D 3.4 Standardized framework for interoperable flexibility

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Executive Summary

In a power system, flexibility refers to a wide variety of heterogenous products and their uses. Effectively managing them is pivotal in facilitating a successful energy transition. The complexity of having diverse stakeholders, products, systems, and scenarios, as well as different flexibility applications with distinct requirements and technological ecosystems, has made this a difficult task. Additionally, there is a frequent need for local modifications to fulfill country-specific requirements due to area and specific laws and conditions.

The project DigIPlat aims to address these challenges by helping accelerate the implementation, adoption, and knowledge creation of digital solutions targeting the interoperability of flexibility platforms. This is planned on the one hand through the development of new digital solutions aimed at interoperability of flexibility platforms along ICT, economic, or process-related aspects, and on the other hand through the analysis of existing platforms and the design, test, and analysis of use cases and architecture to allow interoperable cross-border and cross-platform coordination of flexibility for dispatch, balancing, and intraday markets. A major project outcome will be a proposed framework for standardized requirements for the transnational use of flexibility through different flexibility platforms. The WP3 is dedicated to eliciting and analyzing the requirements as well as defining architecture for an interoperable flexibility framework. This deliverable reports the work conducted in T3.4 with the analysis of the requirements and the development of a high-level model for a cross-border interoperable flexibility framework. It is to be noted that the newly introduced architecture does not intend to replace existing systems and subsystems but to subsume them in one common framework.

Along with detailed discussion with the involved partners and consulting the state-of-the-art, the primary input for this work is the use cases and requirements documented in D3.3. These findings are refined and used to model the fundamental and essential interaction or scenario that represents the key functions expected in the envisioned flexibility platform. This is then complemented with business, high-level, and primary use cases that describe these various processes at the appropriate level of abstraction. To deepen the analysis and to pave the way for practical implementations, a dedicated focus will be put on UC 1 which describes the usage of balancing energy considering network restrictions. This use case proposes an integrated view of the previously separate tasks, balancing, and capacity management.

The architecture modeling focuses on a black-box representation of an interoperable flexibility platform as a platform that enables Load Frequency Control Operators (LFCOs) and System Operators (SO) to gather, activate, and settle flexibility bids for providing flexibility services in consideration of potential restrictions imposed by the connecting distribution and transmission grids. The analysis and modeling are conducted by following the well-known EU and international standards and paradigms. The primary modeling methodology is based on the IEC 63200, also known as the Smart Grid Architecture Model (SGAM), and is carried out by using the formal notation and semantics of UML and SysML. A specialized software Spax Enterprise Architect is used for the modeling based on the Model-Based Systems Engineering paradigm. MBSE is an approach to systems engineering that creates and uses models of the system at its core, for designing and developing systems. This is in sharp contrast to the Documents-Centric Systems Engineering (DCSE) approaches that rely on traditional documents and textual representations. This way, MBSE is valuable in enhancing the communication among multidisciplinary teams, and stakeholders due to its use of a common visual language and framework for representing system requirements, design, and architecture. The improved communication helps reduce misunderstandings and misinterpretations thus enabling better collaboration.

The architectural model is defined in a way to shows the various classes of stakeholders along with their relationships, interactions, and, in some cases, interdependencies. The levels of interactions are organized as a hierarchy of the Business Processes that are executed to fulfill the stakeholder's needs and goals resulting in various interactions and events. The SGAM Business Interoperability Layer is dedicated to representing the classes of stakeholders, their goals, and Business Cases. A further level of detail then shows the High-Level Use Cases that are triggered by the stakeholders to fulfill their goals. Going further, the High-Level Use Cases are decomposed into Primary Use Cases that represent the SGAM Function Interoperability Layer.

The devolved architectural model takes a holistic view of the flexibility platform by considering not just individual components but also their interactions, interfaces, and the system's context within its environment. It can further help in evaluating the trade-offs between conflicting objectives to make informed decisions and thus is a useful input for the subsequent tasks in this project.

Kurzfassung

In einem Stromversorgungssystem bezieht sich Flexibilität auf eine Vielzahl heterogener Produkte und deren Einsatzzwecke. Ein wirksames und effizientes Management dieser Flexibilität ist von zentraler Bedeutung für eine erfolgreiche Energiewende. Die Komplexität der verschiedenen Akteure, Produkte, Systeme und Szenarien sowie die unterschiedlichen Flexibilitätsanwendungen mit ihren unterschiedlichen Anforderungen und technologischen Ökosystemen machen dies zu einer schwierigen Aufgabe. Hinzu kommt, dass häufig lokale Anpassungen erforderlich sind, um die länderspezifischen Anforderungen zu erfüllen, die sich aus den örtlichen und landesspezifischen Gesetzen und Bedingungen ergeben.

Das Projekt DigIPlat zielt darauf ab, diese Herausforderungen anzugehen, indem es dazu beiträgt, die Umsetzung, Annahme und Schaffung von Wissen über digitale Lösungen zu beschleunigen, die auf die Interoperabilität von Flexibilitätsplattformen abzielen. Dies ist einerseits durch die Entwicklung neuer digitaler Lösungen geplant, die auf die Interoperabilität von Flexibilitätsplattformen entlang von IKT-, wirtschaftlichen oder prozessbezogenen Aspekten abzielen. Andererseits soll eine interoperable grenz- und plattformübergreifende Koordinierung von Flexibilität für Dispatch-, Ausgleichs- und Innertagesmärkte durch die Analyse bestehender Plattformen und den Entwurf, den Test sowie die Untersuchung von Anwendungsfällen und Architektur ermöglicht werden. Ein wichtiges Projektergebnis wird ein vorgeschlagenes Framework für standardisierte Anforderungen für die transnationale Nutzung von Flexibilität durch verschiedene Flexibilitätsplattformen sein. WP3 widmet sich der Erhebung und Analyse der Anforderungen sowie der Definition der Architektur für einen interoperables Flexibilitätsframework. In diesem Bericht werden die in T3.4 durchgeführten Arbeiten zur Analyse der Anforderungen und zur Entwicklung eines High-Level-Modells für einen grenzüberschreitendes interoperables Flexibilitätsframework vorgestellt. Es ist zu beachten, dass die neu eingeführte Architektur nicht beabsichtigt, bestehende Systeme und Teilsysteme zu ersetzen, sondern sie in einem gemeinsamen Rahmen zusammenzufassen.

Neben ausführlichen Diskussionen mit den beteiligten Partnern und der Konsultation des Stands der Technik bilden die in D3.3 dokumentierten Anwendungsfälle und Anforderungen den wichtigsten Input für diese Arbeit. Diese Erkenntnisse werden verwendet und verfeinert, um die grundlegenden und wesentlichen Interaktionen und Schlüsselszenarien der Flexibilitätsplattform zu modellieren. Diese Modellierung wird dann durch Geschäfts-, High-Level- und primäre Anwendungsfälle ergänzt, die die verschiedenen Prozesse auf der entsprechenden Abstraktionsebene beschreiben. Um die Analyse weiter zu vertiefen und den Weg für praktische Implementierungen zu ebnen, wird ein besonderer Schwerpunkt auf UC 1 gelegt, der die Nutzung von Ausgleichsenergie unter Berücksichtigung von Netzrestriktionen beschreibt. Konkret schlägt dieser Anwendungsfall eine integrierte Betrachtung der bisher getrennten Aufgaben Ausgleichs- und Kapazitätsmanagement vor.

Die Architekturmodellierung konzentriert sich auf eine Black-Box-Darstellung einer interoperablen Flexibilitätsplattform als Plattform, die es den für die Frequenzregelung verantwortlichen Übertragungsnetzbetreibern (LFCOs) und den Systembetreibern (SOs) generell ermöglicht, Angebote für die Bereitstellung von Flexibilitätsdienstleistungen unter Berücksichtigung möglicher Netzbeschränkungen einzuholen, zu aktivieren und abzurechnen. Die Analyse und Modellierung erfolgten in Anlehnung an die bekannten europäischen und internationalen Standards und Paradigmen. Die primäre Modellierungsmethodik basiert auf der IEC 63200, auch bekannt als Smart Grid Architecture Model (SGAM), und wird unter Verwendung der formalen Notation und Semantik von UML und SysML durchgeführt. Für die Modellierung wird die Spezialsoftware Spax Enterprise Architect verwendet, die auf dem Paradigma des Model-Based Systems Engineering basiert. MBSE ist ein System-Engineering-Ansatz, bei dem Modelle des Systems im Kern für den Entwurf und die

Entwicklung von Systemen erstellt und verwendet werden. Dies steht im Gegensatz zu den dokumentenzentrierten Systems-Engineering-Ansätzen (DCSE), die sich auf traditionelle Dokumente und textuelle Darstellungen stützen. Durch die Verwendung einer gemeinsamen visuellen Sprache und eines gemeinsamen Rahmens für die Darstellung von Systemanforderungen, Design und Architektur ist MBSE ein wertvolles Instrument zur Verbesserung der Kommunikation zwischen multidisziplinären Teams und Interessengruppen. Die verbesserte Kommunikation trägt dazu bei, Missverständnisse und Fehlinterpretationen zu verringern und ermöglicht so eine bessere Zusammenarbeit.

Das dezentrale Architekturmodell betrachtet die Flexibilitätsplattform ganzheitlich, indem es nicht nur die einzelnen Komponenten, sondern auch ihre Interaktionen, Schnittstellen und den Kontext des Systems innerhalb seiner Umgebung berücksichtigt. Es kann außerdem dabei helfen, die Kompromisse zwischen widersprüchlichen Zielen zu bewerten, um fundierte Entscheidungen zu treffen, und ist somit ein nützlicher Input für die nachfolgenden Aufgaben in diesem Projekt.

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List of abbreviations

aFRR	automatic Frequency Restoration Reserve
BE	Balancing Energy
BRP	Balance Responsible Party
BSP	Balancing Service Provider
CAO	Control Area Operator
DCSE	Documents-Centric Systems Engineering
DER	Distributed Energy Resources
DMS	Distribution Management Systems
DSO	Distribution System Operator
EMS	Energy Management Systems
ENTSO-E	European Network of Transmission System Operators for Electricity
EV	Electric Vehicle
FCR	Frequency Containment Reserve
FIBO	Financial Institution Business Ontology
FRO	Flexibility Register Operator
FSP	Flexibility Service Provider
HTML	Hypertext Markup Language
IEC	International Electrotechnical Commission
ISR	Imbalance Settlement Responsible
LFCO	Load Frequency Control Operators
MARI	Manually Activated Reserves Initiative
MBSE	Model-Based Systems Engineering
mFRR	manual Frequency Restoration Reserve
PICASSO	Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation
PO	Platform Operator
PTDF	Power Transfer Distribution Factor
PV	Photovoltaic
SGAM	Smart Grid Architecture Model
SO	System Operators
SysML	Systems Modeling Language
TSO	Transmission System Operator
UML	Unified Modeling Language
VTDF	Voltage Transfer Distribution Factor

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1. Introduction

A streamlined and efficient management of flexibilities within the power system can be a cornerstone in a successful energy transition. Nevertheless, due to a manifold variety of involved stakeholders, products, systems and boundary conditions, a high level of technical and organizational complexity arises. For instance, flexibility usage ranges from day-ahead market participation to the provisioning of Frequency Containment Reserve (FCR) [1]. Each of the flexibility applications has a unique set of requirements and comes with its own technical ecosystem in terms of involved systems, interfaces, communication protocols, and platforms. More often than not, country-specific requirements hinder a pan-European application of IT systems and necessitate local adaptions. Several initiatives such as the Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation (PICASSO) are implemented to foster the cross-country integration of flexibility resources [2]. Despite their undoubted value, they increase the complexity of the whole technical ecosystem. Similarly, aggregation and small-scale flexibility platforms that are used to enable market access for various participants that do not fall under traditional flexibility regimes, further increase the diversity of technical systems.

This deliverable specifically targets the complexity of the involved technical systems by developing a high-level view that connects the market-centric use cases of D3.3 [3] and the implementation efforts conducted in WP4. The newly introduced architecture does not intend to replace existing systems and subsystems but to subsume them in one common framework. To provide an unbiased view without assuming specific implementations, the high-level architecture is based on common requirements instead of available systems that may be taken as a base to implement specific use cases or parts thereof. Starting with the development of a stakeholder structure, common business requirements, and corresponding use cases are defined. The content of D3.3 was then refined to describe and model the fundamental and essential interaction or scenario that represents the key functions expected in the envisioned flexibility platform. This is then complemented with business, high-level and primary use cases that describe these various processes at the appropriate level of abstraction.

To conduct the detailed requirements analysis, the use-case description of D3.3 is first taken as a basis and will be transformed into a detailed, formalized input model for further analysis. To deepen the analysis and to pave the way for practical implementations, a dedicated focus will be put on UC 1 which describes the usage of balancing energy considering network restrictions. This use case proposes an integrated view of the previously separate tasks, balancing and capacity management. It could be advantageous but requires partial interoperability of the two previously separate processes and the flexibility platforms used. Considering the effects of balancing energy activation on grid congestion, problems can fundamentally arise in both distribution- and transmission grids: The use of balancing energy changes grid load flows compared to the initial situation and can lead to congestions of individual grid elements. Therefore, UC1 considers available network capacities for Balancing Energy (BE) activation, i.e., activation of a certain BE bid combination only occurs if it does not lead to a congestion of a Transmission System Operator (TSO) or Distribution System Operator (DSO) network element. If congestion is expected, another BE bid is selected, as shown in Figure 1. The use case thus focuses on preventing BE calls with critical effects on grid congestion. Compared to the status quo, this requires BE bids to be unit-specific or aggregated within a relevant network area. The use case will be illustrated based on automatic Frequency Restoration Reserve (aFRR) - in principle, the system would also be applicable for manual Frequency Restoration Reserve (mFRR).

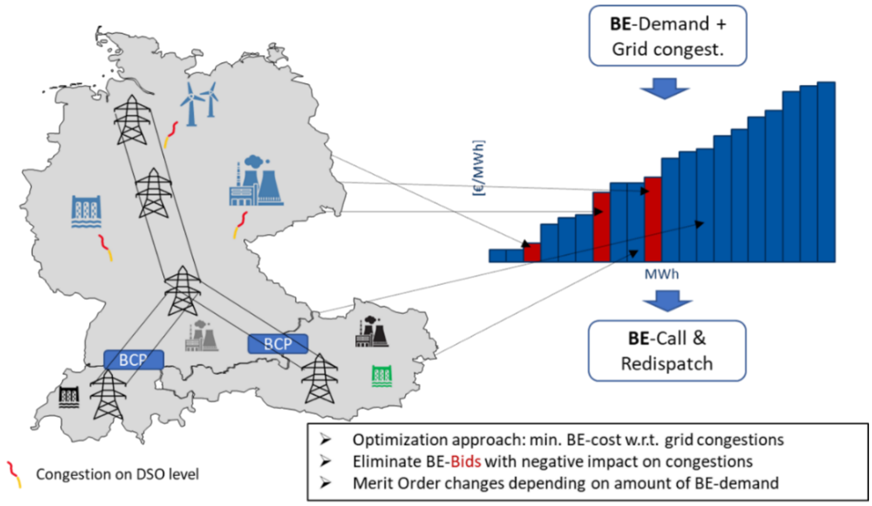

Figure 1 UC 1 – concept

Based on the formalized use cases, detailed requirements, e.g., on communication needs and cross-cutting concerns can be derived. In addition, a transformational roadmap providing recommendations for future platform implementations can be generated based on the formal input requirements and a gap analysis as illustrated in Figure 2. The scope of Task 3.4 and the corresponding deliverable is concerned in identifying user needs and requirements while a more detailed roadmap and gap analysis would be done in subsequent tasks.

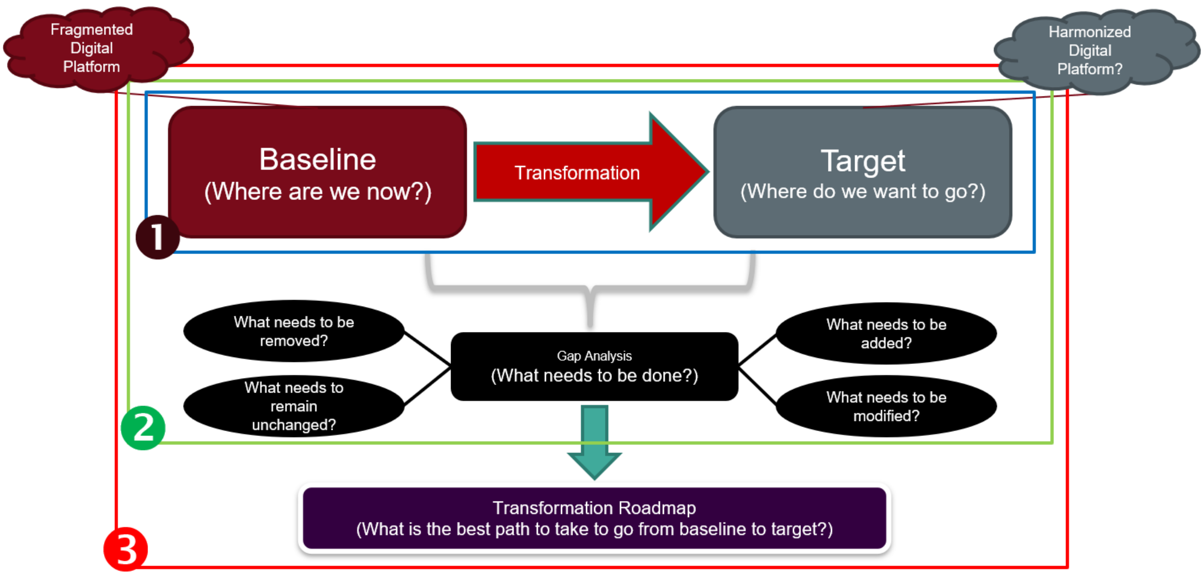

Figure 2 Overview of the formal analysis method following a top-down approach

2. Methodology

This section describes the methodology that is used for completing the modeling and architecture activities in this task. The input for the process is the formalized use cases, literature review, and detailed requirements from the stakeholders as well as the cross-cutting concerns. This is based on the analysis performed using the approach introduced in Figure 2. To process this input to define the system model, Model-Based Systems Engineering (MBSE) approach is used together with the methodology defined in the IEC SRD 63200. This section first introduces MBSE and the Smart Grid Architecture Model (SGAM) and then describes the information-gathering approach.

Model-Based Systems Engineering (MBSE)

Systems engineering is an interdisciplinary approach to help in the design and analysis of complex engineering systems. Using it, on the one hand, ensures that the resulting system satisfies the stakeholder requirements and its intended objectives, while on the other hand, ensures that quality attributes and cross-cutting concerns are addressed properly. It, usually, takes a holistic view of the system, considering not just individual components but also their interactions, interfaces, and the system's context within its environment. It can further help in evaluating the trade-offs between conflicting objectives to make informed decisions during the design process.

Overall, the systems engineering involves creating a high-level system architecture that defines the structural decomposition of the system into components and their interrelationships. This architecture serves as a blueprint for the system-to-be-build's implementation. This is achieved, using systems engineering, by working closely with stakeholders to understand their needs and incorporate their feedback into the design. This is usually an iterative process where refinements and adjustments to the design are carried out as new information becomes available or as requirements evolve.

MBSE is an approach to systems engineering that creates and uses models of the system, in various system modeling languages (UML[1] or SysML[2]), at its core, for designing and developing (complex) systems. This is in sharp contrast to Documents-Centric Systems Engineering (DCSE) that relies on traditional documents and textual representations. This way, MBSE is valuable in enhancing the communication among multidisciplinary teams, and stakeholders due to its use of a common visual language and framework for representing system requirements, design, and architecture. The improved communication helps reduce misunderstandings and misinterpretations thus enabling better collaboration.

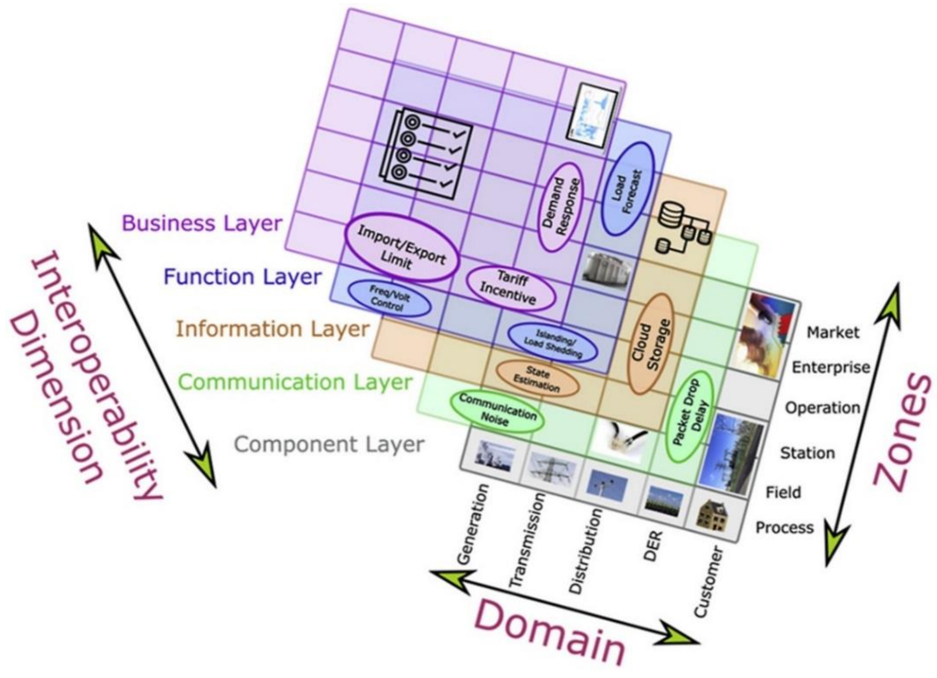

Figure 3: Overview of methodology used with MBSE [4]

It also aids in the establishment of a strong requirements management capacity that allows for traceability between high-level system requirements and technical design aspects. This guarantees that system elements are developed in accordance with the specifications. MBSE may be applied

[1] https/www.omg.org/spec/UML/

[2] https://www.omg.org/spec/SysML

throughout the entire life cycle of a system, from concept and design to implementation, operation, and maintenance. As a result, the system will be well-documented and adaptive as it grows. Furthermore, MBSE technologies allow stakeholders to study and interact with the model interactively using some tools such as Sparx Enterprise Architect[3]. These tools also provide the capabilities to export models in various formats such as HTML, that provide better and rich experience. Also, as the mode is considered a repository, changes made to one element of the model may be verified for effects on other parts automatically, providing consistency and traceability.

As the explanation in this section shows, MBSE is a significantly better-suited and increasingly popular paradigm for modeling complex systems as it provides numerous benefits in terms of usability, efficiency, traceability, and collaboration. Due to these advantages, MBSE is used as the modeling paradigm for the work completed in this task.

It should be emphasized, however, that while MBSE is a well-known and famous modelling paradigm that uses UML and SysML to express representation and semantics, it does not impose a specific methodology to follow. To address this, in this work the well-known IEC SRD 63200:2021 [5], also known as the Smart Grid Architecture Model (SGAM) [6], is selected as the modelling methodology.

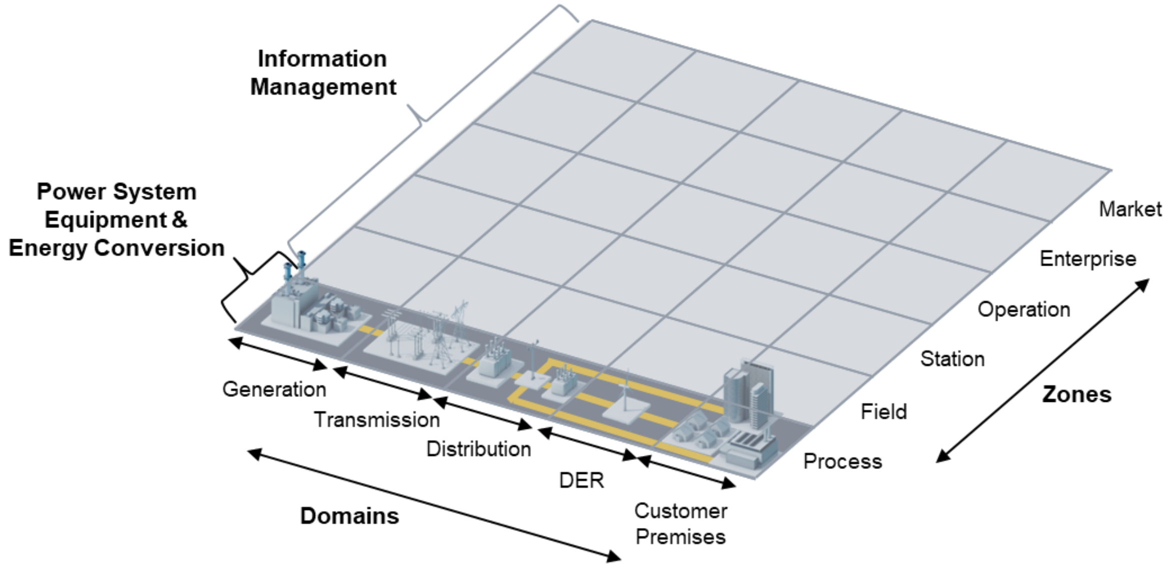

Figure 4: The Smart Grid Architecture Model (SGAM) Plane [6]

The Smart Grid Architecture Model (SGAM)

The Smart Grid Architecture Model (SGAM) is a conceptual framework that provides a structured approach to understanding and designing smart grids. It was developed by CEN-CENELEC-ETSI Smart Grid co-ordination group (now called SEG-CG as Smart Energy Grid co-ordination group) under the European mandate M/490. Later, it was adopted as a standard by IEC as IEC SRD 63200.

The SGAM is a three-dimensional cubical architectural framework designed for modeling Smart Grid applications. The SGAM Plane (Figure 4) is a 5x5 table with rows and columns and is used as a visual representation of the architecture. It divides the smart grid into domains (electrical energy conversion chain) and zones (hierarchical levels of power system management), which help organize and categorize the various components and functions within a smart grid system. The SGAM domains and zones provide a high-level view of the architecture of a smart grid. Below, a brief description of the SGAM domains and zones is provided.

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[3] https://sparxsystems.com/ (visited on 11.10.2023)

The SGAM domains are defined for covering the electrical energy conversion chain [7], and include:

- **Generation**: Representing generation of electrical energy in bulk quantities, such as by fossil, nuclear, and hydro power plants, off-shore wind farms, large scale photovoltaic (PV) power – typically connected to the transmission system
- **Transmission**: Representing the infrastructure and organization that transports electricity over long distances
- **Distribution**: Representing the infrastructure and organization which distributes electricity to customers
- **DER**: Representing distributed electrical resources, directly connected to the public distribution grid, applying small-scale power generation technologies (typically in the range of 3kW to 10,000kW). These distributed electrical resources can be directly controlled by the DSO
- **Customer Premises**: Hosting both – end users of electricity, also producers of electricity. The premises include industrial, commercial, and home facilities (e.g., chemical plants, airports, harbors, shopping centers, homes). Also, generation in the form of e.g., photovoltaic generation, electric vehicle storage, batteries, microturbines, etc., are hosted.

The SGAM Zones are defined to cover the hierarchical levels of power system management, distinguishing between electrical process and information management viewpoints [7], and include:

- **Process**: including both - primary equipment of the power system (e.g., generators, transformers, circuit breakers, overhead lines, cables, electrical loads, etc.) – as well as physical energy conversion (electricity, solar, heat, water, wind, etc.)
- **Field**: including equipment to protect, control, and monitor the processes of the power system, e.g., protection relays or any kind of intelligent electronic devices that acquire and use process data from the power system
- **Station**: representing the aggregation level for fields, e.g., for data concentration, substation automation, etc.
- **Operation**: hosting power system control operation in the respective domain, e.g., distribution management systems (DMS), energy management systems (EMS) in generation and transmission systems, microgrid management systems, virtual power plant management systems (aggregating several DER), electric vehicle (EV) fleet charging management systems
- **Enterprise**: includes commercial and organizational processes, services, and infrastructures for enterprises (utilities, service providers, energy traders, etc.), e.g., asset management, staff training, customer relation management, billing, and procurement
- **Market**: reflecting the market operations possible along the energy conversion chain, e.g., energy trading, mass market, retail market, etc.

In addition to the SGAM plane, the conceptual model also has the concept of Interoperability Layers that organizes and categorizes the various aspects of interoperability in a smart grid. Interoperability is essential in a smart grid context to ensure that different components, systems, and devices from various vendors can work together seamlessly. The SGAM Interoperability Layers provide a structured way to understand and address interoperability challenges. There are five interoperability layers in the SGAM conceptual model [7]. A brief description of each of them (taken from [7]) is provided below:

- **Business**: The business layer represents the business view on the information exchange related to smart grids. SGAM can be used to map regulatory and economic (market) structures (using harmonized roles and responsibilities) and policies, business models and use cases, business portfolios (products & services) of market parties involved. Also, business capabilities, use cases and business processes can be represented in this layer.

- **Function**: The function layer describes system use cases, functions and services including their relationships from an architectural viewpoint. The functions are represented independently from actors and physical implementations in applications, systems, and components. The functions are derived by extracting the use case functionality that is independent from actors.
- **Information**: The information layer describes the information that is being used and exchanged between functions, services, and components. It contains information objects and the underlying canonical data models. These information objects and canonical data models represent the common semantics for functions and services to allow an interoperable information exchange via communication means.
- **Communication**: The emphasis of the communication layer is to describe protocols and mechanisms for the interoperable exchange of information between components in the context of the underlying use case, function, or service and related information objects or data models.
- **Component**: The emphasis of the component layer is the physical distribution of all participating components in the smart grid context. This includes system & device actors, power system equipment (typically located at process and field level), protection and tele-control devices, network infrastructure (wired / wireless communication connections, routers, switches, servers) and any kind of computers.

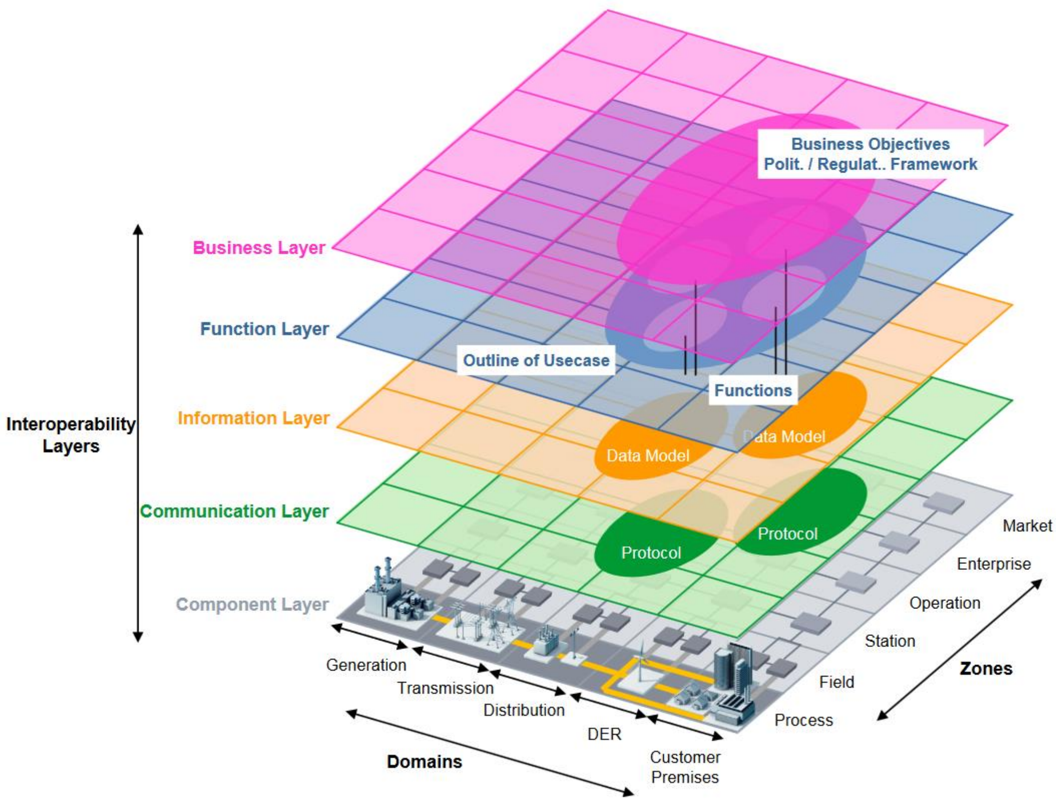

Figure 5: The Smart Grid Architecture Model (SGAM) with its layers, domains, and zones [6].

Information Gathering

Based on the previously developed project deliverables including D3.1 and D3.2 as well as supplementary external references such as [8], [9], and [2], the base information to capture the state of the art processes was compiled. For instance, [8] provides a detailed review and classification of existing flexibility platforms as well as their intended scope. Some modeling efforts regarding the stakeholder structure have also been conducted by ENTSO-E resulting in a comprehensive harmonized electricity market role model [10]. The state-of-the-art was then extended by the project vision of providing digital solutions for the integration of diverse flexibility platforms to describe a comprehensive high-level view of the selected functionality.

In parallel to the initial literature research, the information was gathered by several interactive meetings with domain experts. Starting from the discussions on the primary use cases developed in task 3.3, several meetings were performed in the consortium to iteratively discuss the modeled facts including the intended use cases and related background knowledge. To increase the added value of the architectural model and to utilize synergies, efforts were synchronized with the tasks of work package 4 that ran in parallel with WP 3.3. This architecture model joins the received information of all involved project partners into a single high-level system architecture. Additional review rounds were added for quality management of the newly developed model.

3. Architecture Modeling

The architecture modeling focuses on a black-box representation of an interoperable flexibility platform as described in D3.3, UC 1 [3]. To provide the necessary framework, a generic representation is chosen that does not directly incorporate existing platforms. The generic nature of the targeted architecture should impose few restrictions on the implementation. Hence, deploying existing platforms to achieve the modeled goals is encouraged. Nonetheless, the modeling work tries to include standards and de facto standards to support the integration of existing systems. Such existing systems may either be deployed to implement parts of the platform functionality itself or may be operated by an external entity that needs to access the platform. In both cases, using standards can reduce the adaption and implementation efforts. Since this model specifically targets the overarching framework and focuses on the high-level representation of the system, an implementation-centric representation that does not feature a more general applicability is considered out of scope of T3.4 and will be derived in subsequent tasks.

The targeted system scope is herein informally defined as a platform that enables Load Frequency Control Operators (LFCOs) and System Operators (SO) to gather, activate, and settle flexibility bids for providing flexibility services in consideration of potential restrictions imposed by the connecting distribution and transmission grids. To enable future use cases including the activation of flexibilities by DSOs, the definition includes the SO role instead of restricting the platform operation to load frequency control conducted by TSOs only. A detailed demarcation of the platform scope will be given by the following use-case models. These use cases will further elaborate on the overarching process and the platform boundaries within the process.

Business Layer Model

A detailed hierarchy of business actors was created to model the manifold structure of stakeholders. Whenever reasonable, the ENTSO-E harmonized electricity market role model [10] was applied for a coherent description of actors. Nonetheless, an additional generalization based on the buyer-agent-seller triad adopted from the well-known GoodRelations[4]and its adoption into Schema.org's BusinessFunctions[5], the Financial Institution Business Ontology (FIBO)[6] and the FIBO Markets[7] ontologies, was introduced for further structuring related stakeholders. Figure 6 shows the complete hierarchy of all modeled actors.

[4] https://www.heppnetz.de/ontologies/goodrelations/v1.html#conceptual_overview (visited on 2023-10-10)
[5] https://schema.org/BusinessFunction (visited on 2023-10-10)
[6] https://spec.edmcouncil.org/fibo/ (visited on 2023-10-10)
[7] https://spec.edmcouncil.org/fibo/ontology/FBC/FunctionalEntities/Markets/ (visited on 2023-10-10)

As top-level entities, buyer actors group all stakeholders that access the platform with the intent of obtaining flexibility and capacity management services. The seller actor represents every stakeholder that offers flexibility services via the platform. In addition, a third entity, the agent actor, is introduced grouping all entities that support the operation and management of the platform without directly participating in the processed flexibility transactions. Note that the agent nomenclature describing supportive roles was directly taken from the ontologies. It is not to be confused with the nomenclature found in modeling the interactions of autonomous entities (e.g., in a market environment) which are also often called agents. Due to the specific focus of D3.4 on architectural aspects, the common terminology in this domain was applied for compatibility with related studies instead of developing a new one that resolves cross-domain inconsistencies.

Since the electricity domain is broadly considered heavily regulated, the original triad was extended by a fourth actor representing all regulation bodies. The regulator actor with its goal of enforcing a cost-efficient, reliable, and sustainable energy system in accordance with national and international regulations and laws maintains regulatory relationships with all actors of the original triad. Although accordance with effective regulations must be ensured in all domains beyond the energy sector, dedicated reporting, and organizational obligations may have to be reflected in the system architecture. Hence, the regulatory relationships were introduced to specifically address requirements that are not directly induced by one of the main parties in the triad.

The generalized buyer actor is refined by two ENTSO-E roles, the LFCO responsible for the corresponding load frequency control in the LFC area, and the SO ensuring the operation of a dedicated power system. While a TSO can act as both, LFCO and SO, DSOs that may, for instance, access the platform to consign grid constraints, are solely modeled as SOs, representing current responsibilities. This approach can easily be generalized to enable the DSO to procure flexibility in the future, as required by Art. 32 (1) of Directive 2019/944 (Electricity Directive)[8] [11]. The ENTSO-E model differentiating between LFCO and SO thereby enables a clean separation between use cases that directly involve conventional LFC actions and those that deal with grid capacity management. Nevertheless, both services may be requested by a single TSO (or DSO).

Seller actors are further refined into conventional Balancing Service Providers (BSPs) as defined in the ENTSO-E role model as a party with reserve-providing units or reserve-providing groups able to provide balancing services to one or more LFC Operators and Flexibility Service Providers (FSPs), a more general role than BSP, whose task is to offer or carry out a change in injection or withdrawal requested by the system operator, carried out as part of a system service or congestion management. Since at the time of writing, it is still up to a broad discussion beyond modeling efforts whether FSPs directly manage small-scale flexibilities or whether these flexibilities must be first aggregated, the system model includes both variants. In addition, different market roles such as small-scale FSP and aggregators that coordinate multiple flexibility sources must be supported simultaneously. Hence, FSPs may herein either directly offer individual small-scale flexibilities or aggregate multiple flexibilities into less granular, pooled offers.

To further structure the diverse agent actors that are needed for the platform operation, two groups of agent actors are introduced. The first group consists of operating agents, i.e., the platform operator itself. These operating agents and particularly the platform operator maintain the stable operation of the technical facilities of the platform. In addition, operating agents are responsible for further developing the platform and implementing new functionalities. The second abstract agent is the

[8] Art. 32(1) states that "[m]ember states shall provide the necessary regulatory framework to allow and provide incentives to distribution system operators to procure flexibility services, including congestion management in their areas […]".

reporting agent grouping all entities that mainly request information from the platform without being directly involved in flexibility transactions. Such agents include the roles of Balance Responsible Parties (BRPs), Imbalance Settlement Responsible (ISR), Flexibility Register Operators (FROs) [12], [13], and Control Area Operators (CAO). For instance, in case flexibility bids are aggregated across balance groups, BRPs of all involved balance groups will need to be notified upon activation to avoid spurious mismatches in the energy balances. Pooling across balance groups is already possible for balancing energy, but only through bilateral contracts between BSP & provider, and thus is very difficult to scale across many assets. Close communication between FSP and suppliers or their balance groups through the platform would simplify the provision of schedules, the announcement of supplier changes, and avoid potential counter-regulation by balance groups decisively. Similarly, the supportive services of the platform regarding settlement also add value for the ISR [10], [14]. Therefore, the ISR is explicitly modeled as reporting agent that does not directly participate in transactions but draws information out of the system.

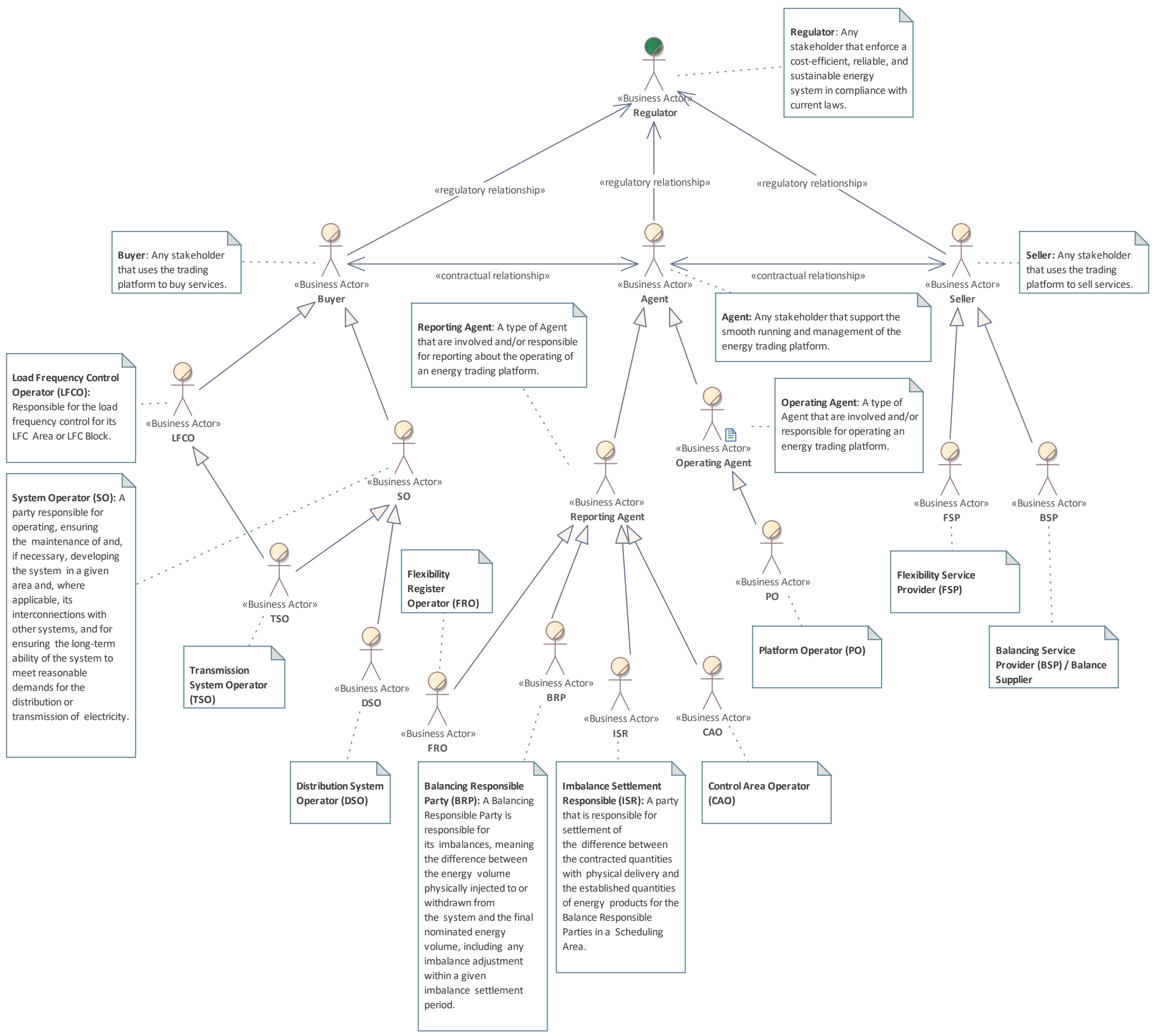

Figure 6: Business Actor Hierarchy

Based on the top level of the business actor hierarchy, the high-level business case analysis models the main business goals, business use cases, and refined high level use cases of each actor. The use case diagram shown in Figure 7 illustrates the main interactions and goals of the SGAM business layer. The highest level of business use cases reflects the business use cases of the major entities buyer, seller, agent, and regulator. In accordance with the actor hierarchy, the business use cases will be further refined into high level use cases that can be associated with the more detailed actor representations. Thereby, the highest business layer aims for general applicability in the domain of flexibility platforms beyond the provisioning of balancing energy. Nonetheless, the refinements of the overarching view specifically focus on the use cases implied by D3.3 UC1.

It is assumed that all buyer actors including both TSOs and DSOs target the safe and stable operation of their systems at the lowest cost possible and hence the effectiveness of the measures is in focus. The generalized business use case of buying flexibility is then refined into one dedicated high level use case covering the procurement of balancing energy services and one covering the novel capacity management services. Following the buyer hierarchy, both can be directly associated with the LFCO and SO actors, respectively. Since the high-level procurement use case is specifically tailored to the procurement of balancing energy services such as aFRR, related flexibility services including balancing capacity or redispatch that are beyond the scope of D3.3 UC1 may be easily added in future versions as adjacent high-level use cases, if needed.

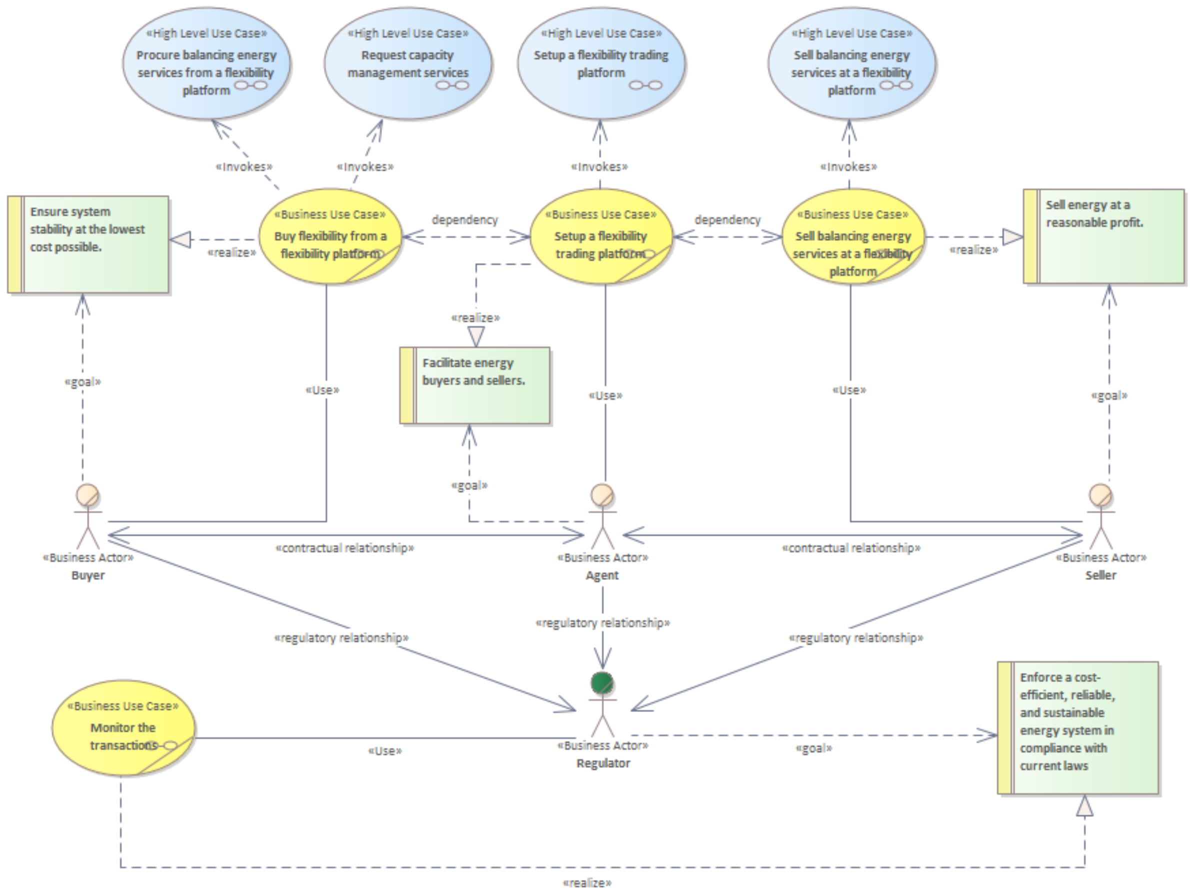

Figure 7: Business Case Analysis

Due to the highly versatile structure of reporting agents and to keep the number of connected use cases manageable, the reporting use cases were subsumed under the more general high-level use case of setting up the flexibility trading platform. In addition, the consolidation of the many reporting use cases aims at reflecting the significance of the tasks in comparison with the buyer and seller use cases that convey the main platform goals. Hence, this resulting high-level use case covers both the actual platform operation as well as the reporting ones. Following the generic nature of the business use case regarding the setup of the platform, an overarching business objective of facilitating energy buyers and sellers was modeled. Following the goal, agent actors enable and support the business of buyers and sellers by providing the flexibility platform at hand.

The use cases connected to selling balancing energy services are generalized for both types of sellers as well. Similarly, one joint business goal of selling flexibility services at a reasonable price is derived.

In the case of the regulator actor, the business use case of monitoring the transactions to enforce a cost-efficient, reliable, and sustainable energy system is included. The detailed relationships among the business cases can be found in Figure 8. Joint by the common flexibility platform, both the buying and selling use cases are interlinked. In addition, the regulatory use case is interlinked with the other business use cases due to the regulatory relationship on the actor level.

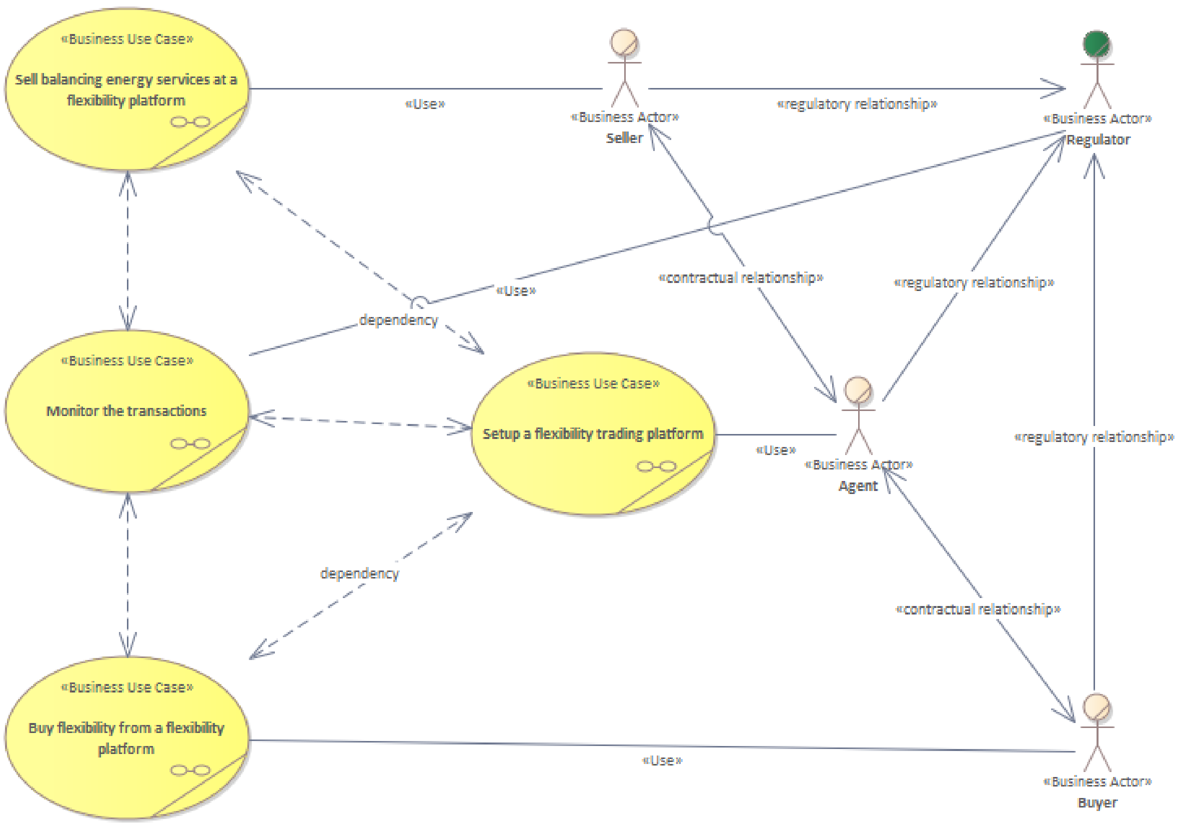

Figure 8: Business Cases and their Relationships

Function Layer Model

On the functional SGAM layer, the high-level use case of procuring balancing energy services from a flexibility platform is divided into five primary use cases that mark the actions needed to fulfill the procurement. Figure 9 shows the use-case diagram of the high-level procurement use case. In addition, Figure 10 shows the activities and their timing that relate to the primary use cases of procuring balancing energy. Before gate closure of the aFRR/mFRR markets, several boundary conditions may have to be submitted by the LFCO to the platform in order to parametrize the following calculations and to correctly perform the task of obtaining the optimal bid list. Such conditions may include the maximum amount of energy that needs to be procured and that is returned in the list of optimal bid combinations. It is expected that a LFCO submits updated boundary conditions whenever changes are encountered. However, for one optimization run, only changes up to gate closure can be considered. Any change request that is submitted after gate closure time will be deferred to the next run or a later time indicated in the change requests. The use case includes the acknowledgment when the updated boundary conditions will be applied. I.e., the LFCO will receive a message in return to any request that indicates the time, the submitted data will be applied.

At gate closure after all flexibility bids are received by the platform, the primary use case of obtaining the optimal bid list can be triggered by the LFCO. This primary use case includes the core activities of the flexibility platform in optimizing the list of received bids such that the submitted grid constraints are considered and no congestions are created. Therefore, the platform actively triggers the optimization procedure that computes the list of filtered bids according to D3.3 UC1. Due to the nature of the filtering and optimization algorithm that takes both distribution and transmission systems via their submitted model representation into account, coordination between TSOs and DSOs can be achieved.

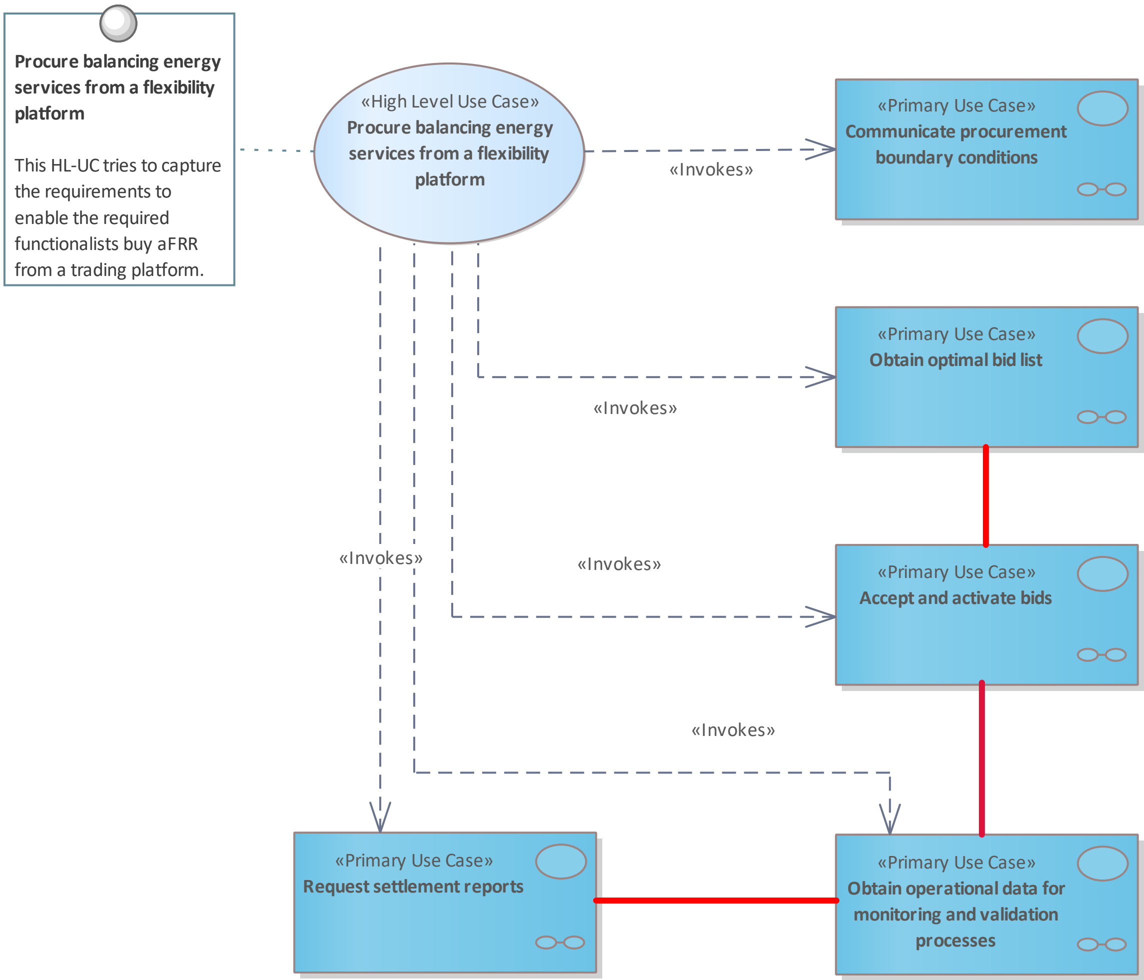

Figure 9: Procure balancing energy services from a flexibility platform (use case diagram)

To avoid malicious bids, the platform must verify whether each seller is eligible to submit bids according to its available information. Bids that do not meet the required prequalification criteria must not be passed on to the optimization procedure. As soon as the optimization results are available, the LFCO may actively download the optimal bid list. In case they are not ready upon request, a corresponding message needs to be returned. To support graceful degradation, querying the unoptimized or, if available, partially optimized list must be supported by the use case as well. The unoptimized list must be available as soon as the gate closure time is reached. Despite the graceful degradation option, the optimality status of each list must always be included.

Since the decision on which optimized bid combination is to be activated depends on the control outputs calculated by the LFCO, and the decision authority on the activated flexibilities is up to the LFCO, the use case does not include any automatic activation of received bids. In addition, coordination among adjacent LFCOs, e.g., by accessing the external systems of the Manually Activated Reserves Initiative (MARI) and PICASSO, are beyond the scope of this use case. It is assumed that any such coordination actions are performed by the LFCOs after receiving the optimal bid list.

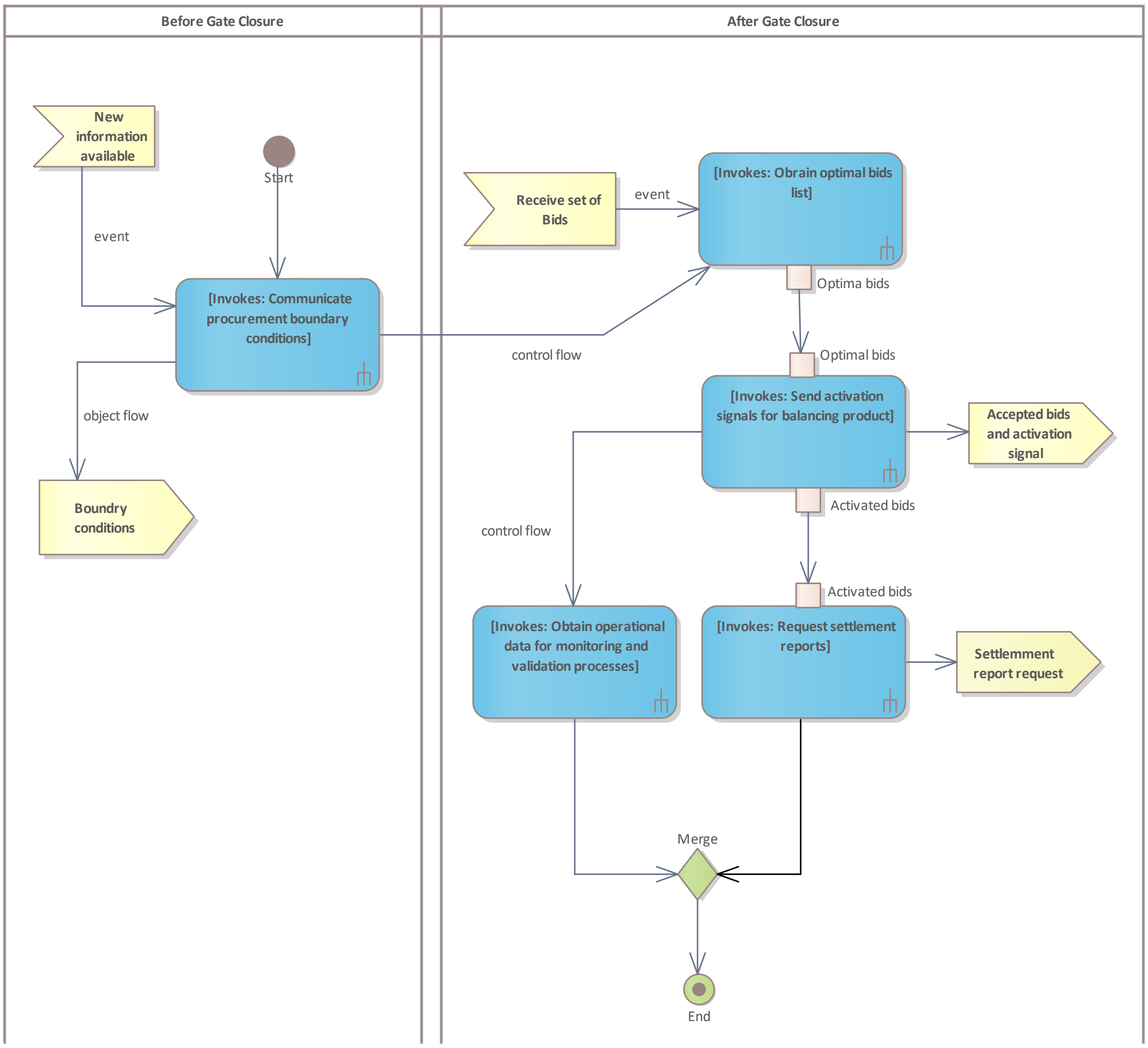

Figure 10: Procure balancing energy services from a flexibility platform (activities)

A dedicated use case was added for the LFCO to put the decisions on the selected flexibilities into action. The primary use case called “accept and activate bids” receives the information on the accepted bids in real time and distributes the information, as needed. Note that at the time of writing, it is still under discussion whether the actual activation signal is distributed via the platform or whether it is directly sent, e.g., to large-scale flexibilities. Hence, it is decided to avoid overspecification and to support both variants at the functional layer. In any case, the platform needs to be able to receive the activation signals for further processing.

Measurements from the flexibility sources are submitted possibly in real time to verify the operation including the current activation status. To enable an LFCO to utilize this information for monitoring and validation, a dedicated use case is added. The platform must be able to relay the information of all registered flexibility sources such as asset measurements that may provide flexibility services for the LFCO. It is still up for discussion whether these services will be provided in real-time or ex-post. Nevertheless, it was decided to differentiate the monitoring from the settlement use case to highlight possibly different timing schemes and target domains within the LFCO. In contrast to settlement information, real-time information may be directly passed on without dedicated quality checks beyond simple consistency rules. The settlement information obtained in the corresponding use case will be received ex-post and may include further quality assurance measures to provide sufficient data quality for billing processes. Hence, the primary use case on requesting the settlement reports can only be triggered as soon as the settlement information is available. Any gaps and missing information must be clearly indicated to avoid spurious settlement and negative financial impacts.

The high-level use case of requesting capacity management services by a SO was also divided into multiple primary use cases as shown in Figure 11. At first, a use case to submit or update the simplified grid models is introduced. That use case will be triggered as soon as new or updated grid information is available. Note that due to data protection requirements, the simplification process is conducted by the SOs and only the corresponding Power Transfer Distribution Factor (PTDF) and Voltage Transfer Distribution Factor (VTDF) matrices are transmitted to the flexibility platform. Hence, evaluation measures that control the quality of the submitted network information are also conducted by the SO, without requesting any direct platform support. The grid model itself may depend on several boundary conditions such as external schedules and other operating points. Since it is expected that the boundary conditions are considerably more frequently updated than the network model, a dedicated use case enabling the transfer of boundary conditions is introduced. Both use cases may be triggered at any time, but to update the information before the next optimization run, the data must be transferred before the corresponding gate closure time. In any case, the SO may specifically request validity dates for the submitted information and the platform must indicate at which time the received changes take effect.

The SO may further utilize the complete list of submitted bids to update internal estimation and amend its operational information. Therefore, another primary use case on obtaining the complete list of bids within the realm of the requesting SO is introduced. To prevent leakage of sensitive market information, no price information is transferred and only bids within the area of the system operator are returned. In case the use case is triggered before gate closure, the currently submitted bids are returned and the non-final state is indicated. Note that the platform will not receive any sensitive operational information from the SO. However, some operational information regarding flexibilities will be received from the platform via another primary use case for obtaining operation information.

In contrast to the bid-list use case that may be triggered before gate closure, obtaining operational information will return information on the activation status within the SO grid in real time. Due to temporal discrepancies between both tasks, it was decided to model them as dedicated primary use cases without joining them into one. Nevertheless, both use cases aim at supporting the system operation of connected TSOs and DSOs. In addition, the use cases shall return enough information to enable a SO to verify the benefits of participating in the platform operation and improving the effectiveness of all submitted network constraints. Hence, also for SOs, a closed engineering loop iteratively improving the grid models based on the received information can be implemented. Due to the sensitive nature of detailed grid models, the management and improvement of any simplified version is conducted outside the platform and no dedicated use case is added to the architecture model.

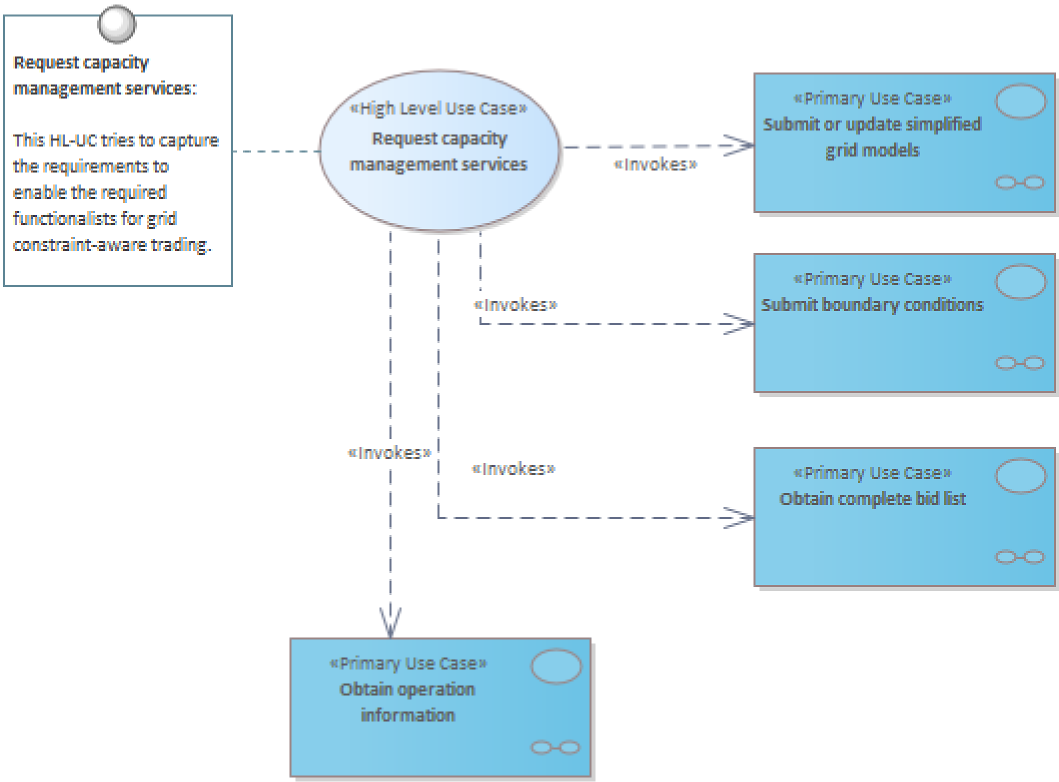

Figure 11: Request capacity management services (use case diagram)

It is assumed that in contrast to a static structure of a relatively low number of LFCOs and SOs, several FSPs will have to be dynamically managed. Hence, dedicated primary use cases are added to support the registration and prequalification process. In general, it is assumed that the LFCO will manage prequalification. To avoid spurious bids that may change the outcome of the optimization runs, the platform still needs to verify the prequalification status of registered assets. Therefore, the sellers locally register at the platform and the responsible LFCOs communicate the corresponding prequalification status. Note that the authoritative master data on the flexibility may be managed by an external flexibility register. Nonetheless, the local registration process is modeled to support the connection of various data sources and to enter information such as access credentials that may not be managed by any other platform. For the seller-related part of the procedure, the primary use case “registration and prequalification” was added. It must be triggered by the seller before the entity can participate in any other use case. Among the registration process and facilities to update the master data, the use case enables the seller to view its prequalification status for verification.

Before gate closure, any prequalified seller may trigger the use case on submitting location-aware bids. In contrast to conventional bids that do not convey any information on the asset location itself, the modified bid structure must locate each bid within the power grid. To support aggregated bids grouping the services of multiple small-scale flexibilities, a bid may not be limited to a single asset. Since at the time of writing, the discussions and related research efforts on the optimal bid structure are still ongoing, bids cannot be modelled in full detail. To avoid log-in effects, multiple prototypical bid structures are considered in the model that may be restricted in future versions:

- Exactly one asset per bid. In this case, every bid can be directly related to a single location within the network, but no aggregation and exchange of small-scale flexibilities is feasible.
- Multiple assets per bid. This structure features aggregation by supporting joint bids from multiple assets. It is assumed that each location and corresponding master data such as the

maximum flexibility contribution of each asset is known, but the exact share within each bid can be dynamically determined at run-time by the seller. For the optimization procedure, worst-case contributions must be assumed. Splitting the bids into geographically meaningful batches is up to the seller.

- Equivalent network location. The seller must name a single position in the upstream network that connects all assets from that region. The equivalent position may not reflect the individual, detailed positions of all aggregated assets within the connecting distribution grid but may only point to a common upstream node. Hence, network restrictions in the downstream distribution grid may not be reflected in full detail. Similarly, only assets from a specific network region can be aggregated. To avoid spurious bids, the platform must verify the structure of such bids by the known topological information.

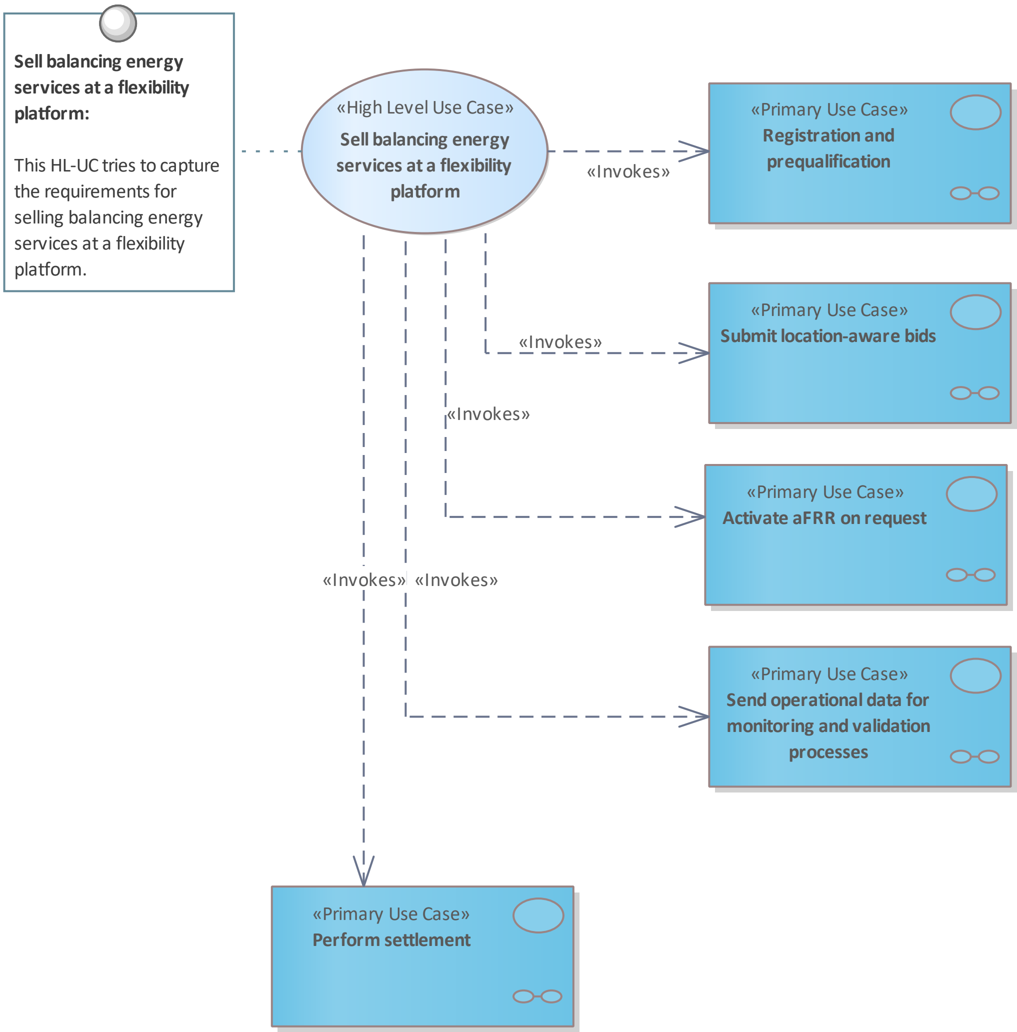

Figure 12: Sell balancing energy services at a flexibility platform (use case diagram)

Until gate closure, submitted bids may be actively modified and corrected. Furthermore, it is yet open for discussion whether some or all bids can be submitted via an external market platform or will have to be relayed to an external market platform. In the first case, externally submitted bids have to be fetched from the external platforms, e.g., to maintain compatibility with existing TSO platforms. Since it is expected that the external systems will not manage any location information, the seller must amend any missing location information via the flexibility platform. In the second case when relaying bids or bid combinations to external platforms, additional measures need to be taken to remove any sensitive information that should not be transferred to external systems. The platform must validate all received bids from the market platform. In case some received bids may not contain valid location information, the seller must be notified and a worst-case assumption on the power grid may be taken.

Another primary use case is dedicated to the activation of aFRR on request. In case balancing energy or some flexibilities are directly activated, the use case will not be triggered. To specifically support small-scale flexibilities via a unified interface [8] [9], it was decided to add the activation use case to the model. In addition, operational information such as measurements for monitoring and validation may have to be submitted in real time via the dedicated use case. Again, a settlement use case that allows setting the quality-controller ex-post information and performing all necessary settlement steps is added to differentiate between the different timing regimes.

The high-level use case of setting up a flexibility trading platform by the agents (depicted in Figure 13) is divided into three primary use cases. The first primary use case is summarized as the management of master and prequalification data. The Platform Operator (PO) needs to manage all master data concerning connected LFCOs and SOs. In contrast to the self-managed registration of sellers such as BSPs and FSPs, the management of the TSO and DSO data is considered a less frequent task and therefore to maintain model simplicity associated with the realm of the PO. Nonetheless, the PO may delegate several management obligations to the connected LFCOs and SOs, if needed. In addition, the information or parts thereof may also be fetched from external, authoritative information sources, if available. For instance, in case an external flexibility register gets available, prequalification information and other master data may be directly fetched from the authoritative register without the need of implementing direct LFSO and SO interfaces.

To further refine the primary use case of managing master data and prequalification as well as to specifically model the interaction with external prequalification processes, the primary use case was split into two dedicated functions as shown in Figure 14. A function for updating the list of prequalified assets is introduced. This function models the direct counterpart of the self-registration process for sellers and represents the authoritative source of information regarding the prequalification status. Since the prequalification itself is managed outside the flexibility platform by the responsible LFCOs, the responsibility of entering the authoritative information is delegated to the corresponding TSO. The other function for viewing and updating the master data contains all information that is needed to run the system but will be managed by the platform operation itself.

The second primary use case targets the core activities of the platform operator in monitoring and operating the system. Herein, all activities to develop and maintain the technical assets that are implementing the platform services are subsumed. The third primary use case for setting up and operating the flexibility trading platform as shown in Figure 13 relates to the manifold reporting requirements, that could be simplified by the flexibility platform. One of these reporting duties relates to the notification associated BRPs about any activated flexibility within their balance group. To net costly imbalances, the BRPs of all activated flexibilities as well as the associated BRP of each activating LFCO have to be actively contacted on the amount of activated flexibility. The process is triggered ex-post as soon as all settlement information is available. Figure 15 illustrates the modeled balance group data exchange in detail. The send activated flexibility function is thereby extended by two subfunctions, one managing the BRP associated to a single flexibility and the other notifies the BRP of each LFCO.

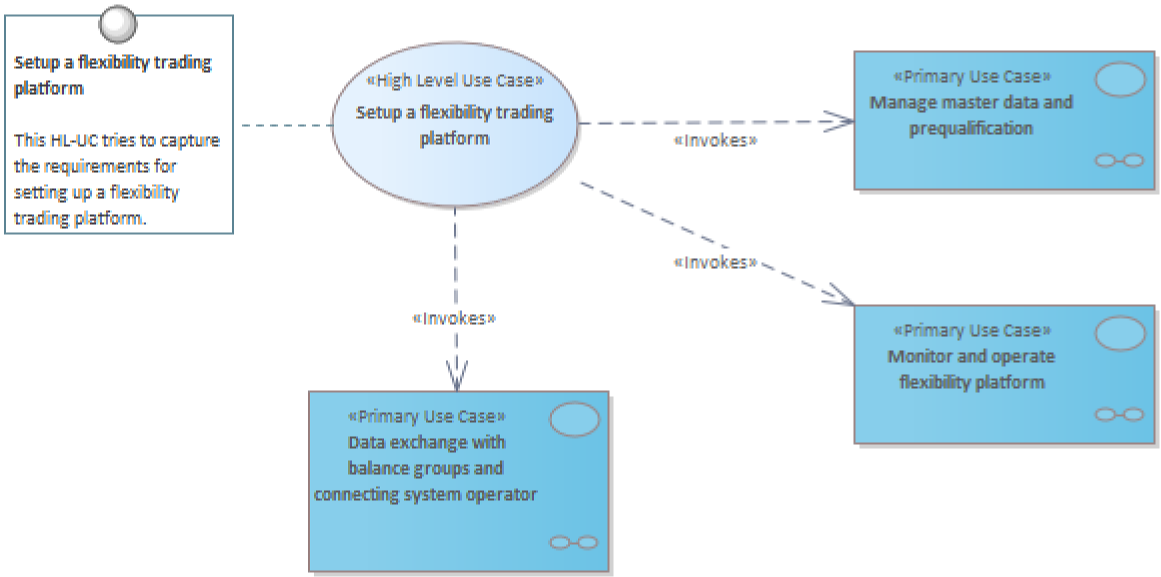

Figure 13: Setup a flexibility trading platform (use case diagram)

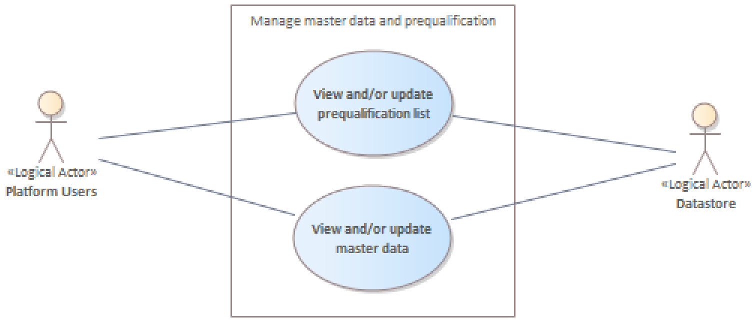

Figure 14: Manage master data and prequalification

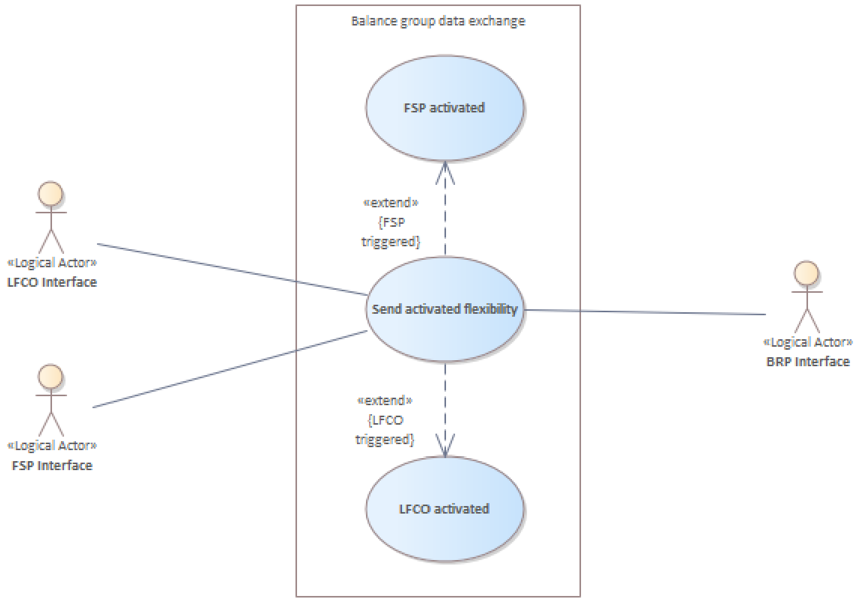

Figure 15:Balance group data exchange

4. Conclusion

This deliverable documented the architectural model for the flexibility platform that would help in developing an interoperable flexibility platform to fulfill the objectives of the DigIPlat project. Such a platform would be valuable in facilitating a successful energy transition with its capabilities to support efficient flexibility management.

The architecture modeling focuses on a black-box representation and is primarily focused on the findings reported in D3.3. The analysis and modeling are conducted by following the well-known EU and international standards and paradigms. It also aids in the establishment of a strong requirements management capacity that allows for traceability between high-level system requirements and technical design aspects. This provides a way to make sure that system elements are developed by the specifications. It is also valuable in enhancing the communication among multidisciplinary teams, and stakeholders due to its use of a common visual language and framework for representing system requirements, design, and architecture. The improved communication helps reduce misunderstandings and misinterpretations thus enabling better collaboration.

To provide the necessary framework, a generic representation is chosen that does not directly incorporate existing platforms. The generic nature of the targeted architecture should impose few restrictions on the implementation. Hence, deploying existing platforms to achieve the modeled goals is encouraged. Nonetheless, the modeling work tries to include standards and de facto standards, related to energy trading, to support the integration of existing systems. Such existing systems may either be deployed to implement parts of the platform functionality itself or may be operated by an external entity that needs to access the platform. In both cases, using standards can reduce the adaption and implementation efforts. Since this model specifically targets the overarching framework and focuses on the high-level representation of the system, an implementation-centric representation that does not feature more general applicability is considered out of the scope of T3.4 and will be derived in subsequent tasks.

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Annex: Business Roles and Objectives

Table 1 summarizes the main business roles and objectives modeled in the high-level architecture. Whenever suitable, definitions were taken from [10] and [14].

Table 1: Overview on business roles and objectives

Business Actor	Harmonized Role	Role Outline	Business Objectives	Business Needs
TSO	Load Frequency Control (LFC) Operator	Responsibility for LFC in a dedicated area or block	Maintain the system stability and minimize frequency deviations.	Dispatchable balancing services to restore frequency deviations
Unit or Group Operator	Balancing Service Provider (BSP)	Party that provides balancing-specific services to a LFC Operator	Maximize profit from selling balancing services	Platform to offer services and to receive activation signals
Unit or Group Operator	Flexibility Service Provider (FSP)	Party that provides generic flexibility services	Maximize profit from selling flexibility services	Platform to offer services and to receive activation signals
TSO	System Operator (SO)	Operates a grid area	Generate income by operating the transmission grid. Ensure that all physical grid constraints are met.	Consumption and generation schedules to check potential congestions. Redispatch services to resolve them.
DSO	System Operator (SO)	Operates a grid area	Generate income by operating the distribution grid. Ensure that all physical grid constraints are met.	Consumption and generation schedules to check potential congestions. Redispatch services to resolve them.
	Balancing Responsible Party (BRP)	Responsibility for the difference between the sum of physical injected or withdrawn to finally nominated energy	Minimize the difference between physical and nominated energy with minimal financial effort	Needs to be informed on elected bids targeting its balancing group
	Imbalance Settlement Responsible (ISR)	Responsible for settlement of the difference between the contracted quantities with physical delivery and the established quantities of energy products for the BRPs in a Scheduling Area	Settlement and billing of imbalances	Needs to be informed on the actual power flows as well as the activated balancing services
TSO	Control Area Operator (CAO)	The system operator that operates a coherent part of the interconnected system	Generating income by operating a control area	Requires information on offered and activated flexibility
	Platform Operator (PO)	A possibly neutral entity that operates the flexibility platform	Selling the services provided by the flexibility platform	Technical facilities and interfaces to proactively operate the platform