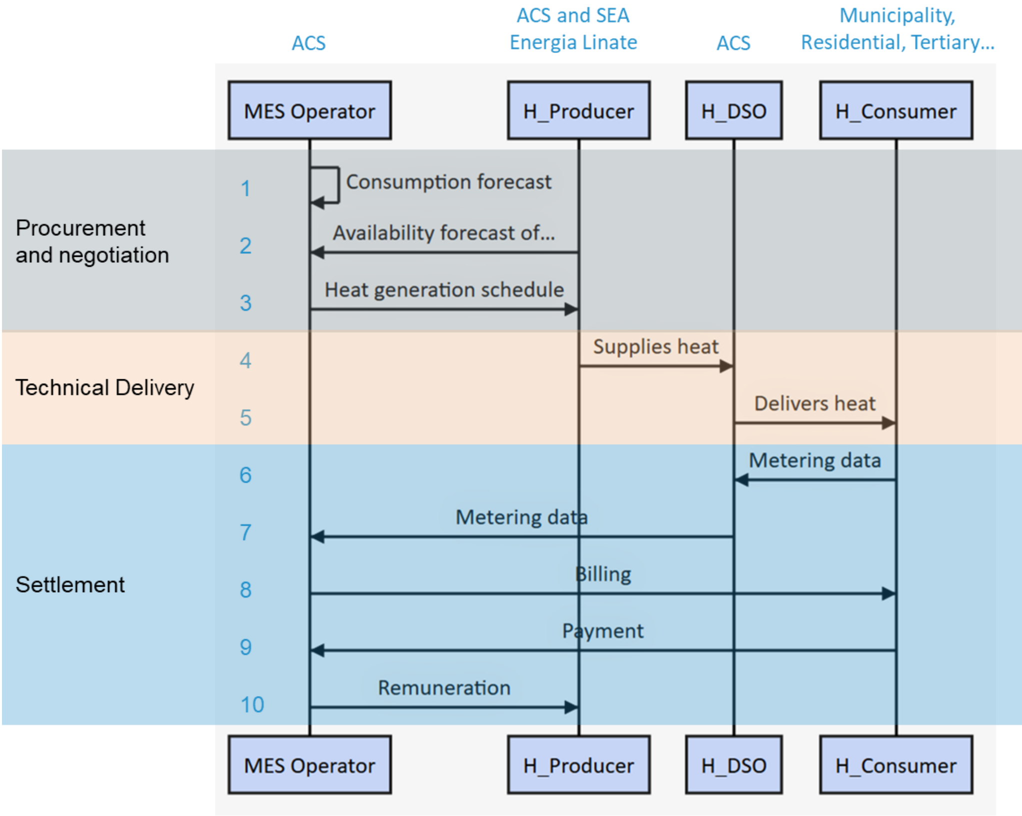


Figure 24 - ACS: sequence diagram for the heat system

Procurement and negotiation

1. The MES Operator (ACS) assessed the expected thermal load or heat demand of the heat consumers (and consequently the electrical production and consumption forecast of the plant) according to the day-ahead ambient temperature forecast.
2. The heat producers (ACS and SEA Energia Linate) send their heat generation availability forecast to the MES Operator (ACS).
3. Based on the forecasts, the MES Operator (ACS) computes and sends the heat generation schedule to the heat producers (ACS and SEA Energia Linate).

Technical delivery

4. The heat producers (ACS and SEA Energia Linate) generate and provide heat to the heat DSO (ACS).
5. The heat DSO (ACS) delivers heat to the consumers (Municipality, residential, tertiary…).

Settlement

6. The heat consumers (Municipality, residential, tertiary…) make the metering data available to the heat DSO (ACS), who collects them.
7. The heat DSO (ACS) sends metering data on the actual consumption to the MES Operator (ACS).
8. The MES Operator (ACS) invoices the heat consumers (Municipality, residential, tertiary…).

9. The heat consumers (Municipality, residential, tertiary…) pay the MES Operator (ACS) for the heat consumed.
10. The MES Operator (ACS Canavese) remunerates the third-party heat producer (SEA Energia Linate) for the heat fed into the heat network.

9.4.3 Gas sector

Table 27 provides the stakeholders identified for the gas system, along with the roles they carry out.

Table 27 - ACS: stakeholders and roles for the gas system

Stakeholder	Role	Type of Role	Comment
ACS	Consumer	Internal/external	Gas engines, gas boilers.
ACS	MES Operator	Internal/external	
A2A Energia	Supplier	External	A2A Energia provides both electricity and gas to ACS
UNARETI	Distribution Network Operator	External	UNARETI is the operator of both the electric distribution network and the gas distribution network.
UNARETI	Metering-related roles	External	
Società Nazionale Metanodotti (SNAM)	Transmission Network Operator	External	Planning, building, managing, storage.
Gestore Mercati Energetici (GME)	Market Operator	External	
Autorità di Regolazione per Energia Reti e Ambiente (ARERA)	Regulator	External	Italian regulator for energy, networks and environment. Carries out regulatory and supervisory activities in the sectors of electricity, natural gas, water services, waste cycle and district heating.

Figure 25 shows the main relevant interactions between the identified roles and provides the sequence diagram for the gas system.

Remarks: in the figure, for simplicity and in order to highlight the main relevant interactions,

- the interactions with the regulator are not represented,
- the ACS role of consumer is merged with its MES operator role,
- the metering-related roles of UNARETI are merged with its DSO role.

The interactions are further detailed below for the three main phases of the service provision process.

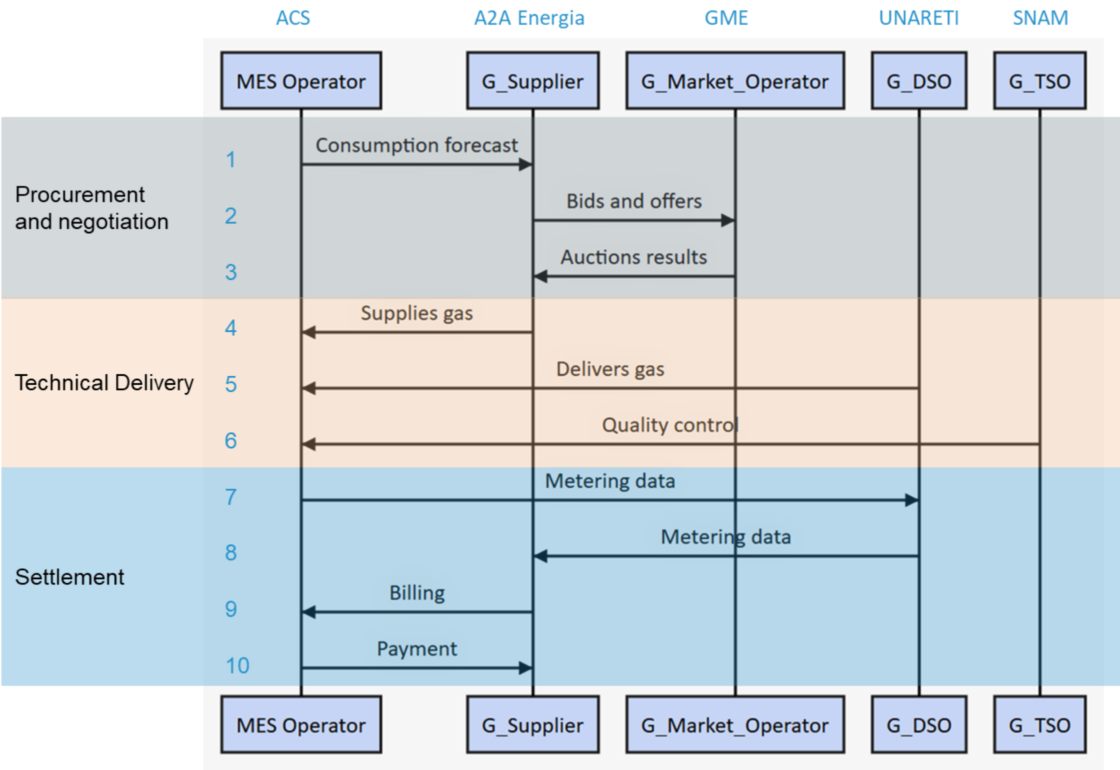


Figure 25 - ACS: sequence diagram for the gas system

Procurement and negotiation

1. The MES Operator (ACS) communicates its consumption forecast to the gas supplier (A2A Energia).
2. The gas Supplier (A2A Energia) engages in trade in the day-ahead and intraday gas markets and submits bids/offers to the market operator (GME).
3. The market operator (GME) communicates the auction results to the gas supplier (A2A Energia).

Technical delivery

4. From the transactional perspective, the supplier (A2A Energia) "supplies" gas to the MES Operator (ACS).
5. But the physical delivery of gas to the MES Operator (ACS) is ensured by the distribution network or the DSO (UNARETI).
6. The gas TSO (SNAM) measures and checks the quality of the gas delivered to the MES Operator (ACS).

Settlement

7. The MES Operator (ACS) makes the metering data available to the DSO (UNARETI).
8. The DSO (UNARETI) sends metering data to the gas Supplier (A2A Energia) for billing purposes.
9. The gas supplier (A2A Energia) invoices the MES Operator (ACS) for the gas consumed.
10. The MES Operator (ACS) pays the Gas Supplier (A2A Energia) for the gas consumed.

9.5 Neath Port Talbot

There are several multi-energy systems to be found in the Neath Port Talbot (NPT) area as described in [1] and [2]. However in MAGNITUDE, the NPT case study focusses on the Baglan Bay 525 MW CCGT power plant and on the TATA Steel works because of their large generation capacity, and electricity and gas consumption.

The following sections provide the results of the detailed analysis of the current situation for the NPT case study for the electricity, heat and gas sectors.

9.5.1 Electricity sector

Table 28 provides the stakeholders identified for the electricity system, along with the roles they carry out.

Table 28 - NPT: stakeholders and roles for the electricity system [33], [34]

Stakeholder	Role	Type of Role	Comment
TATA Steel	Producer	Internal/external	Generated electricity is mainly self-consumed.
TATA Steel	Consumer	Internal/external	Largest single consumer of energy in Wales.
TATA Steel	MES Operator	Internal/external	Tata steel participates in the frequency response market, reserve markets and plans to participate in the capacity market.
Baglan Bay CCGT	Producer	Internal/external	
Baglan Bay CCGT	MES Operator	Internal/external	Consumes gas and produces electricity
Baglan Bay CCGT	BRP	Internal/external	Generating plant connected to the transmission network register as Balancing Mechanism Units (BMUs). They participate in the balancing market.
Supplier/BRP/BMU	Supplier	External	
Supplier/BRP/BMU	BRP	External	
Supplier/BRP/BMU	(Flexibility) Aggregator	External	Suppliers participating in the wholesale market register as Balancing Mechanism Units. They can actively participate in the balancing market if they meet certain conditions.

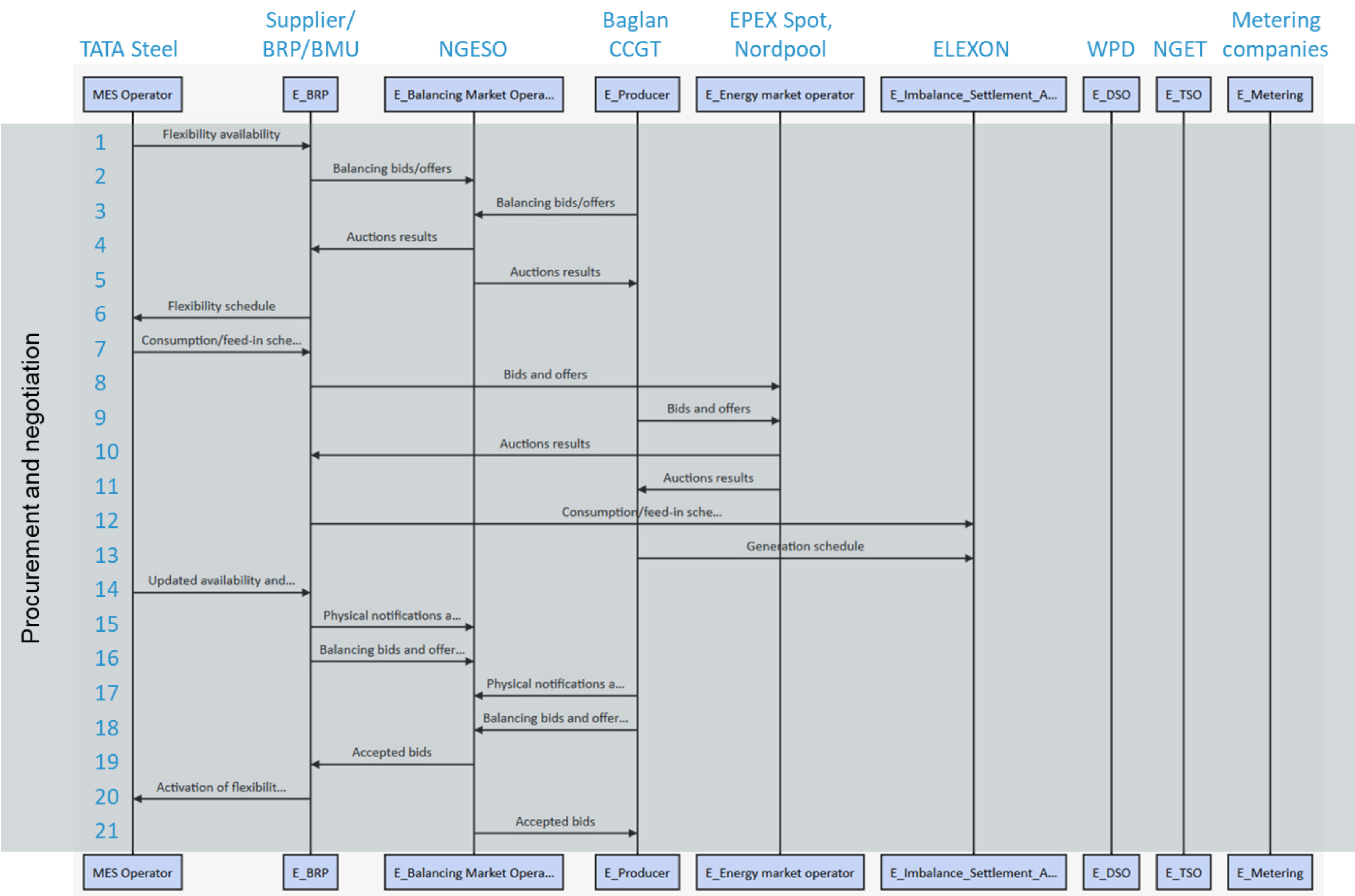
Stakeholder	Role	Type of Role	Comment
EPEX Spot, Nord Pool	Energy Market operator	External	
National Grid Electricity System Operator (NGESO)	Balancing market operator	External	
National Grid Electricity Transmission (NGET)	TSO	External	
EXELON	Imbalance settlement Agent	External	
Western Power Distribution (WPD)	DSO	External	
Metering companies	Metering –related roles	External	There are several metering companies.
Office of Gas and Electricity Markets (OFGEM)	Regulator	External	Independent National Regulatory Authority for the electricity and gas sectors.

Figure 26 shows the main relevant interactions between the identified roles and provides the sequence diagram for the electricity system.

Remarks: in the figure, for simplicity and in order to highlight the main relevant interactions,

- the interactions with the regulator are not represented,
- the Tata Steel roles of producer and consumer are merged with its MES operator role,
- the Baglan Bay CCGT roles of MES operator and BRP (or BMU) are merged with its producer role,
- the roles of supplier and flexibility aggregator of Tata Steel's Supplier are merged with its BRP role.

The interactions are further detailed below for the three main phases of the service provision process.


TATA Steel
Supplier/ BRP/BMU
NGESO
Baglan CCGT
EPEX Spot, Nordpool
ELEXON
WPD
NGET
Metering companies
MES Operator
E_BRP
E_Balancing Market Opera...
E_Producer
E_Energy market operator
E_Imbalance_Settlement_A...
E_DSO
E_TSO
E_Metering
Procurement and negotiation
1 Flexibility availability
2 Balancing bids/offers
3 Balancing bids/offers
4 Auctions results
5 Auctions results
6 Flexibility schedule
7 Consumption/feed-in sche...
8 Bids and offers
9 Bids and offers
10 Auctions results
11 Auctions results
12 Consumption/feed-in sche...
13 Generation schedule
14 Updated availability and...
15 Physical notifications a...
16 Balancing bids and offer...
17 Physical notifications a...
18 Balancing bids and offer...
19 Accepted bids
20 Activation of flexibilit...
21 Accepted bids

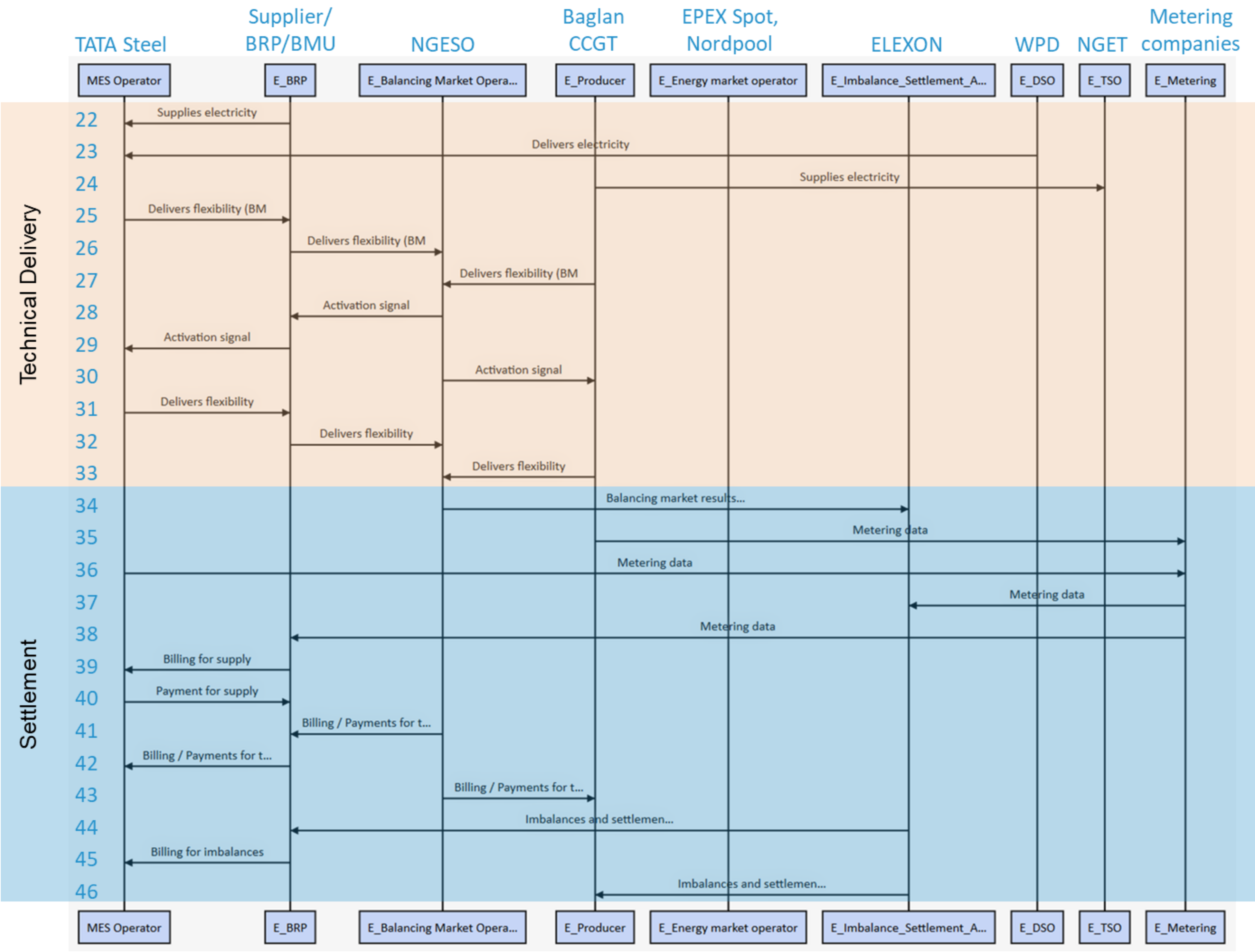


Figure 26 - NPT: sequence diagram for the electricity system

Procurement and negotiation

1. The MES Operator (TATA Steel) communicates its flexibility availability to the BRP or BMU (Supplier/BRP/BMU).
2. The BRP/BMU (Supplier/BRP/BMU) markets the MES Operator flexibility in the frequency response market and reserve market, and submits bids/offers to the Balancing Market Operator (NGESO). Auctions generally occur well ahead of real-time and units can be contracted for large periods up to several months.
3. The Producer (Baglan CCGT) markets its own flexibility in the frequency response market and reserve market, and submits bids/offers to the Balancing Market Operator (NGESO).
4. The Balancing Market Operator (NGESO) communicates the auction results to the BRP/BMU (Supplier/BRP/BMU).
5. The Balancing Market Operator (NGESO) communicates the auction results to the Producer (Baglan CCGT).
6. The BRP/BMU (Supplier/BRP/BMU) communicates the auction results and flexibility schedule to the MES Operator (TATA Steel).
7. For day ahead and intraday trades, the MES Operator (TATA Steel) communicates its planned consumption/feed-in schedule to the BRP (Supplier/BRP/BMU).
8. The BRP (Supplier/BRP/BMU) engages in trade in the day-ahead and intraday markets and submits bids/offers to the energy market operator (EPEX Spot, Nordpool).
9. The Producer (Baglan CCGT) engages in trade in the day-ahead and intraday markets and submits bids/offers to the energy market operator (EPEX Spot, Nordpool).
10. The energy market operator (EPEX Spot, Nordpool) communicates the auction results (day-ahead and intraday) to the BRP (Supplier/BRP/BMU).
11. The energy market operator (EPEX Spot, Nordpool) communicates the auction results (day-ahead and intraday) to the Producer (Baglan CCGT).
12. The BRP (Supplier/BRP/BMU) sends the final consumption/generation schedule to the Imbalance Settlement Agent (ELEXON) after closure of the markets.
13. The Producer (Baglan CCGT) sends the final generation schedule to the Imbalance Settlement Agent (ELEXON) after closure of the markets.
14. The MES Operator (TATA Steel) communicates its updated availability and associated costs to the BRP/BMU (Supplier/BRP/BMU).
15. In the framework of the balancing mechanism, the BRP/BMU (Supplier/BRP/BMU) sends the Balancing Market Operator (NGESO) the Final Physical Notifications (FPNs), i.e. its generation or consumption profile for each settlement period (30 mins) of the day, along with the operational data, namely technical data such as ramp rates or how quickly it can alter its generation or consumption [35].
16. The BRP/BMU (Supplier/BRP/BMU) sends bids/offers to the Balancing Market Operator (NGESO), namely how much the BRP/BMU is willing to pay or be paid by NGESO to increase or decrease its consumption or generation by a given amount.
17. In the framework of the balancing mechanism, the Producer (Baglan CCGT) sends the Balancing Market Operator (NGESO) the Final Physical Notifications (FPNs), i.e. its generation profile for each settlement period (30 mins) of the day, along with the operational data, namely technical data such as ramp rates or how quickly it can alter its generation.

18. The Producer (Baglan CCGT) sends bids/offers to the Balancing Market Operator (NGESO), namely how much it is willing to pay or be paid by the NGESO to decrease or increase its generation by a given amount.
19. The Balancing Market Operator (NGESO) sends the results of the accepted bids and offers to the BRP/BMU (Supplier/BRP/BMU).
20. The BRP/BMU (Supplier/BRP/BMU) sends the MES Operator (TATA Steel) the information for the activation of its flexibilities in the framework of the Balancing mechanism.
21. The Balancing Market Operator (NGESO) sends the results of the accepted bids and offers to the Producer (Baglan CCGT).

Technical delivery

22. From the transactional perspective, the Supplier BRP/BMU (Supplier/BRP/BMU) supplies electricity to the MES Operator (TATA Steel).
23. But the physical delivery of electricity to the MES Operator (TATA Steel) is ensured by the distribution network or the DSO (WPD).
24. The Producer (Baglan CCGT) generates and supplies electricity to the transmission system and therefore the TSO (NGET).
25. The MES Operator (TATA Steel) delivers to the BRP/BMU (Supplier/BRP/BMU) the flexibility requested in the framework of the Balancing mechanism.
26. The BRP/BMU (Supplier/BRP/BMU) in turn delivers the flexibility of its pool to the Balancing Market operator (NGESO), in accordance with the accepted bids of the Balancing mechanism.
27. The Producer (Baglan CCGT) delivers flexibility to the Balancing Market operator (NGESO) in accordance with the accepted bids of the Balancing mechanism
28. If it is needed for the compensation of imbalances, the Balancing Market operator (NGESO) sends an activation signal to the BRP/BMU (Supplier/BRP/BMU) to activate the delivery of services and reserves procured in advance on the frequency response market and reserve market.
29. The BRP/BMU (Supplier/BRP/BMU) dispatches the resources in its pool and accordingly sends an activation signal to the MES Operator (TATA Steel).
30. At the same time as step 25, the Balancing Market operator (NGESO) sends an activation signal to the Producer (Baglan CCGT) to activate the delivery of services and reserves procured in advance on the frequency response market and reserve market.
31. The MES Operator (TATA Steel) delivers the requested flexibility to the BRP/BMU (Supplier/BRP/BMU).
32. The BRP/BMU (Supplier/BRP/BMU) in turn delivers the requested flexibility of its pool to the Balancing Market operator (NGESO).
33. The Producer (Baglan CCGT) delivers the requested flexibility to the Balancing Market operator (NGESO).

Settlement

34. The Balancing Market operator (NGESO) sends the results of the Balancing Mechanism (accepted bids and offers) and the Balancing adjustment actions taken outside the Balancing Mechanism to the Imbalance Settlement Agent (ELEXON).

35. The MES Operator (TATA Steel) makes metering data available to its metering company (Metering companies).
36. The Producer (Baglan CCGT) makes metering data available to its metering company (Metering companies).
37. The metering companies (Metering companies) send the metering data to the Imbalance Settlement Agent (ELEXON) for it to perform imbalance settlement.
38. The metering companies (Metering companies) send the metering data to the supplier BRP/BMU (Supplier/BRP/BMU).
39. The supplier BRP/BMU (Supplier/BRP/BMU) invoices the MES Operator (TATA Steel) for the electricity consumed.
40. The MES Operator (TATA Steel) pays the supplier BRP/BMU (Supplier/BRP/BMU) for the electricity consumed.
41. The Balancing Market operator (NGESO) provides the billing for the payments to the BRP/BMU (Supplier/BRP/BMU) according to bids/offers accepted on the Balancing Mechanism and the Balancing adjustment actions.
42. The BRP/BMU (Supplier/BRP/BMU) provides the payments for the provided flexibility services to the MES Operator (TATA Steel).
43. The Balancing Market operator (NGESO) provides the billing for the payments to the Producer (Baglan CCGT) according to bids/offers accepted on the Balancing Mechanism and the Balancing adjustment actions.
44. The Imbalance Settlement Agency (ELEXON) provides the billing for the payments/penalties related to the imbalances and ensures the payment flows with the BRP/BMU (Supplier/BRP/BMU).
45. The BRP/BMU (Supplier/BRP/BMU) settles payments or penalties related to the imbalances with the MES Operator (TATA Steel).
46. The Imbalance Settlement Agency (ELEXON) provides the billing for the payments/penalties related to the imbalances and ensures the payment flows with the Producer (Baglan CCGT).

9.5.2 Heat sector

Table 29 provides the stakeholders identified for the heat system, along with the roles they carry out.

Table 29 - NPT: stakeholders and roles for the heat system

Stakeholder	Role	Type of Role	Comment
TATA Steel	Consumer	Internal	
TATA Steel	Producer	Internal	
TATA Steel	Storage provider	Internal	Steam accumulators
TATA Steel	MES Operator	Internal	

Since there is no district heating system involved in the scope considered for the NPT case study. The number of roles is very limited and they are only internal roles. Therefore no sequence diagram has been represented.

9.5.3 Gas sector

Table 30 provides the stakeholders identified for the gas system, along with the roles they carry out.

Table 30 - NPT: stakeholders and roles for the gas system [36], [37]

Stakeholder	Role	Type of role	Comment
TATA Steel	Consumer	Internal/external	A daily metered (DM) consumer.
TATA Steel	Producer	Internal	Gas produced for internal use only.
TATA Steel	MES Operator	Internal/external	
Industrial gas producer	Producer	Internal	Industrial gas producer which provides gas for TATA Steel only.
Baglan CCGT	Consumer	Internal/external	
Baglan CCGT	MES Operator	Internal/external	
Other (smaller) gas consumers (Hospital, schools, etc.)	Consumer	External	Non-daily metered customers.
Gas suppliers	Supplier	External	
Gas shippers	Shipper	External	Shippers can trade between themselves on various gas markets, linked to the National Balancing Point (NBP)[4].
Gas shippers	BRP	External	The gas shippers are encouraged to balance their gas inputs and outputs. Otherwise they may pay penalties.
Wales and West Utilities (WWU)	Distribution System Operator	External	

[4] The NBP is a virtual location originally created to support the balancing of the gas system. However, it evolved to also become a trading point. This is where shippers nominate their buys and sells, and where the TSO carries out its daily balancing activity.

Stakeholder	Role	Type of role	Comment
National Grid Gas	Transmission System Operator	External	
National Grid Gas	Imbalance settlement Agent	External	
ICE Endex exchange	Market operator	External	Appointed by National Grid Gas. Operates the On-the-Day Commodity Market (OCM), which is the day ahead and within-day market, as well as the balancing market for natural gas in the UK
Metering companies	Metering-related roles	External	
Office of Gas and Electricity Markets (OFGEM)	Regulator	External	Independent National Regulatory Authority for the electricity and gas sectors.

Figure 27 shows the main relevant interactions between the identified roles and provides the sequence diagram for the gas system.

Remarks: in the figure, for simplicity and in order to highlight the main relevant interactions,

- the interactions with the regulator are not represented,
- the roles of consumer of TATA Steel are merged with the MES operator role,
- in the same way, the role of consumer of Baglan CCGT is merged with the role of MES operator,
- the role of producer of TATA Steel and of the industrial gas producer is not represented since these are purely internal roles,
- the role of BRP of the gas shippers is merged with their shipper role,
- the Imbalance settlement Agent role of National Grid Gas is merged with its TSO role.

OTC trading between the market participants is not represented in this sequence diagram. OTC trades are enacted through a broker or an informal agreement made directly between two parties, which is then accounted for in the system through the nominations.

The interactions are further detailed below for the three main phases of the service provision process.

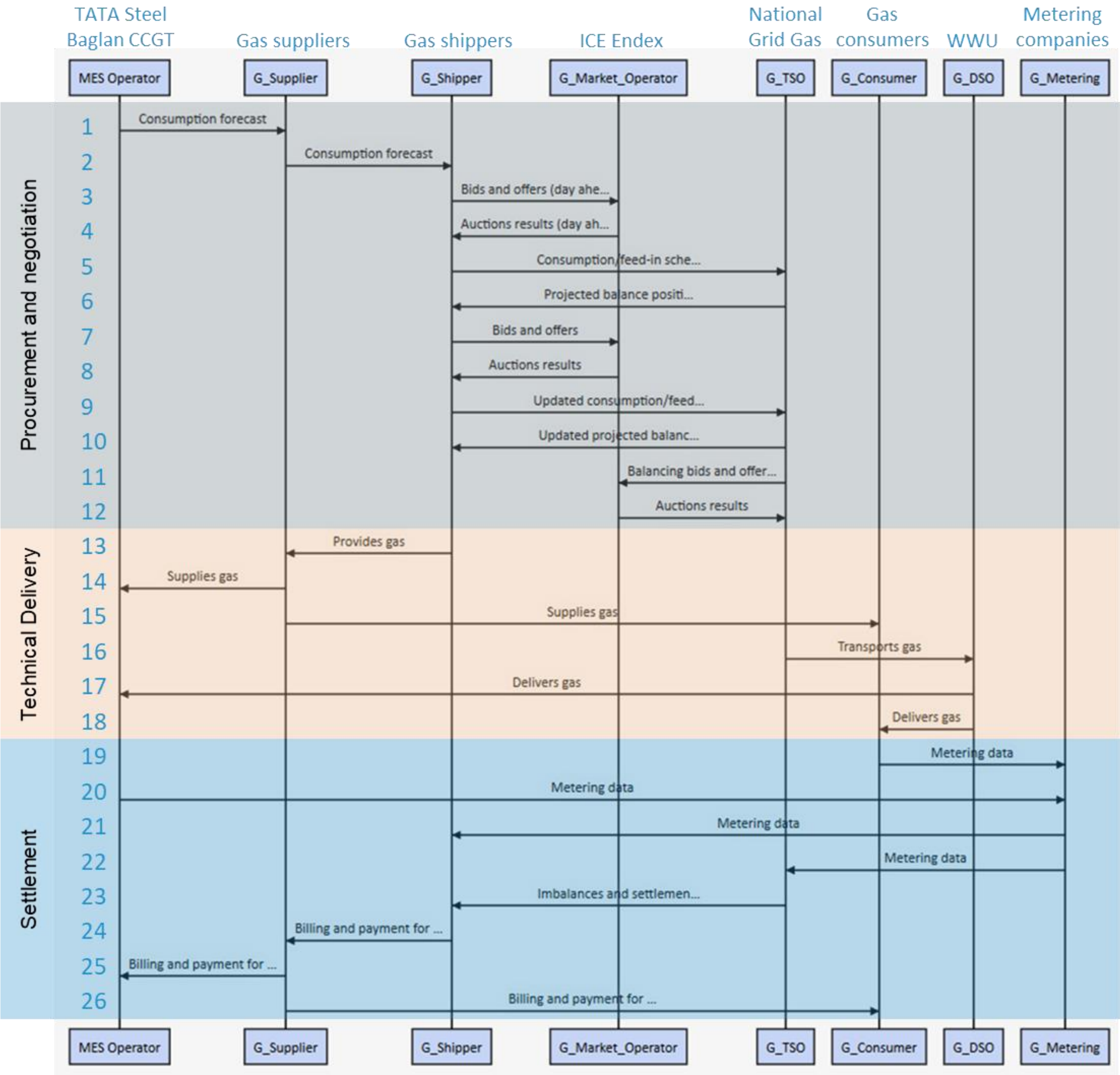


Figure 27 - NPT: sequence diagram for the gas system

Procurement and negotiation

1. The MES Operators (TATA Steel, Baglan CCGT) communicate their expected consumption to the gas suppliers (Gas suppliers).
2. The gas suppliers (Gas suppliers), in turn, communicate the expected consumption (expected sales) to the gas shippers (Gas shippers).
3. Before the Gas Day, the gas shippers (Gas shippers) trade in various kinds of markets in different time frames, and in particular in day ahead on the On-the-day commodity market (OCM), operated by the gas market operator (ICE Endex exchange), where shippers try to balance their schedules.
4. For the day ahead trade on the OCM, the market operator (ICE Endex exchange) communicates the market results to the gas shippers (Gas shippers).
5. The gas shippers (Gas shippers) communicate their gas flow nominations and notified trades to the TSO (National Grid Gas).

6. The TSO (National Grid Gas) communicates their projected end-of-day balance position to the shippers (Gas shippers).
7. On the Gas Day, the gas shippers (Gas shippers) trade on the On-the-day commodity market, where shippers try to balance their schedules, and submit bids and offers to the gas market operator (ICE Endex exchange).
8. The gas market operator (ICE Endex exchange) communicates the market results to the gas shippers (Gas shippers).
9. The gas shippers (Gas shippers) communicate the updates of their gas flow nominations and notified trades to the TSO (National Grid Gas).
10. The TSO (National Grid Gas) communicates the updates of their projected end-of-day balance position to the shippers (Gas shippers).
11. If needed to reduce imbalances, the TSO (National Grid Gas) performs its task of residual balancer by carrying out market-balancing actions on the On-the-day commodity market and therefore submits bits and offers to the gas market operator (ICE Endex exchange).
12. The gas market operator (ICE Endex exchange) communicates the market results to the TSO (National Grid Gas).

Steps 7 to 12 can be repeated several times during the Gas Day.

Technical delivery

13. From the transactional perspective, the gas shippers (Gas shippers) provide gas to the gas suppliers (Gas suppliers).
14. In the same way, from the transactional perspective, the gas suppliers (Gas suppliers) supply gas to the MES operators (TATA Steel, Baglan CCGT).
15. And the gas suppliers (Gas suppliers) supply gas to their other gas consumers (Gas consumers).
16. But from the physical point of view, the TSO (National Grid Gas) ensures the transport of gas through the gas transmission system and delivers it to the gas distribution network or to the DSO (WWU).
17. The physical delivery of gas to the MES Operators (TATA Steel, Baglan CCGT) is ensured by the distribution network or the DSO (WWU).
18. In the same way, the physical delivery of gas to the other consumers (Gas consumers) is ensured by the distribution network or the DSO (WWU).

Settlement

19. The gas consumers (Gas consumers) send their metering data to their respective metering companies (Metering companies).
20. The MES operators (TATA Steel, Baglan CCGT) make metering data available to their metering companies (Metering companies).
21. The metering companies (Metering companies) send metering data to the gas shippers (Gas shippers).
22. The metering companies (Metering companies) send metering data to the TSO (National Grid Gas).
23. The TSO (National Grid Gas) provides the billing for the payments/penalties related to the imbalances and ensures the payment flows with the gas shippers (Gas shippers).
24. The gas shippers (Gas shippers) provide the billing and receive the payment for the gas provision to gas suppliers (Gas suppliers).

25. The gas suppliers (Gas suppliers) invoice the MES operators (TATA Steel, Baglan CCGT) for the gas supply and receive the payment.
26. The gas suppliers (Gas suppliers) invoice the other gas consumers (Gas consumers) for the gas supply and receive the payment.

9.6 EMUASA

The following sections provide the results of the detailed analysis of the EMUASA case study for the electricity, heat and gas sectors.

9.6.1 Electricity sector

Table 31 provides the stakeholders identified for the electricity system, along with the roles they carry out.

Table 31 - EMUASA: stakeholders and roles for the electricity system

Stakeholder	Role	Type of Role	Comment
EMUASA	Producer	Internal	CHP onsite generation. There is no surplus electricity from CHP, everything is used to cover the electricity demand in the process lines of the plant.
EMUASA	Consumer	Internal/external	Consumes the electricity produced on site and imports the remaining consumption from the grid.
EMUASA	MES operator	Internal/external	
Supplier/BRP	Supplier	External	
Supplier/BRP	BRP	External	
OMIE	Energy Market Operator	External	Operates the day-ahead and intraday energy markets
Red Eléctrica de Espana (REE)	TSO	External	
Red Eléctrica de Espana (REE)	Imbalance Settlement Agent	External	
E-distribución	DSO	External	
E-distribución	Metering related roles	External	

Stakeholder	Role	Type of Role	Comment
Comisión Nacional de los Mercados y la Competencia (CNMC)	Regulator	External	Regulatory body ensuring the proper functioning of all types of markets in the interests of consumers and companies. In particular regulatory authority for the electricity and gas sectors.

Figure 28 shows the main relevant interactions between the identified roles and provides the sequence diagram for the electricity system.

Remarks: in the figure, for simplicity and in order to highlight the main relevant interactions,

- the interactions with the regulator are not represented,
- the roles of producer and consumer of EMUASA are merged with its MES operator role,
- the role of supplier is merged with the BRP role,
- the role of Imbalance settlement Agent of REE is merged with its TSO role,
- the metering-related roles of e-distribución are merged with its DSO role.

The interactions are further detailed below for the three main phases of the service provision process.

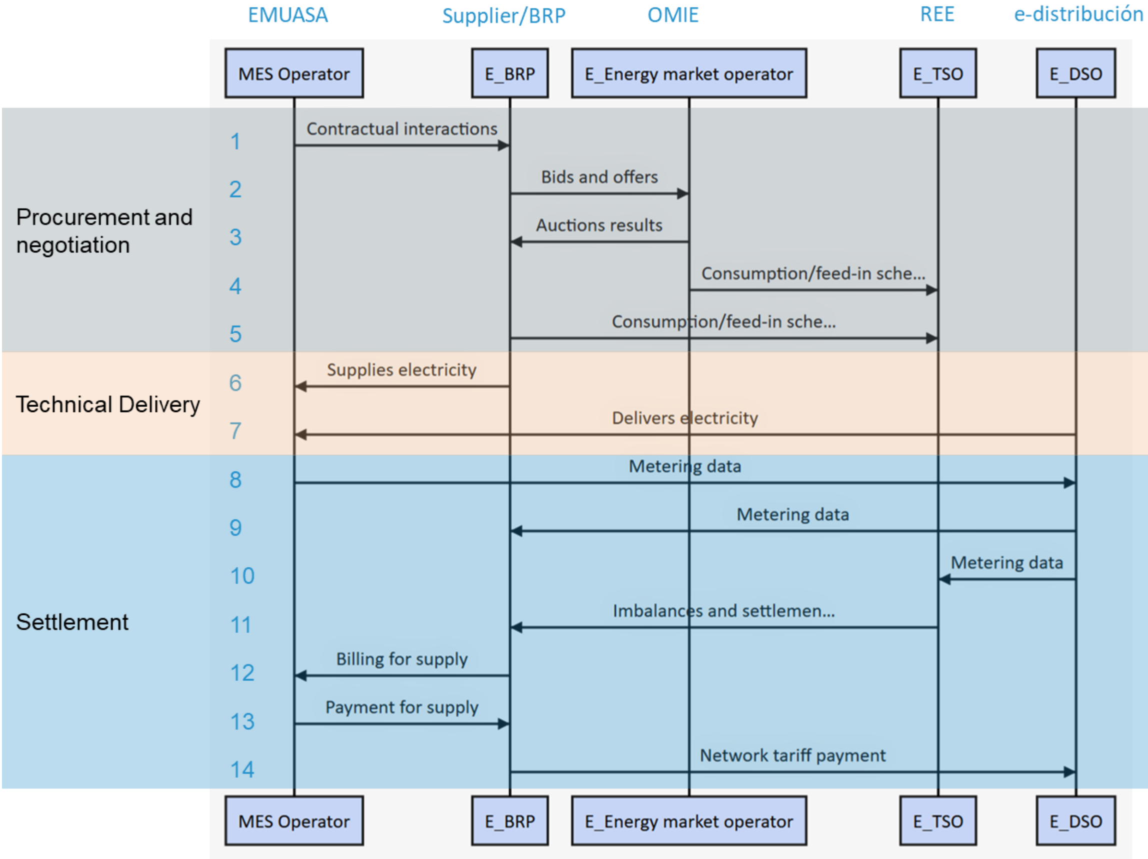


Figure 28 - EMUASA: sequence diagram for the electricity system

Procurement and negotiation

1. Possibly long before, the MES Operator (EMUASA) signs a contract with the electricity supplier (Supplier/BRP), who also is assumed to be a BRP, for the procurement of electricity.
2. The BRP (Supplier/BRP) engages in trade in the day-ahead and intra-day markets and submits bids/offers to the energy market operator (OMIE).
3. The energy market operator (OMIE) communicates the auction results to the BRP (Supplier/BRP).
4. The energy market operator (OMIE) communicates the consumption and feed-in schedules resultant of the day-ahead market to the TSO (REE) as an input for the subsequent restrictions market.
5. After closure of the markets, the BRP (Supplier/BRP) submits the final consumption/generation schedule to the Imbalance Settlement Agent who is also the TSO (REE).

Technical delivery

6. From the transactional perspective, the Supplier BRP (Supplier/BRP) supplies electricity to the MES Operator (EMUASA).
7. But the physical delivery of electricity to the MES Operator (EMUASA) is ensured by the distribution network or the DSO (e-distribución).

Settlement

8. The MES Operator (EMUASA) makes metering data available to the DSO (e-distribución), or the DSO (e-distribución) collects the metering data from the meter of the MES Operator (EMUASA).
9. The DSO (e-distribución) sends metering data to the supplier/BRP (Supplier/BRP).
10. The DSO (e-distribución) sends metering data to the Imbalance settlement Agent/TSO (REE).
11. The TSO (REE) performs imbalance settlement with the BRP (Supplier/BRP).
12. The supplier/BRP (Supplier/BRP) invoices the MES Operator (EMUASA) for the supply of electricity.
13. The MES Operator (EMUASA) pays the supplier/BRP (Supplier/BRP) for the supply of electricity.
14. The supplier/BRP (Supplier/BRP) manages the payments to the DSO (e-distribución) of the tariffs for the use of the grids.

9.6.2 Heat sector

Table 32 provides the stakeholders identified for the heat system, along with the roles they carry out.

Table 32 - EMUASA: stakeholders and roles for the heat system

Stakeholder	Role	Type of Role	Comment
EMUASA	Producer	Internal	CHP onsite production, **surplus available** but not usable since there is not a higher heat demand. The CHP plant includes 3 engines, one of them as reserve, which allow to produce 100% of the thermal and 48% of the electricity requirements of the plant.

EMUASA	Consumer	Internal	Own consumption for sludge heating before digestion.
EMUASA	MES Operator	Internal	

Regarding the heat sector in the EMUASA case study, the number of roles is very limited, and they are only internal roles. Therefore, no sequence diagram is represented.

9.6.3 Gas sector

Table 33 provides the stakeholders identified for the gas system, along with the roles they carry out.

Table 33 - EMUASA: stakeholders and roles for the gas system

Stakeholder	Role	Type of Role	Comment
EMUASA	Producer	Internal	Onsite production by the 3 digesters
EMUASA	Consumer	Internal	Onsite consumption by CHP and boilers, (maybe by cars in the future)
EMUASA	Storage provider	Internal	Two double-membrane spherical gasometers. The amount of biogas stored is controlled by the line pressure. If the pressure is higher because biogas consumption is not enough (CHP plant shutdowns), there is a **flare to burn biogas excess**.
EMUASA	MES Operator	Internal	

Like for the heat sector, the number of roles involved in the gas sector in the EMUASA case study is very limited, and they are only internal roles. Therefore, no sequence diagram is represented.

9.7 Paris Saclay

The following sections provide the results of the detailed analysis of the Paris Saclay case study for the electricity, heat, cooling and gas sectors.

9.7.1 Electricity sector

Table 34 provides the stakeholders identified for the electricity system, along with the roles they carry out.

Table 34 – Paris Saclay: stakeholders and roles for the electricity system

Stakeholder	Role	Type of Role	Comment
IDEX	Consumer	Internal/external	Consumes electricity for the heat pumps and the geothermal pumps
IDEX	MES Operator	Internal/external	Operator of the MES
EPAPS	MES Owner	Internal/external	Owner of the MES, namely EPAPS owns the whole district heating and cooling systems: heating and cooling networks, as well as heat and cooling generating plants (geothermal heat plant, gas boiler, thermo-refrigerating pumps located in sub-stations, etc.).
Supplier/BRP	BRP	External	
EPEX SPOT	Energy Market Operator	External	
RTE	TSO	External	
RTE	Imbalance Settlement Agent	External	
Enedis	DSO	External	
Enedis	Metering-related roles	External	
Commission de Régulation de l'Energie (CRE)	Regulator	External	French Energy Regulatory Commission. It ensures that the electricity and gas markets function smoothly, for the benefit of end consumers and in line with energy policy objectives.

In the table, a new specific role is introduced to take into account the relationship between IDEX, who is the MES operator, and EPAPS, who is the owner of the MES. The modalities of their relationship are described in a contract between them. Even if this MES owner role and the associated interactions are important for the Paris Saclay business model, this role is not represented in the sequence diagram below.

Figure 29 shows the main relevant interactions between the identified roles and provides the sequence diagram for the electricity system.

Remarks: in the figure, for simplicity and in order to highlight the main relevant interactions,

- the interactions with the regulator are not represented,
- the interactions between the MES owner role and the MES operator role are not represented,
- the role of consumer of IDEX is merged with its MES operator role,

- the role of supplier is merged with the BRP role,
- the role of Imbalance Settlement Agent of RTE is merged with its TSO role,
- the metering-related roles of Enedis are merged with its DSO role.

It should be highlighted that a large part of the long term and day ahead energy procurement is still carried out through OTC trading or bilateral relationships. Representing this situation in Figure 29 can be done by replacing the interactions between the Supplier/BRP and the Energy Market Operator (steps 2 and 3) by OTC trading or bilateral relationships.

The interactions are further detailed below for the three main phases of the service provision process.

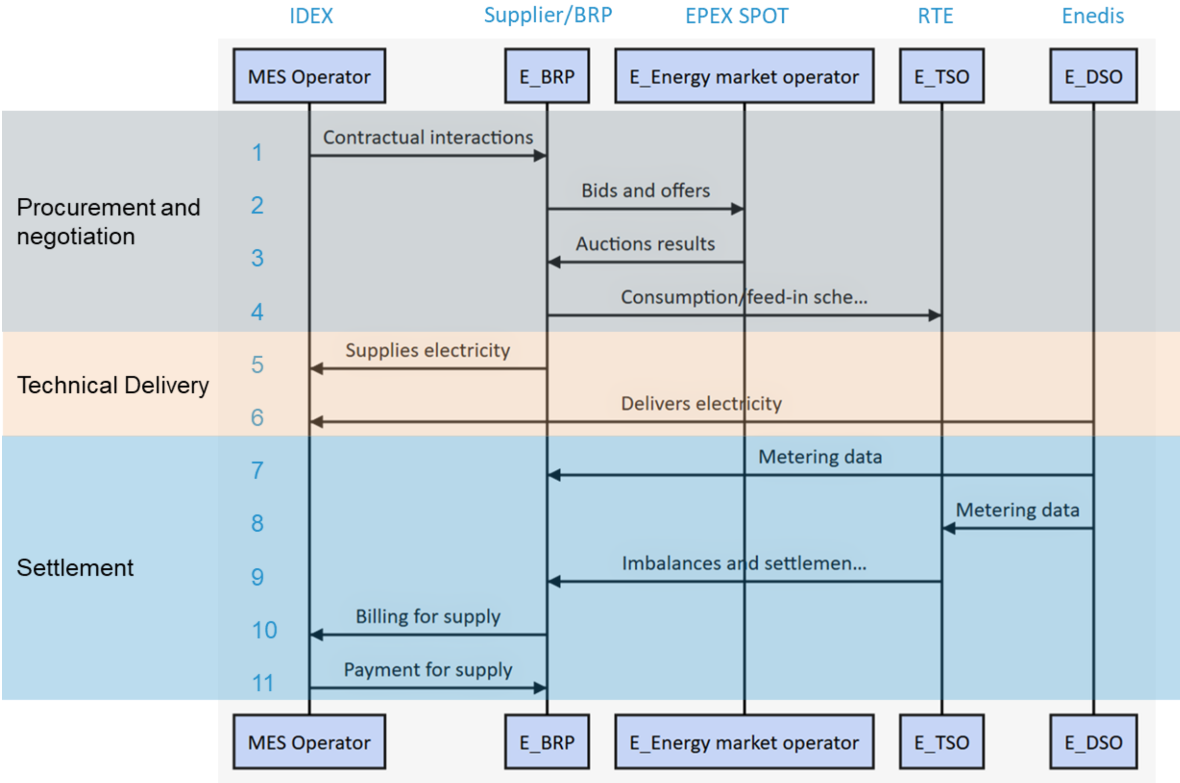


Figure 29 – Paris Saclay: sequence diagram for the electricity system

Procurement and negotiation

1. Possibly long before, the MES Operator (IDEX) signs a contract with the electricity supplier (Supplier/BRP), who also is assumed to be a BRP, for the procurement of electricity.
2. The BRP (Supplier/BRP) engages in trade in the day-ahead and intra-day markets and submits bids/offers to the energy market operator (EPEX SPOT).
3. The energy market operator (EPEX SPOT) communicates the auction results to the BRP (Supplier/BRP).
4. After the closure of the markets, the BRP (Supplier/BRP) submits the final consumption/generation schedule to the Imbalance Settlement Agent who is also the TSO (RTE).

Technical delivery

5. From the transactional perspective, the Supplier BRP (Supplier/BRP) supplies electricity to the MES Operator (IDEX).

6. But the physical delivery of electricity to the MES Operator (IDEX) is ensured by the distribution network or the DSO (Enedis).

Settlement

7. The DSO (Enedis) sends metering data to the supplier/BRP (Supplier/BRP).
8. The DSO (Enedis) sends metering data to the Imbalance settlement Agent/TSO (RTE).
9. The TSO (REE) performs imbalance settlement with the BRP (Supplier/BRP).
10. The supplier/BRP (Supplier/BRP) invoices the MES Operator (IDEX) for the supply of electricity.
11. The MES Operator (IDEX) pays the supplier/BRP (Supplier/BRP) for the supply of electricity.

9.7.2 Heat sector

Table 35 provides the stakeholders identified for the heat system, along with the roles they carry out.

Table 35 - Paris Saclay: stakeholders and roles for the heat system

Stakeholder	Role	Type of Role	Comment
IDEX	Producer	Internal/external	Heat produced via geothermal energy, heat pumps and gas boiler
IDEX	Distribution System Operator	Internal/external	Designs, implements, operates and maintains the district heating and cooling networks
IDEX	MES operator	Internal/external	
EPAPS	MES Owner	Internal/external	Owns the whole district heating and cooling systems: heating and cooling networks, as well as heat and cooling generating plants (geothermal heat plant, gas boiler, thermo-refrigerating pumps located in sub-stations).
IDEX	Supplier	Internal/external	Supplies heat to the heat consumers at a price defined in the contract between EPAPS and IDEX.
IDEX	Metering-related roles	Internal/external	Metering of the heating and cooling consumed by each building connected to the DHC network
Heat Consumers	Consumer	External	Residential and tertiary consumers, R&D centres, laboratories and universities.
EPAPS	Regulator	External	EPAPS is the representative of the State and of the local communities. EPAPS ensures both the performances and feasibility of the DHC network, and the defence of the interests of the end users.

Figure 30 shows the main relevant interactions between the identified roles and provides the sequence diagram for the heat system.

Remarks: in the figure, for simplicity and in order to highlight the main relevant interactions,

- the interactions with the regulator are not represented,
- the interactions with the MES owner role of EPAPS are not represented,
- the IDEX role of supplier is merged with the MES operator role,
- the metering-related roles are merged with the DSO role.

The interactions are further detailed below for the three main phases of the service provision process.

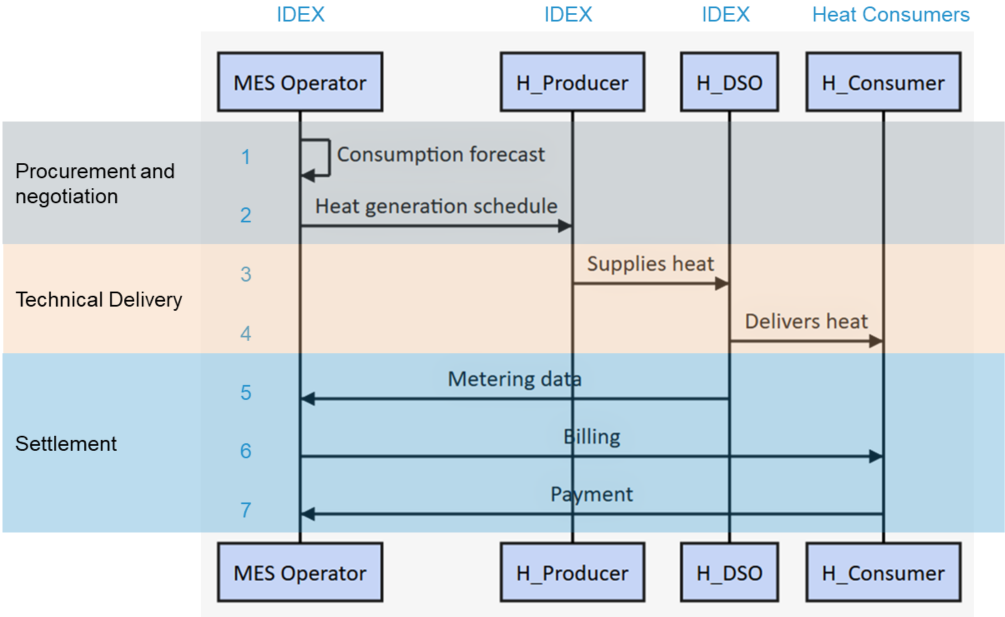


Figure 30 - Paris Saclay: sequence diagram for the heat system

Procurement and negotiation

1. The MES Operator (IDEX) forecasts the heat demand.
2. The MES Operator (IDEX) communicates the heat generation schedule to the heat Producer (IDEX).

Technical delivery

3. The heat Producer (IDEX) supplies heat to the district heating network or the heat DSO (IDEX).
4. The heat DSO (IDEX) delivers heat to the heat consumers (Heat consumers).

Settlement

5. The heat DSO (IDEX) sends metering data to the MES Operator (IDEX).
6. The MES operator (IDEX) invoices the heat consumers (heat consumers) for the heat supply.
7. The heat consumers (heat consumers) pay the bill to the MES operator (IDEX).

9.7.3 Cooling sector

Table 36 provides the stakeholders identified for the cooling system, along with the roles they carry out.

Table 36 - Paris Saclay: stakeholders and roles for the cooling system

Stakeholder	Role	Type of Role	Comment
IDEX	Producer	Internal/external	Cooling produced by thermo-refrigerating pumps (located in sub-stations)
IDEX	Distribution System Operator	Internal/external	Designs, implements, operates and maintains the district heating and cooling network.
IDEX	MES operator	Internal/external	
EPAPS	MES owner	Internal/external	Owns the whole district heating and cooling systems: heating and cooling networks, as well as heat and cooling generating plants (geothermal heat plant, gas boiler, thermo-refrigerating pumps located in sub-stations).
IDEX	Supplier	Internal/external	Supplies cooling to the consumers at a price defined in the contract between EPAPS and IDEX
IDEX	Metering-related roles	Internal/external	Metering of the heating and cooling consumed by each building connected to the DHC network
Cooling Consumers	Consumer	External	Residential and tertiary consumers, R&D centres, laboratories and universities.
EPAPS	Regulator	External	EPAPS is the representative of the State and of the local communities. EPAPS ensures both the performances and feasibility of the DHC network, and the defence of the interests of the end users.

Figure 31 shows the main relevant interactions between the identified roles and provides the sequence diagram for the cooling system.

Remarks: in the figure, for simplicity and in order to highlight the main relevant interactions,

- the interactions with the regulator are not represented,
- the interactions with the MES owner role of EPAPS are not represented,
- the IDEX role of supplier is merged with the MES operator role,
- the metering-related roles are merged with the DSO role.

The interactions are further detailed below for the three main phases of the service provision process.

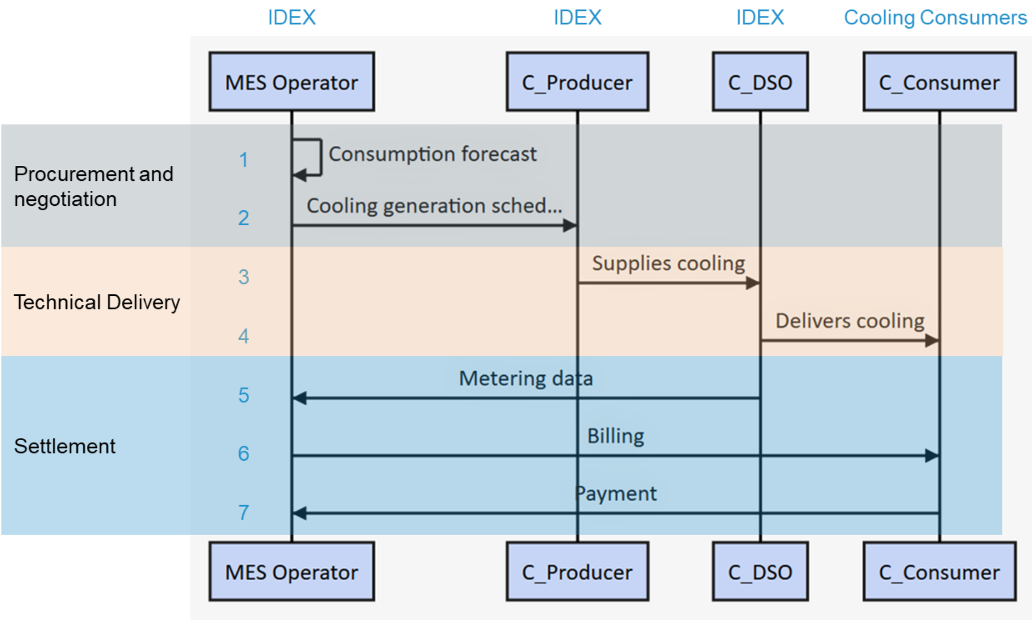


Figure 31 - Paris Saclay: sequence diagram for the cooling system

Procurement and negotiation

1. The MES Operator (IDEX) forecasts the cooling demand.
2. The MES Operator (IDEX) communicates the cooling generation schedule to the cooling Producer (IDEX).

Technical delivery

3. The cooling Producer (IDEX) supplies cooling to the district cooling network or the DSO (IDEX).
4. The DSO (IDEX) delivers cooling to the cooling consumers (Cooling consumers).

Settlement

5. The DSO (IDEX) sends metering data to the MES Operator (IDEX).
6. The MES operator (IDEX) invoices the cooling consumers (Cooling consumers) for the cooling supply.
7. The cooling consumers (cooling consumers) pay the bill to the MES operator (IDEX).

9.7.4 Gas sector

Table 37 provides the stakeholders identified for the gas system, along with the roles they carry out.

Table 37 - Paris Saclay: stakeholders and roles for the gas system

Stakeholder	Role	Type of Role	Comment
IDEX	Consumer	Internal/external	Consumes gas in the gas boilers in order to increase the temperature of the DHC network end produce heating during the coldest period in winter.

IDEX	MES operator	Internal/external	
EPAPS	MES owner	Internal/external	
Gas Supplier	Supplier	External	
GRDF	DSO	External	
GRDF	Metering-related roles	External	
Commission de Régulation de l'Energie (CRE)	Regulator	External	French Energy Regulatory Commission. It ensures that the electricity and gas markets function smoothly, for the benefit of end consumers and in line with energy policy objectives.

Figure 32 shows the main relevant interactions between the identified roles and provides the sequence diagram for the gas system.

Remarks: in the figure, for simplicity and in order to highlight the main relevant interactions,

- the interactions with the Regulator are not represented,
- the interactions with the MES owner role of EPAPS are not represented,
- the gas consumer role of IDEX is merged with its MES operator role,
- the metering-related roles of GRDF are merged with its DSO role.

The interactions are further detailed below for the three main phases of the service provision process.

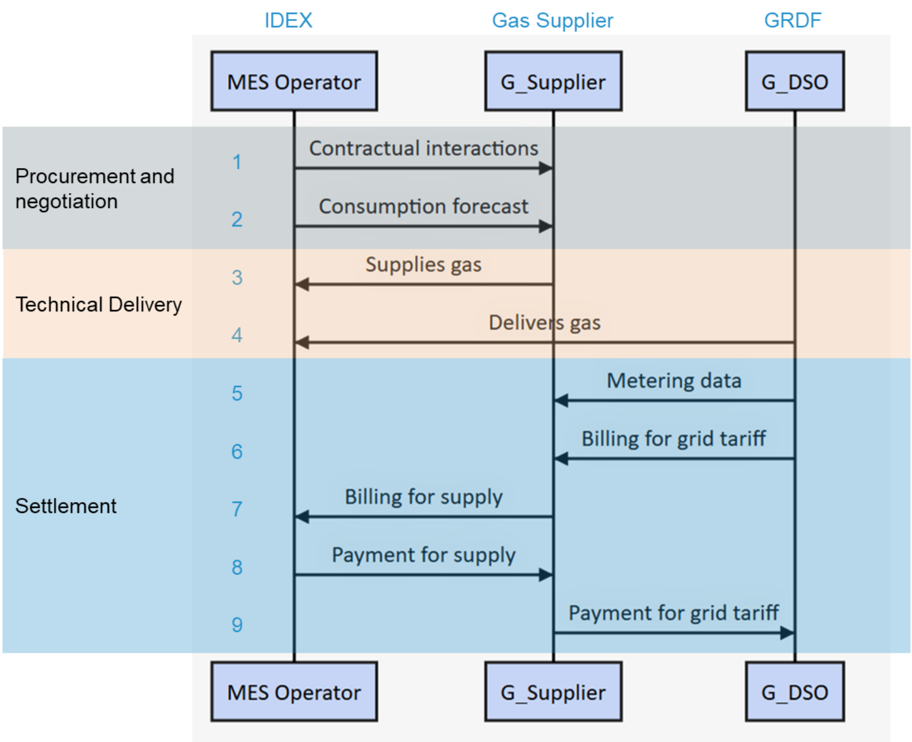


Figure 32 - Paris Saclay: sequence diagram for the gas system

Procurement and negotiation

1. The MES Operator (IDEX) signs a contract with the gas supplier (Gas Supplier) for the procurement of gas.
2. The MES Operator (IDEX) send its gas consumption forecast to the gas supplier (Gas Supplier).

Technical delivery

3. From the transactional perspective, the gas supplier (Gas Supplier) “supplies” gas to the MES Operator (IDEX).
4. But the physical delivery of gas to the MES Operator (IDEX) is carried out through the gas network or the gas DSO (GRDF).

Settlement

5. The gas DSO (GRDF) sends metering data to the gas supplier (Gas Supplier).
6. The gas DSO (GRDF) invoices the gas supplier (Gas Supplier) for the grid tariffs of its consumers.
7. The gas supplier (Gas Supplier) invoices the MES Operator (IDEX) for the gas supplied and for the grid tariff.
8. The MES Operator (IDEX) pays the bill to the gas supplier (Gas Supplier).
9. The gas supplier (Gas Supplier) pays the bill to the gas DSO (GRDF) for the grid tariffs of its consumers.