Integrated Development Platform for Customer and Aggregator Energy Management Systems (Grant Agreement No 101172675)

D2.3 Final Requirements and IDOP Architecture

Date: 2026-08-31

Version 1.0

DRAFT

Published by the INDEPENDENT Consortium

Dissemination Level: PU - Public

Co-funded by the European Union

Document control page

Document file: D2_3_Final_Requirements_and_IDOP_Architecture.docx
Document version: 1.0
Document owner: **VTT**

Work package: WP2 Requirements and Common System Architecture
Deliverable type: R - Document, report

Document status: ☒ Approved by the document owner for internal review
☒ Approved for submission to the EC

Document history:

Version	Author(s)	Date	Summary of changes made
0.1	Anne Immonen (VTT)	2026-05-12	Initial document created, including document structure and table of contents.
0.2	Jussi Kiljander (VTT), Aleksi Vuorenmaa (Caverion), Jan Mayer (fortiss), Dušan Gabrijelčič (JSI)	2026-05-28	Initial content developed for business use cases, requirements, architecture and trust, security and privacy material.
0.3	Jussi Kiljander (VTT), Janne Takalo-Mattila (VTT), Aleksi Vuorenmaa (Caverion), Ana Constantin (Bosch), Markus Duchon (fortiss), Michael Kluge (Consolinno)	2026-06-20	Pilot-specific business use cases and architecture-related content updated, including German, Finnish and Swedish pilot material and supporting technical descriptions.
0.4	Mahsa Faraji Shoyari (fortiss), Ana Constantin (Bosch), Jussi Kiljander (VTT	2026-08-14	Architecture, requirements and pilot-related content further refined; figures and detailed descriptions updated.
0.5	Anne Immonen (VTT), Dušan Gabrijelčič (JSI), Jussi Kiljander (VTT)	2026-08-20	Requirements, trust/security/privacy perspective, interoperability descriptions and overall document consistency refined.
0.6	Jussi Kiljander (VTT), Anne Immonen (VTT), Michael Kluge (Consolinno), Tim Olsson (NIBE), Mahsa Faraji Shoyari (fortiss)	2026-08-24	Final substantial updates before internal review, including requirements, architecture, interoperability and partner-specific content.
0.9	Jussi Kiljander (VTT), Anne Immonen (VTT)	2026-08-25	Version submitted to internal review
1.0	Jussi Kiljander (VTT), Anne Immonen (VTT)	2026-08-31	Final version submitted to the European Commission

Internal review history:

Reviewed by	Date	Summary of comments
Arso Savanovic (SCOM)	2026-08-28	Accepted with minor corrections and comments.
Mahsa Faraji Shoyari (FORTISS)	2026-08-31	Accepted with minor corrections and comments.

DRAFT

Legal Notice

The information in this document is subject to change without notice.

The Members of the INDEPENDENT Consortium make no warranty of any kind with regard to this document, including, but not limited to, the implied warranties of merchantability and fitness for a particular purpose. The Members of the INDEPENDENT Consortium shall not be held liable for errors contained herein or direct, indirect, special, incidental or consequential damages in connection with the furnishing, performance, or use of this material.

INDEPENDENT is funded by the European Union's Horizon Europe Framework Programme for Research and Innovation under Grant Agreement No 101172675. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor CINEA can be held responsible for them.

Index:

1 Executive summary 7

2 Introduction 8

2.1 Purpose, context and scope 8
2.2 Main changes compared to the initial version 8
2.3 Content and structure 9

3 Business use cases 11

3.1 Business use cases for the German pilot 11
3.2 Business use cases for the Finnish pilot 14
3.3 Business use cases for the Swedish pilot 16
3.4 Business use cases for the Slovenian pilot 18

4 Common requirements 21

4.1 Functional requirements 21
4.2 Non-functional requirements 22
4.2.1 Cross-cutting platform quality requirements 22
4.2.2 Trust, security and privacy requirements 23
4.2.3 Requirements for interoperability and standard compliance 26

5 Common system architecture 27

5.1 Integrated Development and Operations Platform 27
5.2 IDOP based system architecture 28
5.2.1 Context View 28
5.2.2 Functional View 32
5.2.3 Information View 35
5.2.4 Deployment View 44
5.2.5 Trust, security and privacy perspective 46

6 System use cases 49

6.1 Demand-side flexibility aggregation for energy wholesale markets 49
6.2 Demand-side flexibility aggregation for TSO reserve markets 51
6.3 Local flexibility management 53

7 Conclusion 56

8 List of figures and tables 57

8.1 Figures 57
8.2 Tables 57

9 References 58

10 Appendices 59

10.1 Appendix A — SUC-WMA: Demand-side Flexibility Aggregation for Energy Wholesale Markets 59
10.1.1 Description of the use case 59
10.1.2 Diagrams of use case 62
10.1.3 Technical details 63
10.1.4 Step by step analysis of use case 64
10.1.5 Information exchanged 67
10.1.6 Requirements 68
10.1.7 Common terms and definitions 70
10.1.8 Custom information 71
10.1.9 References 71
10.2 Appendix B — SUC-TRM: Demand-side Flexibility Aggregation for TSO Reserve Markets 72
10.2.1 Description of the use case 72
10.2.2 Diagrams of use case 75
10.2.3 Technical details 77
10.2.4 Step by step analysis of use case 78
10.2.5 Information exchanged 82
10.2.6 Requirements 84
10.2.7 Common terms and definitions 86

DRAFT

10.2.8 Custom information 87
10.2.9 References 87
10.3 Appendix C — SUC-LFM: Local Flexibility Management 88
10.3.1 Description of the use case 88
10.3.2 Diagrams of use case 91
10.3.3 Technical details 95
10.3.4 Step by step analysis of use case 96
10.3.5 Information exchanged 100
10.3.6 Requirements 103
10.3.7 Common terms and definitions 105
10.3.8 Custom information 106
10.3.9 References 107

DRAFT

Abbreviations and acronyms

Abbreviation	Description
AEMS	Aggregator Energy Management System
BAS	Building Automation System
BMS	Building Management System; Battery Management System, depending on context
BUC	Business Use Case
CEM	Customer Energy Manager
CEMS	Customer Energy Management System
CIM	Common Information Model
CO2	Carbon dioxide
DER	Distributed Energy Resource
DERA	European Data Exchange Reference Architecture
DR	Demand Response
DSFM	Demand-Side Flexibility Management
DSO	Distribution System Operator
EDO	Electricity Distribution Operator
EUI	End User Interface
EV	Electric Vehicle
FCR	Frequency Containment Reserve
FCR-D	Frequency Containment Reserve for Disturbances
FCR-N	Frequency Containment Reserve for Normal operation
FRBC	Fill-Rate Based Control
GDPR	General Data Protection Regulation
HEMS	Home Energy Management System
HVAC	Heating, Ventilation and Air Conditioning
IDOP	Integrated Development and Operations Platform
IEC	International Electrotechnical Commission
MILP	Mixed-Integer Linear Programming
MPC	Model Predictive Control
MQTT	Message Queuing Telemetry Transport
ODE	Ordinary Differential Equation
OPC UA	Open Platform Communications Unified Architecture
PEBC	Power Envelope Based Control
PLC	Programmable Logic Controller
PV	Photovoltaic
RM	Resource Manager
SA	Semantic Adapter
SAREF	Smart Applications REFerence ontology
SM	Smart Meter
SUC	System Use Case
TLS	Transport Layer Security; Traffic Light Signal, depending on context
TO	Technical Operator
TS&P	Trust, Security and Privacy
TSO	Transmission System Operator
UC	Use Case
VPP	Virtual Power Plant
WP	Work Package

1 Executive summary

This document describes the final requirements and architecture for the Integrated Development and Operations Platform (IDOP) implemented in WP2. The requirement engineering and architecture design was implemented in two main phases, each of which consisted of several agile R&D iterations. This document comprises the work done in WP2 in the tasks of T2.1 - Use cases and requirements, T2.2 - Architecture of the INDEPENDENT Platform, and T2.3 - Security and GDPR-compliant privacy design. The common standards and best practices are followed in requirements engineering and architecture design to ensure interoperability, trust and privacy.

The IDOP consists of three packages: Customer Energy Management System (CEMS), Aggregator Energy Management System (AEMS), and DevSecOps & Investment Support Package. The work started by describing business use cases of four project pilots: German, Finnish, Swedish and Slovenian. The requirements engineering for the IDOP and associated incentives and business models (T2.1) was an iterative process, analyzing the use cases from the business viewpoint and ending up with an initial set of general requirements associated to CEMS, AEMS, and DevSecOps & Investment Support Package. These requirements were used as a starting point for designing a common architecture for the IDOP. In the second phase, the requirements were described in more detail (from functional and non-functional viewpoints) and the architectural descriptions were updated accordingly based on these requirements and feedback from the first phase pilots.

The architecture design is described with the help of an example system utilizing the IDOP. The architecture design (T2.2) followed the common standards for architecture documentation. The architecture of an IDOP based system is described from the context, functional, information and deployment viewpoints. The context and functional viewpoints are represented with corresponding diagrams, and the architectural elements of the diagrams are described in more detail and associated with the data the elements manage. The information view is presented by describing the data units, types, relevant resources, systems, and information/knowledge identified in the context and functional views. Finally, the deployment view represents how the components are implemented and deployed into different computing platforms. The use cases described in T2.1 were also explored from multiple trust, security, and privacy (TS&P) dimensions and the TS&P related features are designed to ensure a common, open, and privacy-aware trust management and security architecture (T2.3).

At the end of this document, three different kinds of system use cases are described that enabled the design of the interaction between functional components: demand-side flexibility aggregation for energy wholesale markets, demand-side flexibility aggregation for TSO reserve markets, and local flexibility management.

DRAFT

2 Introduction

2.1 Purpose, context and scope

Requirements engineering and architecture design of the IDOP was implemented in two phases. This document describes the final requirements and the initial system architecture of the IDOP.

This document gathers the work implemented in the following tasks:

- T2.1 - Use cases and requirements
- T2.2 - Architecture of the INDEPENDENT Platform
- T2.3 - Security and GDPR-compliant privacy design

T2.1 documents the business use cases from each pilot and derives requirements for the IDOP and associated business models. The task used as a starting point the use cases and requirements documented in existing standards and technical reports (i.e., IEC/TR 62746-2:2015 and EN 50491-12-1), and the related projects (RESONANCE and iFLEX). The use cases were documented by providing an objective, scope and description of each use case. In addition, the use cases were analyzed for possible conflicts and missing functions. The requirements engineering was an iterative process that follows the established Smart Grids UC methodology. In the first phase of the requirements engineering and architecture design, the requirements were defined from the business perspective and were described with the requirements description table. In phase two, the requirements were also identified from the technical viewpoint.

T2.2 describes the common architecture for the IDOP based on the use cases and requirements. The architecture design was an iterative approach, and the work followed the ISO/IEC/IEEE 42010:2011 standard, documenting the architecture with the stakeholders, views, and perspectives. At first, the context view was defined that specified the relevant stakeholders and external systems that interact with the CEMS and AEMS developed with the IDOP. Next, the context view was divided into logical subcomponents in a functional view, documenting the modules of CEMS and AEMS. After the functional view, the identified data models were specified and documented in the information view. Finally, the deployment view described how the CEMS and AEMS are packaged and deployed into different computing platforms (i.e., cloud, edge computing platforms, mobile phones). The architecture was designed further with three system use cases that enabled to identify the interactions and responsibilities for the functional components. All four viewpoints were described in the first phase. In the second phase, the descriptions were updated with feedback from the first phase pilots.

T2.3 designs the trust, security and privacy (TS&P) related features of the common IDOP and its functional components. The use cases described in T2.1 are explored from multiple TS&P dimensions, from trust and identity management, secure communication between components and entities, secure and privacy aware data spaces provisioning to implementation and operations oriented DevSecOps. The design process took into account the requirements from standards, regulations and national regulation, and followed the architectural views as described in T2.2. The design concluded outlining the trust, security, and privacy requirements for the INDEPENDENT Platform.

2.2 Main changes compared to the initial version

Compared with D2.1, this deliverable updates the initial requirements and IDOP architecture based on the second phase of requirements engineering, pilot feedback and further technical design work. The main changes concern the refinement of pilot-specific business use cases, the restructuring and extension of common requirements, and the further elaboration of the IDOP architecture and key interfaces.

Pilot-specific business use cases have been updated where needed:

- German pilot: An update was made to DE-BUC1 – Flexibility Aggregation and Trading to support external activation signals in a standard-compliant way. Since no operational aggregator is available in the German pilot, the aggregator interaction is addressed through simulation. The DSO grid signals are considered together with the flexibility offers provided from the industrial site. In the initial external view of the site, the flexibility offer does not yet

DRAFT

include detailed asset identification; this will be further developed during the second piloting phase.

- German pilot: DE-BUC2 – Cost-oriented energy system optimisation has been extended to address upcoming regulatory changes related to Market Integration of Storage and Charging Points (MiSpeL) submitted by the Federal Network Agency (BNetzA). These changes affect the residential pilot sites, which may be permitted to opt for a flat-rate share of the energy fed into the grid, including energy previously stored in a local battery. The industrial pilot site will be evaluated in this context with respect to the newly introduced MiSpeL demarcation option.
- German pilot: The German use cases have also been updated to reflect the planned use of the S2 interface between Resource Managers and the Customer Energy Manager, including S2-based flexibility activation and cost-oriented scheduling.
- Finnish pilot: A new business use case, FI-BUC3, has been introduced to cover the industrial site deployed in phase 2. FI-BUC2 has been revised to better cover cooperation with GLocalFlex, including the local flexibility marketplace provided by that project.
- Swedish pilot: No major updates or changes to the initial Swedish business use cases have been deemed necessary.
- Slovenian pilot: The Slovenian business use cases are now included in the deliverable. They cover automated implicit demand response, local flexibility market and TSO–DSO cooperation, and the flexibility package and BSP SouthPool cooperation concept.

Common requirements have been restructured and extended:

- D2.1 presented an initial set of common requirements grouped into CEMS Package requirements, AEMS Package requirements, and DevSecOps & Investment Support requirements.
- In this deliverable, the requirements are reorganised into functional and non-functional requirements.
- Functional requirements now cover CEMS capabilities, AEMS capabilities and investment planning support.
- Non-functional requirements now cover cross-cutting platform quality requirements, trust, security and privacy requirements, and interoperability and standard compliance requirements.
- This separation clarifies the distinction between the capabilities expected from IDOP-based systems and the quality, security, privacy and interoperability constraints under which they must operate.

The System architecture has been improved with more detailed information view and trust, security and privacy perspectives:

- The interface between the Customer Energy Manager and the Aggregator Energy Management System has been described in more detail based on IEC 62746-4.
- The S2 interface between Resource Managers and the Customer Energy Manager has been described in more detail based on EN 50491-12-2.
- The Semantic Adapter Interface has been extended into a SAREF-aligned data model for integrating heterogeneous resource-side systems.
- The trust, security and privacy requirements have been moved into the non-functional requirements structure. The updated structure clarifies the relationship between cross-cutting platform quality requirements, secure deployment and operations, governed data sharing, identity and trust management, secure communication, access control, privacy compliance, consent, auditability and personal data lifecycle management.
- The TS&P perspective in the architecture section has been further refined to explain how these requirements are addressed in the IDOP-based system architecture.

2.3 Content and structure

This document is structured as described in the following:

DRAFT

- Section 3 documents the work done in T2.1 by describing the business use cases of the German, Finnish, Swedish and Slovenian pilots. The section presents the pilot context, objectives and use-case descriptions that provide the basis for deriving common IDOP requirements.
- Section 4 presents the common requirements for the IDOP. The requirements are separated into functional and non-functional requirements. Functional requirements cover the CEMS Package, AEMS Package and investment planning support. Non-functional requirements cover cross-cutting platform quality requirements, trust, security and privacy requirements, and interoperability and standard compliance requirements.
- Section 5 documents the common system architecture for the IDOP defined in T2.2 and complemented by the trust, security and privacy design work of T2.3. The section first introduces the IDOP packages and then describes an example IDOP-based system architecture through context, functional, information and deployment views, together with a trust, security and privacy perspective.
- Section 6 presents the system use cases used to support and validate the architecture by describing interactions between functional components in representative demand-side flexibility management scenarios: demand-side flexibility aggregation for energy wholesale markets, demand-side flexibility aggregation for TSO reserve markets, and local flexibility management.
- Section 7 concludes the work.

DRAFT

3 Business use cases

3.1 Business use cases for the German pilot

Phase 1 of the pilot encompass an industrial site and ten residential pilot sites. These pilots aim to demonstrate the scalability of the DE-BUC1, DE-BUC2, and DE-BUC3 use cases. It is anticipated that a tradeable amount of flexibility will soon be identified for the industrial site. The residential pilot installations focus on local optimization and compliance with the German §14a EnWG for grid intervention. The S2 communication between grid operators and the CEM is currently only implemented within simulations. An S2 standard compliant interface is not provided by German DSO towards their individual consumers. The consultation process only started in 2024 at the legislator body Bundesnetzagentur.

Table 1: Business use case 1 of the German pilot.

Name of the use case	**DE-BUC1 Flexibility Aggregation and Trading**
Objective and scope	The objective of this use case is to enable both the Customer Energy Manager (CEM) and Aggregators to aggregate and facilitate the trading of flexibility potentials. This requires that Resource Managers (RMs) have the capability to shift loads within a defined flexibility corridor. Additionally, effective communication of flexibility potential between the RM and the CEM must be established. On the other side, the Aggregator must develop and provide a pricing model tailored to flexibilities, ensuring seamless integration into the market. As no Aggregator is available in the German pilot, the use case focuses on the simulation of Aggregator interactions, including the aggregation of flexibility information from DE-BUC2, the provision of flexibility offers, and the validation of activation workflows and pricing concepts based on requirements gathered from consortium Aggregator partners. The current aggregation of local flexibility potential is re-evaluated in the industrial context to clearly identify the flex assets and their behavioral differences. A potential on-site replacement of these flexibility assets will evaluated due to massive differences in operational costs of the local assets (e.g. battery storages vs. thermal storages).
Description	This use case enables the aggregation, valuation, and activation of flexibility potentials from distributed energy resources managed by the CEM. The flexibility potential is determined by the CEM through the analysis of the energy potential of the connected RMs, applying suitable calculation methods to identify the available flexibility and its feasible utilization mode. The utilization mode provides critical information on whether the identified flexibility can be dispatched continuously, only above a minimum threshold, or only as a complete flexibility package. The resulting flexibility information, including availability, dispatchable capacity, activation constraints, time windows, and utilization mode, is aggregated by the CEM and prepared for communication to an Aggregator. Since no operational Aggregator is available within the German pilot, the interaction with the Aggregator will be implemented and validated in a simulation environment. For this purpose, flexibility information generated in **DE-BUC2** will be scaled up from individual assets to a virtual portfolio level, representing a realistic aggregation of multiple flexibility providers. To ensure a realistic simulation of market interactions, requirements for flexibility data exchange, portfolio representation, activation requests, and pricing inputs will be collected from Aggregator partners within the consortium. Based on these requirements, a simulated Aggregator interface and activation process will be developed. The simulated Aggregator receives the aggregated flexibility information and applies a flexibility pricing and selection logic to identify suitable flexibility offers. It can then request flexibility activation by sending activation messages to the CEM.

	Upon receiving an activation request, the CEM dispatches and controls the relevant assets while respecting the requested capacity, operational constraints, and utilization mode. This demonstrates how aggregated flexibility could be offered to and utilized by an Aggregator in future large-scale deployments, even though the validation within the German pilot is limited to a simulation-based setup.

Table 2: Business use case 2 of the German pilot.

Name of the use case	**DE-BUC2 Cost orientated energy system optimization**
Objective and scope	The objective of this use case is to enable the CEM to optimize energy systems in a cost-oriented manner. Achieving this requires the implementation of an energy system model and the collection of real-time data from all assets. The outcome is the generation of optimized schedules for all relevant assets, enabling cost-effective operation of the energy system. To support this use case, seamless data exchange between all RMs and the CEM must be established, allowing the sharing of asset information and the optimized schedules for each RM. Furthermore, the integration of external data such as weather conditions and price forecasts is essential for effective optimization. The use case will integrate the S2-interface between RM and CEM, formulate the cost-oriented scheduling problem as a MILP, and validate the approach through a stepwise transition from simulation-based testing towards field-test preparation using simulated RMs, Neural ODE models, real measurement data, the CEM, and the optimization platform FlexMeasures. Due to the upcoming massive regulatory changes in *Market Integration of Storage and Charging Points (MiSpeL)*" submitted by the Federal Network Agency (BNetzA) the residential piloting sites with small PV installations will be introduced to the new flat-rate option. That would allow a pre-defined maximum of renewable energy to be declared as accountable. That increases the revenue potential per site by nearly 350€ annually. The industrial piloting site is not eligible for the flat-rate option so the potential usage of the Demarcation option will be evaluated.
Description	For this purpose, cost-related data is additionally required for each RM. This includes operating costs (energy-based or time-based) as well as start costs. Furthermore, general energy system data is necessary, such as energy prices, forecasts of energy demand, and expected energy generation. Based on this data, the energy system is modelled within an optimization framework to determine the most cost-efficient operating strategy. The outcomes of this process are schedule recommendations for the individual regulatory modules. However, if relevant parameters deviate from the planned operation and exceed operational limits, the regulatory module may deviate from the predefined schedule. The described optimization cycle is repeated at regular time intervals. During each iteration, the current data of the RMs is collected, deviations from the forecasts are analysed, and the optimization is re-executed based on newly generated forecasts. The use case will be extended by integrating the S2-interface for standardized communication between RM and CEM. The RM provides asset information, flexibility constraints, and operational limits, while the CEM performs the cost-oriented optimization and returns optimized schedules. The optimization problem will be formulated as a MILP, minimizing operating costs while considering energy prices, forecasts, start costs, operational constraints, and feasible operating modes. Validation will follow a stepwise approach from pure simulation, to CEM

DRAFT

	and FlexMeasures integration, to Neural ODE-based simulation, to the use of real measurement data, and finally towards field-test preparation with real-device data exchange.

Table 3: Business use case 3 of the German pilot

Name of the use case	**DE-BUC3 Emergency Management**
Objective and scope	The objective of this use case is to empower TSOs or DSOs to leverage CEMs for emergency management within the grid. This involves enabling CEMs to provide detailed information about their ability to support grid interventions by adjusting their schedules as required. Specific regulations need to be specified by the system operator. The use case will investigate how TSO and DSO emergency management signals can be communicated to a CEM and how these requests can be translated into S2-based flexibility activations of connected RMs. Particular attention will be given to the separation between grid operator to CEM communication and CEM to RM communication, the latter being implemented through the S2-interface. The German piloting CEM is empowered to receive PLIM signals from DSOs but the local assets cannot fulfill every aspect of specific power limitations. A possible substitution of assets is currently evaluated (e.g. heat pump power limitation as replacement for an EV-charger limitation).
Description	This use case enables TSOs and DSOs to leverage CEMs for grid emergency management. Grid operators provide information about the current grid status and, when necessary, request corrective actions such as load reduction, load increase, or other flexibility measures to support grid stability. Upon receiving such a request, the CEM evaluates the flexibility available from its connected Resource Managers (RMs) and determines suitable response actions while respecting local operational constraints. The communication between the CEM and the RMs is based on the S2-interface, where the RM provides information about device flexibility and operational limits, and the CEM coordinates how this flexibility is utilized. The CEM then translates the grid request into control actions for the individual RMs and monitors their execution. The use case will further investigate how emergency and flexibility signals are communicated between TSOs/DSOs and the CEM, and how these signals can be mapped to S2-based flexibility requests towards the connected RMs. Reliable and near real-time communication is required to ensure an effective response during critical grid conditions. The evaluation will include both load reduction and load increase scenarios.

DRAFT

3.2 Business use cases for the Finnish pilot

The Finnish pilot consists of two supermarkets, an apartment building, and an industrial site, representing commercial, residential, and industrial consumers, respectively. During phase 1 of the project, the Finnish pilot focused on the supermarket and apartment building demonstration sites. In phase 2, the pilot scope is extended with the introduction of an industrial site.

FI-BUC1 targets large commercial consumers that acquire their energy directly from wholesale markets and is demonstrated in the supermarket pilot. FI-BUC2, presented in Table 5, targets residential consumers and is demonstrated in the apartment building pilot. To further expand the scope of the pilot, FI-BUC3 introduces industrial demand-side flexibility and participation in local flexibility markets. This business use case, presented in Table 6, extends the applicability of the INDEPENDENT framework across commercial, residential, and industrial consumer segments.

Table 4: Business use case 1 of the Finnish pilot.

Name of the use case	**FI-BUC1: Explicit demand response in the wholesale energy markets**
Objective and scope	This use case focuses on explicit demand response in the wholesale energy markets. The BUC targets large consumers that acquire their energy directly from the markets. The goal of the BUC is to enable large consumer to benefit from varying energy prices by utilizing demand flexibility directly in the wholesale energy markets.
Description	This business use case focuses on large consumers that acquire their energy directly from the day-ahead (and intraday) markets. In this case the retailer and the building owner (consumer) are typically part of the same organization as is the case with the supermarkets in the Finnish pilot.[1] The retailer acts as an Aggregator whose objective is to use the flexibility of the consumers to acquire the energy as cost-efficiently as possible from the day-ahead (and intraday) market. By targeting the day-ahead and intraday markets, and managing the aggregated balance, the Retailer can minimize costs by purchasing energy during the cheapest hours and shifting consumption accordingly. To this end, the Aggregator is equipped with an Aggregator Energy Management System (AEMS) and each building is operated by a Customer Energy Management System (CEMS). The AEMS provides CEMS with two-day price forecast for the day-ahead market. Each CEMS optimizes their energy consumption to minimize their cost with respect to the price forecast (and possible local incentives). Additionally, the CEMS provide AEMS with baseline and flexibility forecast (including costs for flexibility activation). The AEMS leverages flexibility forecasts, building consumption baselines, and electricity price forecasts to optimize energy procurement and usage in the energy markets. Both the Retailer and the building owner benefit from reduced energy costs. A contract between the large consumer (i.e., the owner of the buildings) and the retailer specifies how the cost savings are shared between the parties.

Table 5: Business use case 2 of the Finnish pilot.

Name of the use case	**FI-BUC2: Residential demand-side flexibility and local flexibility markets**
Objective and scope	The primary objective of this use case is to demonstrate how residential demand-side flexibility can be forecasted, managed, and utilized through automated energy management and local flexibility market participation.

[1] It is also possible that the large consumer subcontracts the retailer services from external company in which case there needs to be a contract between these actors.

	The CEMS monitors building operation, forecasts available flexibility from the heating system, and coordinates flexibility activation while maintaining occupant comfort. The use case demonstrates interoperability between building-level energy management, flexibility forecasting, and external flexibility market platforms.
Description	This business use case focuses on the management and utilization of demand-side flexibility in a residential apartment building. The pilot site consists of a multi-apartment residential building equipped with a hybrid heating system comprising an exhaust air heat pump and district heating. The building's thermal inertia and heating infrastructure provide flexibility that can be utilized without compromising resident comfort. A Customer Energy Management System (CEMS) is installed to automate flexibility management. The CEMS interacts with the Building Automation System (BAS) to monitor building operation, estimate available flexibility, and coordinate flexibility activation through the heating system. To support these functions, the CEMS uses forecasting models together with operational data from the building and its energy systems. The flexibility management decisions are constrained by predefined comfort boundaries and operational limits specified by the Facility Manager. To demonstrate interoperability with external flexibility services, the pilot includes cooperation with the GLocalFlex project. The CEMS publishes forecasts of available flexibility, which can be used by market-facing applications to offer flexibility on the GLocalFlex marketplace. Following a successful market transaction, activation requests are communicated back to the building, where the flexibility is automatically delivered through the heating system. This demonstrates end-to-end integration between residential energy management, flexibility forecasting, local flexibility markets, and building control systems.

Table 6: Business use case 3 of the Finnish pilot.

Name of the use case	**FI-BUC3: Demand response of an electric-intensive industrial process**
Objective and scope	The primary objective of this use case is to reduce energy costs and limit facility peak load by applying demand response (DR) to an electric-intensive industrial process, and to study the process load as a potential resource for Fingrid's reserve markets. The CEMS receives real-time market spot price signals and uses them to control and optimise the process's energy consumption. It covers both implicit DR, which shifts process operation in response to price fluctuations, and explicit DR, which curtails the process load on a dispatch signal and can cap load against a site peak limit. The same controllable load can also be offered into reserve markets as an additional revenue stream, subject to each product's bid-size and response-time requirements.
Description	Demand response enables an industrial site operator to adjust energy consumption based on dynamic pricing and external signals, allowing for cost savings and reduced peak load. In this BUC, the focus is the powder-coating line process heating, the most energy-intensive process at the pilot site. The process holds parts within a required temperature window for a set dwell time, and it tolerates a trade-off between temperature and dwell. Together with the ovens thermal inertia, this gives the flexibility the CEMS uses for DR.

DRAFT

	A CEMS is installed to automate energy management, using process data from the site's existing OPC UA connection. It interacts with the process control system (PLC) to 1) shift oven operation in response to 15-minute spot prices, 2) curtail oven load on a dispatch signal, and 3) cap oven load against a site peak-power limit when needed. To this end, the CEMS uses inputs like oven temperature measurements, oven heater output, electricity consumption and power measurements, line and dwell parameters, and cure-quality parameters to optimize operations. These factors, along with predetermined boundaries set by the site operator, guide the system's decisions. In the operational concept, quality and safety limits are enforced in the PLC and the CEMS can only request values within them. The line's controllable load is also assessed as a resource for Fingrid's reserve markets. AEMS pools the oven with other flexible loads, so participation is not limited by individual bid-size thresholds, and a wider range of reserve products becomes available. Feasibility depends on how fast the oven load can be modulated within the cure-quality window, which the BUC evaluates against each product's response-time requirement. The site operator ensures that the system operates within the setpoints required for cure quality and throughput. While the CEMS manages energy use automatically, the oven operator can override setting if necessary, ensuring both cost savings and process integrity are maintained.

3.3 Business use cases for the Swedish pilot

The Swedish Pilot involves residential homes equipped with heat pumps, EV Chargers, PV electricity generation, battery storage and possibly other controllable energy resources. Resources may have local smart control systems and may be connected by equipment manufacturers' connectivity solutions or be connected via an Aggregator's deployed control equipment hosting CEMS services.

Within this context, the pilot will address three business use cases that have as a common objective to lower costs or even create revenues for the homeowners without sacrifices in experienced climate system comfort.

Table 7: Business use case 1 of the Swedish pilot.

Name of the use case	**SE-BUC01: Ancillary Services using aggregated heat pumps in residential buildings**
Objective and scope	Heat pumps are commonly used in Swedish homes, potentially allowing tens of thousands of units to participate in TSO service markets if response times and volumes meet requirements. In this use case, an Aggregator will connect, aggregate and bid aggregated heat pump resources for ancillary services in Sweden, evaluating their technical and financial viability as part of the pilot.
Description	The Aggregator (market integrator) will connect heat pump resources via the manufacturer's cloud connectivity solution that act as a sub-aggregator. The aggregated heat pumps are thus seen as a virtual CEMS (CEM with large amount of RMs). As each residential heat pump represents a quite small amount of available flex power, typically in the range of 1-2 kW, multiple layers of aggregation will be required to cater for required bid volumes, including safety margins. A simulation on mFRR ancillary services in Sweden using residential heat pumps suggests a yearly revenue of about EUR 120 per home and without hardware investment needed on site. Other ancillary services are expected to yield revenues in the same range and the potential revenue per heat

DRAFT

	pump is thus expected to be relatively small. A profitable solution will require very low operational costs per unit. A challenge of this use case is to ensure that operations do not cause any discomfort in terms of temperature or hot water availability for the residents. Additionally, homeowners have the option to override the central control with local control and behaviour, allowing them to maintain their comfort preferences and manage their energy resources according to their needs. This might lead to situations where planned ancillary services cannot be delivered as bid for this heat pump. This needs to be taken into consideration at both CEMS and AEMS levels.

Table 8: Business use case 2 of the Swedish pilot.

Name of the use case	**SE-BUC02: Ancillary Service Stacking combining heat pumps, PV and battery resources**
Objective and scope	The objective of this use case is to evaluate how a combination of energy resources can support ancillary service stacking with increased revenue generation compared to a single service solution as in SE-BUC01. The primary scope is to include PV electricity generation, batteries and heat pumps, but additional resources may be included.
Description	Ancillary Service Stacking refers to the practice of using energy resources, like batteries, to provide multiple grid services simultaneously. These services can include capacity services, energy shifting, and fast-response ancillary services. In this use case, we aim to evaluate how a combination of several different controllable resources from residential buildings can be used in a service stacking context. Batteries contribute with the possibility of fast response and high-power levels per device and heat pumps can contribute with low cost for flexibility and longer endurance over time to over or under consume energy.

Table 9: Business use case 3 of the Swedish pilot.

Name of the use case	**SE-BUC03: Optimization of power tariffs costs combining heat pumps, PV and battery resources**
Objective and scope	The main objective of this use case is to minimize power tariff costs in a residential setting with a combination of several smart energy resources where each one has a significant impact on the power used. As a sub objective, the parallel maximum participation in ancillary services should be considered for increased revenues. The scope includes residential homes with heat pump, battery and EV charger resources connected to 5-10 different grid companies.
Description	Homeowners face several challenges related to power tariffs, especially as energy consumption increases due to large electricity consumers like heating systems, hot water generation, and electric vehicle (EV) charging. Key issues include peak demand charges and penalty fees. Many electricity providers impose penalties if a household exceeds or increases its contracted power limit. High-demand appliances—such as EV chargers, heat pumps, and water heaters—can create peak loads, especially when used simultaneously. The Swedish Energy Markets Inspectorate (Ei) has decided that starting in 2027, a capacity charge based on network constraints, must be included in the network tariff for all electricity customers. As of now (January 2025), around 50 of Sweden's approximately

	170 electricity grid companies have already implemented a capacity charge. Grid companies are free, within limits, to use different tariff models leading to a large variation in terms and fees. While aiming for minimized tariff costs, it will still be possible to take part in certain types of ancillary services to some extent, especially considering use case SE-BUC02, wherein clever combinations of different devices could mitigate risk of costly power tariff for the end consumer. This option will be investigated in this use case to further increase profitability of smart energy control systems.

3.4 Business use cases for the Slovenian pilot

The Slovenian pilot involves residential homes, apartment buildings and industrial facilities. In the INDEPENDENT project three pilot use cases will be addressed: the Automated implicit demand response involving all three pilot groups, the Local flexibility market and TSO-DSO cooperation involving residential homes and the Flexibility package and BSP SouthPool cooperation engaging a broader range of households in Celje region. The three use cases have different objectives: the first one aims at lowering the costs and increase self-consumption, the second one aims at utilizing available residential houses flexibility at network level and the third one validates utilization of a flexibility package offered by the retailer.

Table 10: Business use case 1 of the Slovenian pilot

Name of the use case	**SI-BUC01: Automated implicit demand response**
Objective and scope	The scope of the use case is related to (1) households and their distinct resources, to (2) apartment buildings with diverse set of energy sources for heating and to (3) industrial facilities. The energy users' resources are controlled according to the implicit external or internal signals, like day ahead prices, network tariffs, CO2 emissions mix information or local PV production. The objective of the use case is to automate the optimization of individual local load and generation within the energy users, aiming to lower costs, increase self-consumption, reduce CO2 emissions, or improve resource usage efficiency.
Description	Automated implicit demand response uses information from external sources, such as day ahead prices, network tariffs or CO2 emissions and internal sources, like PV production, to optimize the usage of energy users' resources according to the end user preferences and environment conditions, like weather. This optimization aims to lower energy costs, increase self-consumption, reduce CO2 emissions, or improve resource usage efficiency. In case of individual households, the households' resources like heat pumps, EVs, PVs, white goods and batteries are modelled as Resource Managers (RM) and controlled by the Customer Energy Manager (CEM) according to specific implicit signal or combination of such signals. According to the signal, weather conditions and individual RM load and generation models, the CEM prepares optimized schedule for the next time horizon. The procedure is repeated at predefined time slots. The apartment building uses electricity and gas as energy sources for heating. The two heating sources together with a building will be modelled as RMs. According to the weather conditions, overall price of energy, state of the heating system and its past states combined with the building, the CEM decides which energy source to use and which set-points to set and follow in the next time horizon. The diary farm is an industrial facility that includes a cold storage, various industrial processing equipment, a PV and a battery. The primary signals for the implicit control are network tariffs, PV production and entire load of the facility. The aim of the optimization is to limit the peak load of the facility. The CEM prepares the cold storage and battery optimal schedule for the next horizon

DRAFT

	according to the implicit signals and repeats the procedure of the schedule preparation at predefined time slots.

Table 11: Business use case 2 of the Slovenian pilot

Name of the use case	**SI-BUC02: Local flexibility market and TSO – DSO cooperation**
Objective and scope	The use case connects consumers, prosumers, aggregators, DSOs and the TSO with the local flexibility market. The consumers, prosumers and aggregators act as a flexibility providers and the DSOs and the TSO as flexibility seekers in the market. The local flexibility market enables communication of flexibility needs and flexibility offers between market participants and settlement of the deals agreed on the market. The TSO can utilize flexibility offered in the local flexibility market if the DSOs network allows it based on the current network conditions.
Description	In a local flexibility market, System Operators (SO, DSO or TSO) seek flexibility by publishing requests for additional energy resources. Flexibility providers, such as aggregators, respond with offers based on their capabilities. The SO evaluates the offers and selects one based on flexibility request and predefined criteria. Upon acceptance, the provider delivers the required flexibility while adhering to specified conditions, such as amount, duration and locality. After the provision is complete, the market verifies the delivery against the request and settles the financial aspects of the transaction. In access to the local flexibility market, the DSOs have priority over TSO. Offers not utilized by the DSOs can be accessed by the TSO if allowed by conditions in the DSO network. The market employs a traffic light signal (TLS) system to signal the status of the low-voltage distribution network at any time. In the case of a green light, the distribution network will allow an increase in either consumption or production of electricity. An orange signal will mean that action is required in terms of adjusting consumption or production on the distribution network side. A red signal will mean that the network does not allow any increase and is practically operating at its maximum capacity, so no flexibility in the DSO local network can be utilized by the TSO.

Table 12: Business use case 3 of the Slovenian pilot

Name of the use case	**SI-BUC3: Flexibility package and BSP SouthPool cooperation**
Objective and scope	The objective of the use case is to describe how prosumers can offer their flexibility through a flexibility package prepared by the retailer. The package assumes a battery will be installed at the prosumer that can be controlled by the retailer. The flexibility harvested can be used to optimize retailer market participation and to offer it on the BSP SouthPool for diverse set of services.
Description	A retailer offers a flexibility package to its prosumer clients. The flexibility package includes a battery the retailer can control in exchange for a fixed price of energy. The retailer control of the battery and related production and consumption at the household aims at flexibility harvesting of the battery (and household) flexibility potential. The harvested flexibility will be used to optimize retailer market participation and mitigate the market price volatility. The flexibility can also be offered on the BSP SouthPool market. The business use case is based on the use of implicit Demand Response (DR) in connection with day-ahead electricity prices, where the retailer manages the control of the prosumer's solar power plant, battery storage system and other appliances. In exchange for control over the devices, the user receives an extended billing period of up to one year. This allows electricity to be stored through day during periods of low prices and used during periods of high prices, optimizing costs, improving renewable energy efficiency, increasing self-sufficiency, and providing a competitive advantage for the retailer and electricity

DRAFT

	price reduction for prosumers.

DRAFT

4 Common requirements

This section gathers the common functional and non-functional requirements for the IDOP. The functional requirements are derived mainly from the business use cases, while the non-functional trust, security and privacy requirements are derived from the TS&P analysis, relevant standards, regulatory considerations, and the architecture design work.

4.1 Functional requirements

The functional requirements for the Integrated Development and Operations Platform are derived mainly from the business use cases and grouped according to the main IDOP packages and supporting capabilities. Requirements for the CEMS Package are presented in Table 13, requirements for the AEMS Package in Table 14, and requirements for investment planning support in Table 15. Cross-cutting non-functional requirements are presented separately in Section 4.2.

Table 13: Requirements for Customer Energy Management Systems Package.

ID	Requirement	Description
CR1	Integration with legacy automation and metering infrastructure.	CEMS need to be able to collect measurement data and send control signals to building and home automation systems, smart meters, and other metering infrastructure in the consumer premises.
CR2	Optimise energy consumption	CEMS need to be able to optimize energy consumption taking into account user preferences and limits, dynamic energy and network prices, local production from PVs, and energy efficiency of the building/site. The CEMS will control resources (flexible assets) according to the optimized schedule.
CR3	Baseline power forecast	CEMS need to be able to provide the AEMS with baseline power forecast (i.e., optimized load profile).
CR4	Flexibility forecast/estimate	CEMS need to be able to provide AEMS with forecast/estimate of the available flexibility and related costs (i.e., what is the compensation required if CEMS deviate from the locally optimal profile).
CR5	React to explicit flexibility activations	CEMS need to be able to activate the offered flexibility when requested by the AEMS.
CR6	React to explicit emergency management requests from TSO and DSO	CEMS need to be able to increase or decrease electrical power taken from the grid in response to explicit emergency management requests from TSOs or DSOs, while respecting local operational constraints.
CR7	User interaction	CEMS need to be able to collect user preferences, limits, and goals. CEMS need to be able to provide users with visualisations on energy consumption, system state, and results of DSFM actions (e.g. costs savings and CO2 emission reductions).

Table 14: Requirements for Aggregator Energy Management Systems.

ID	Requirement	Description
AR1	Integration with energy and flexibility markets	AEMS need to be integrated with relevant energy (day-ahead and intraday) and flexibility markets (e.g. TSO reserve and DSO local flexibility markets) to perform automated bidding.
AR2	Market price forecasting	The AEMS need to provide CEMS with day-ahead price forecast. Additionally, price forecasts for the intraday and flexibility markets are required in the multi-market bidding.
AR3	Aggregated flexibility management	AEMS need to be able to aggregate baseline forecasts and flexibility forecasts or offers from multiple CEMS and use the aggregated flexibility representation for portfolio management, market bidding and activation planning.
AR4	Flexibility bidding	The AEMS need to be able to optimize the flexibility when bidding in energy and flexibility markets.

AR5	User interaction	The AEMS need to provide aggregators with user interface to manage their goals and preferences, and view performance reports and system status information.
AR6	Support for sub-aggregation	The AEMS Package needs to support the decoupling of technical aggregation and market integration/bidding functionalities into independent AEMS. This is required because some actors may focus on technical aggregation of demand-side flexibility, while others may focus on market integration and bidding.

Table 15: Requirements for investment planning support.

ID	Requirement	Description
IPR1	Support for investment analysis	The IDOP shall provide tools for analysing potential benefits, costs, payback times and return on investment for demand-side flexibility solutions, using relevant operational data, flexibility estimates and scenario assumptions.
IPR2	Scenario-based investment assessment	The IDOP shall support comparison of alternative investment and deployment scenarios, such as different resource combinations, control strategies, market participation options or data availability assumptions, to support decision-making by customers, aggregators and technology providers.

4.2 Non-functional requirements

The non-functional requirements define cross-cutting quality constraints for the IDOP architecture. They are organised into general platform quality requirements, detailed trust, security and privacy requirements, and interoperability and standard compliance requirements. The cross-cutting requirements provide high-level operational and architectural expectations, while the following subsections specify the security, privacy and interoperability mechanisms in more detail.

4.2.1 Cross-cutting platform quality requirements

The cross-cutting platform quality requirements apply across the CEMS, AEMS, DevSecOps, data-space and user-facing components. They define general quality expectations for deployment, operation, monitoring, resilience, maintainability and scaling. Detailed requirements for trust, security and privacy are specified in Section 4.2.2, and interoperability-specific requirements are specified in Section 4.2.3.

Table 16: Cross-cutting platform quality requirements.

ID	Requirement	Description
NFR1	Secure deployment and operations	The IDOP shall support secure deployment, configuration, monitoring and operation of CEMS and AEMS components across cloud and edge environments. Detailed trust, security and privacy mechanisms are specified in Section 4.2.2.
NFR2	Governed data sharing	The IDOP shall support governed sharing of building and industrial-site data among stakeholders through data spaces and related data management services. Security, privacy and access-control requirements for such sharing are specified in Section 4.2.2, while interoperability and data-space architecture requirements are specified in Section 4.2.3.
NFR3	Operational monitoring and observability	The IDOP shall provide operational monitoring, logging and status information for deployed CEMS, AEMS, data-space and DevSecOps components to support system operation, troubleshooting and maintenance.
NFR4	Resilience and fallback operation	The IDOP architecture shall support safe fallback behaviour when communication, forecasting, optimisation, data access or external services are temporarily unavailable.

NFR5	Maintainability and modular deployment	IDOP components shall be modular, configurable, updateable and deployable using DevSecOps practices, enabling controlled updates, maintenance and reuse across pilot contexts.
NFR6	Scalability	The IDOP architecture shall support scaling from pilot deployments to larger numbers of resources, CEMS, AEMS, users, sites, data exchanges and market interactions.

4.2.2 Trust, security and privacy requirements

This section specifies the trust, security and privacy requirements for the INDEPENDENT IDOP. The requirements complement the cross-cutting platform quality requirements in Section 4.2.1 and provide more detailed requirements for identity and trust management, secure communication, access control, privacy compliance, consent, auditability and personal data lifecycle management. The requirements are grouped into general TS&P design requirements, trust requirements, security requirements and privacy requirements.

Table 17: General TS&P IDOP design requirements

ID	Requirement	Description
GR1	By-design	Develop novel trust, security and privacy mechanisms through trust-by-design, security-by-design, privacy-by-design and trust-security-and-privacy-by-default principles, ensuring trust, security and privacy considerations are integrated into the system from its inception.

Table 18: Trust Requirements

ID	Requirement	Description
TR1	Manage identities	Manage identities of the system entities in a privacy preserving manner and in a scalable way fit for intended IDOP usage
TR2	Manage trust between system entities	Bootstrap the relationships between system entities and actors in a secure and privacy preserving manner

DRAFT

Table 19: Security Requirements

ID	Requirement	Description
SR1	Secure communication	All the communication between IDOP components, system entities and users should be secure assuring data integrity, authenticity, confidentiality and non-repudiation services. The communication should be done in manner to minimize end-user systems exposure, like avoiding in-bound connections, connecting through trusted nodes, etc. Standard secure communication protocols should be used for this purpose.
SR2	Access control sensitive assets and data	Implement access control mechanisms in a way suitable for the system's scale and performance. Guard access to sensitive assets and data through authorization policies and their enforcement at system interfaces
SR3	Least privilege	Apply the principle of least privilege to all users, system entities and software components by granting only the minimum permissions required to perform their assigned functions. Access rights shall be explicitly authorized and revoked when no longer required, minimizing the potential impact of compromised identities or system components.
SR4	Zero-trust	Ensure that every access request is authenticated, authorized and evaluated against applicable security policies before access to protected resources is granted. Access decisions shall be based on authenticated identities, contextual information and fine-grained authorization policies, avoiding implicit trust between communicating entities.

Specific privacy related requirements originating from GDPR regulation, complementing security requirements in

DRAFT

Table 19, are listed in Table 20 below.

Table 20: Privacy Requirements

ID	Requirement	Description
PR1	Compliance	Ensure general compliance with EU privacy regulations
PR2	Explicit data flows	Establish explicit data flows to provide information about data origins, rightful owners, data nature, and data consumers
PR3	Explicit consent	Require end-user explicit consent for data processing and ensure the presence of the intended data processor among authorized processors
PR4	Data minimization	Implement data minimization techniques to collect and process only the necessary data
PR5	Transparency	Provide transparency and user awareness regarding personal data processing, enabling users to make informed decisions when granting or withdrawing consent.
PR6	Auditability and traceability	Ensure that all operations involving personal data are auditable and traceable by maintaining sufficient records of data access, processing and sharing activities to support accountability, compliance verification and incident investigation.
PR7	Personal data lifecycle management	Support the complete lifecycle management of personal data, including secure collection, storage, retention, archival and secure deletion in accordance with applicable privacy policies and regulatory requirements.

DRAFT

4.2.3 Requirements for interoperability and standard compliance

Interoperability and standard compliance requirements ensure that IDOP-based systems can exchange information through common standards and semantic models. The related requirements are summarised in Table 21.

Table 21: Interoperability requirements.

ID	Requirement	Description
IR1	Standards-based RM–CEM interoperability	The IDOP shall support standard-compliant information exchange between Resource Managers and Customer Energy Managers based on the S2 interface defined in EN 50491-12-2, including resource capabilities, measurements, forecasts, flexibility descriptions, constraints, control instructions and reception feedback.
IR2	Standards-based CEM–AEMS interoperability	The IDOP shall support standard-compliant information exchange between Customer Energy Management Systems and Aggregator Energy Management Systems based on IEC 62746-4 (IEC, 2024), including resource and aggregation descriptions, baseline/reference energy curves, price or incentive information, flexibility bids/offers, activation instructions, reporting and evaluation data.
IR3	SAREF-aligned semantic adapter interface	The IDOP shall provide a SAREF-aligned semantic representation for data originating from heterogeneous resource-side systems, including BAS, HEMS, smart meters, heat pump services, EV charging systems, PV systems, batteries, industrial process systems, weather services and other pilot-specific data sources.
IR4	Legacy protocol and vendor-system integration	The IDOP shall support integration with legacy and vendor-specific systems through protocol-specific semantic adapters, allowing data and control endpoints from systems (e.g., OPC UA, BACnet, Modbus, OCPP, IEC 63110, oBIX, SG Ready) and proprietary APIs to be mapped into the common IDOP information model where relevant.
IR5	Machine-readable interface specifications	The IDOP shall document interfaces and data models in a machine-readable or implementation-ready form where feasible, enabling software components developed by different partners to validate exchanged messages against agreed data structures.
IR6	Explicit semantic mapping metadata	The IDOP shall preserve mapping metadata for semantic adapters, including source-system identifiers, native endpoint names or tags, protocols or APIs, units, update frequency, mapping version, data owner, access rights and data-quality information.
IR7	Multi-market interface compatibility	The AEMS Package shall support integration with relevant energy and flexibility markets, including wholesale markets, TSO reserve markets, DSO flexibility markets and local flexibility platforms, using standard, open or market-specific interfaces as applicable.
IR8	Data-space interoperability and governance	The IDOP shall support interoperable and governed data sharing for buildings and industrial sites using principles compatible with DERA, IDS and Gaia-X data-space architectures, including identity, catalogue/broker, connector and policy-based data exchange mechanisms where applicable.

5 Common system architecture

This section first describes the main packages and modules of the IDOP, after which an IDOP based example system is presented to illustrate how the modules of the IDOP can be used.

5.1 Integrated Development and Operations Platform

The architecture of the Integrated Development and Operations Platform consists of three main packages as illustrated in Figure 1.

Figure 1: Overview of the Integrated Development and Operations Platform.

The CEMS Package includes five modules aligned with the CEMS architecture introduced in the EN 50491-12-1 standard (CENELEC, 2018). Separate modules are provided for the Resource Manager (RM) and Customer Energy Manager (CEM). These modules deliver the respective S2 interface libraries, optimization models, and control algorithms. These modules support three categories of optimization targets: local optimization, implicit control, and explicit control. Furthermore, they implement five control models as specified in the EN 50491-12-2 standard (CEN-CENELEC, 2022). Additionally, the CEM module implements the Resource Role of the DSFM interface defined in the new IEC 62746-4 standard (IEC, 2024). The Semantic Adapters for EMSs and SAs module provides interfaces for a wide variety of resources, including heat pumps, building automation systems, photovoltaic systems, smart meters, and other metering infrastructure. The Neural ODE Toolbox enables automated resource modelling with Neural ODEs, supporting optimal Model Predictive Control (MPC) of resources and accurate baseline and flexibility forecasting. The User Interface module allows different user types to define preferences and goals, monitor CEMS performance, and provide feedback.

The AEMS Package consists of four modules. The Aggregated Load Management module offers standard-compliant interfaces for aggregating and managing flexibility from CEMS and implements the Operator Role of the CEMS interface (to be defined in the IEC 62746-4 standard (IEC, 2024)). The Probabilistic Forecasting Tools module provides methods for probabilistic forecasting of prices, aggregated demand, and flexibility required in stochastic multi-market bidding. Aggregated demand and flexibility forecasting provide hierarchical forecasting to correct aggregated forecasts by learning from the residuals of the CEMS-level forecast generated with Neural ODEs. The Multi-Market Interfaces and Bidding module includes market interfaces and optimization models for multimarket operations to break market silos and maximize the value of flexibility. Interfaces for eight different energy wholesale,

TSO, and DSO flexibility markets were developed during the project. The Customer Information Systems module ensures secure and GDPR-compliant data management services for customer data, supporting customer pooling based on their retailer or network topology location, as required in explicit demand response (DR) for wholesale markets and flexibility services for DSO-TSO cooperation.

The DevSecOps & Investment Support Package consists of three modules. The DevSecOps Toolbox module facilitates automated deployment, security, and operations of CEMS and AEMS. Trust, security, and privacy (TS&P) are integrated as shared responsibilities throughout the system life cycle. Each module instance is packaged as a microservice (container) for flexible deployment in cloud and edge environments. For instance, deploying CEMS on an edge computing platform ensures operational resilience against network disruptions. The Data Spaces for Building and Industrial Sites module provides Gaia-X and European Data Exchange Reference Architecture (DERA) 3.0 compatible data spaces, enabling secure and governed data sharing across stakeholders. This supports resource modelling and data-driven estimation of benefits from IDOP. The Data-driven Tool for Investment Analysis simulates benefits and payback times using models and parameters consistent with operational control and forecasting, enhancing the accuracy of return-on-investment forecasts.

5.2 IDOP based system architecture

To better understand the IDOP and its usage, it is useful to document the architecture of an example IDOP based system. In this section, an example system utilizing the IDOP is documented. The system architecture represents an operational DSFM system and therefore mainly focuses on the CEMS and AEMS packages. The architecture documentation follows the ISO/IEC/IEEE 42010:2011 standard (*ISO/IEC/IEEE 42010:2011 - Systems and software engineering - Architecture description*, 2011), which includes engaging stakeholders and utilizing a views and perspectives methodology. In the next sub-sections, the IDOP based system is presented with four architectural views, and security and privacy perspective.

5.2.1 Context View

Figure 2 illustrates an example of the IDOP based system: an AEMS aggregates several CEMS (and possible other AEMS as well), manages their flexibility, and provides the combined flexibility to the energy and flexibility markets. The IDOP elements (i.e., AEMS and CEMS) are represented with green, site-specific external systems with blue and energy and flexibility markets with orange.

DRAFT

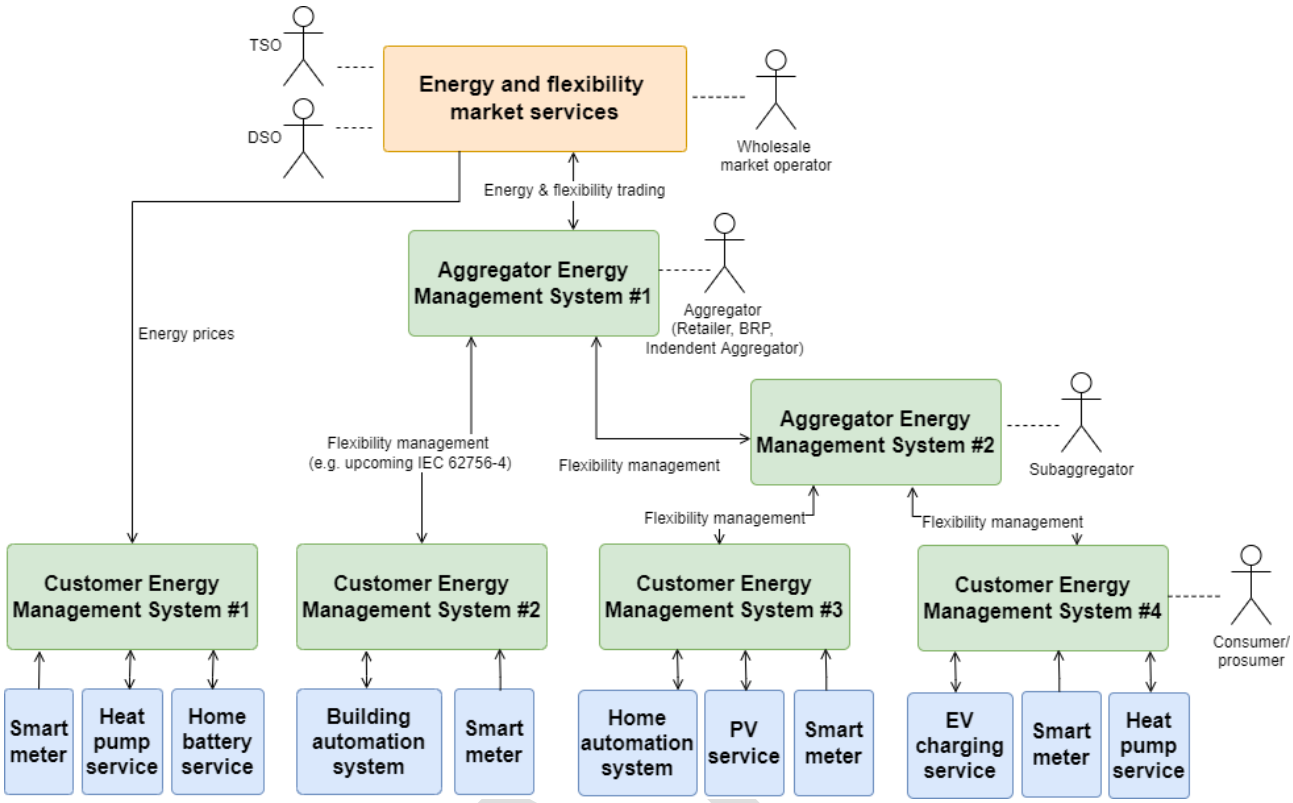


Figure 2: IDOP based system.

Figure 3 illustrates a context view of an IDOP based system: the main components; an AEMS and a CEMS, are presented as black-boxes and their interaction with each other, other stakeholders and external systems are described. The elements of the context view are described in more detailed in Table 22.

DRAFT

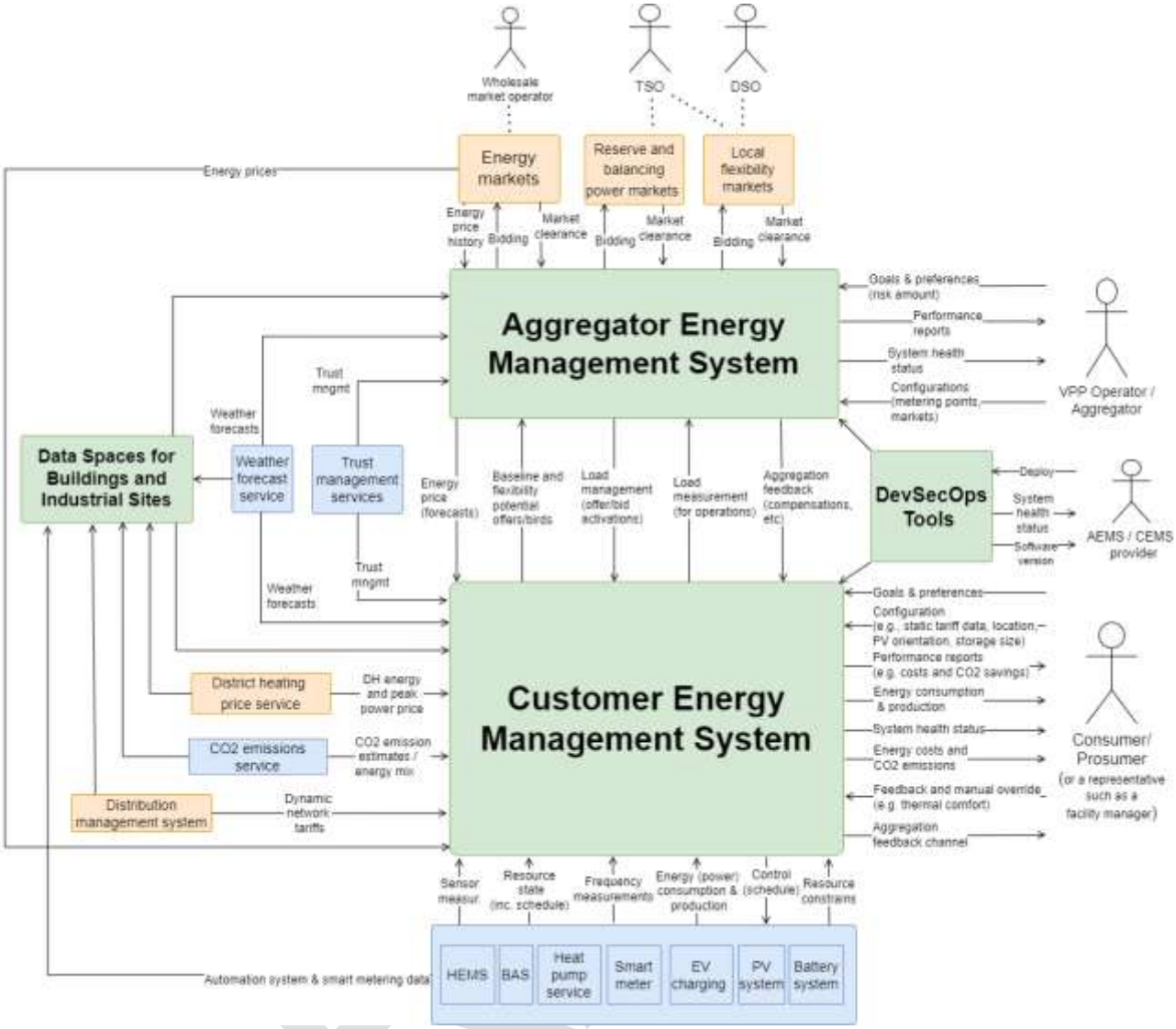


Figure 3: Context view of an IDOP based system.

Table 22: Description of elements of the context view.

Element	Description	Managed data
Aggregator Energy Management System	A solution for aggregating and managing flexible resources in multi-market setting. Based on the AEMS Package of the IDOP.	Bidding Load management signal price forecast Performance reports System health status
Local flexibility markets	Markets that provides data about current bidding and market clearance to AEMS.	Bidding Market clearance
Reserve and balancing power markets	Markets that provides data about current bidding and market clearance to AEMS.	Bidding Market clearance
Energy markets	Markets that provides data about current bidding and dynamic price history data to AEMS.	Bidding Market clearance Energy price (and history)

Customer Energy Management System	Provides automated energy and flexibility management. Based on the CEMS Package of the IDOP.	Baseline and flexibility potential offers Load measurement Control (schedule)
Data Spaces for Buildings and Industrial Sites	IDOP based Data Spaces for sharing data about buildings and industrial sites. The data spaces provide an alternative way (in addition to direct access) for sharing data between the external systems, AEMS and CEMS.	Basically, any data that can be shared between the stakeholders, including: energy consumption and production data, metering point configuration data, building automation data, distribution management data, CO2 emission data, etc.
DevSecOps Tool	Tools for managing CEMS and AEMS services with focus on integration of security as a core part of the development and operations.	AEMS and CEMS deployment commands, system health status, system configuration, software version, etc.
Weather forecast service	A service that provides weather data	Weather data (current, history)
Trust management services	A service that enables establishing trust among entities in the system. Enables recognition of end user identities, their credentials, corresponding resources and their relation to roles in the system.	Trust management data
Distribution management system	Provides the dynamic network tariffs.	Dynamic network tariffs
District heating price service	Provides the current district heating prices	Dynamic district heating prices
CO2 emission service	Provides data about the equivalent CO2 emissions	Energy mix / estimate of the CO2 emission
HEMS	Home Energy Management System that monitors energy flows of the building. Provides information about energy consumption and production, and the state of the flexible assets. Controls the building's energy resources (devices, flexible asset) according to control commands.	Sensor measurement data Resource state Frequency measurements Energy consumption Energy production Constraints for a flexible asset Resource control
BAS	Building Automation System that monitors and manages various systems in a building. Provides information about energy consumption and production, and the state of the flexible assets. Controls the building's energy resources (devices, flexible asset) according to control commands	Sensor measurement data Resource state Frequency measurements Energy consumption Energy production Constraints for a flexible asset Resource control
Heat pump service	A service that controls heat pump unit(s) and provides energy when required.	Energy consumption Energy production Resource state
Smart meter	An official power meter (i.e., metering point), that enables to remotely read the power and energy measurements.	Power and energy measurement for electricity.
EV charging	A charging station for electronic vehicle. Provides data about energy consumption and production data, and the state, and receives control commands.	Energy consumption Energy production Resource state

PV system	Photovoltaics system, provides data about the energy production and state of the resource.	Energy production Resource state
Battery system	A system that stores energy and provides it when needed.	Energy production Resource state
Wholesale market operator	Operates in energy markets	N/A
TSO	Transmission System Operator, operates in reserve and balancing power markets and in local flexibility markets	N/A
DSO	Distribution System Operator, operates in local flexibility markets	N/A
VPP operator / aggregator	A stakeholder who operates / aggregates a virtual power plant.	Goals Preferences Configurations (metering points, markets)
Facility manager	A stakeholder that is in charge of a larger property. Provides goals and preferences, and system configurations, and receives performance reports, system health status, data about energy consumption and production, and energy costs and CO2 emissions	Goals Preferences Configurations (static tariff data, location, PV orientation, storage size) Feedback and manual override (thermal comfort)
Consumer / prosumer	An individual resident. Provides goals and preferences, and feedback on the system operation, and receives energy costs, and energy consumption and production data. As a prosumer, provides tariff data.	Goals Preferences Configurations (static tariff data, location, PV orientation, storage size) Feedback and manual override (thermal comfort)
AEMS / CEMS Provider	A technology provider for the AEMS and/or CEMS platforms. This company is responsible for deployment and operations of the technical systems. Typically, there are separate companies at for the CEMS and AEMS.	Deployment and operations data System health status (e.g. software version, etc.)

5.2.2 Functional View

In the functional view, the IDOP based system is divided into functional components. Figure 4 describes the functional view of an example system.

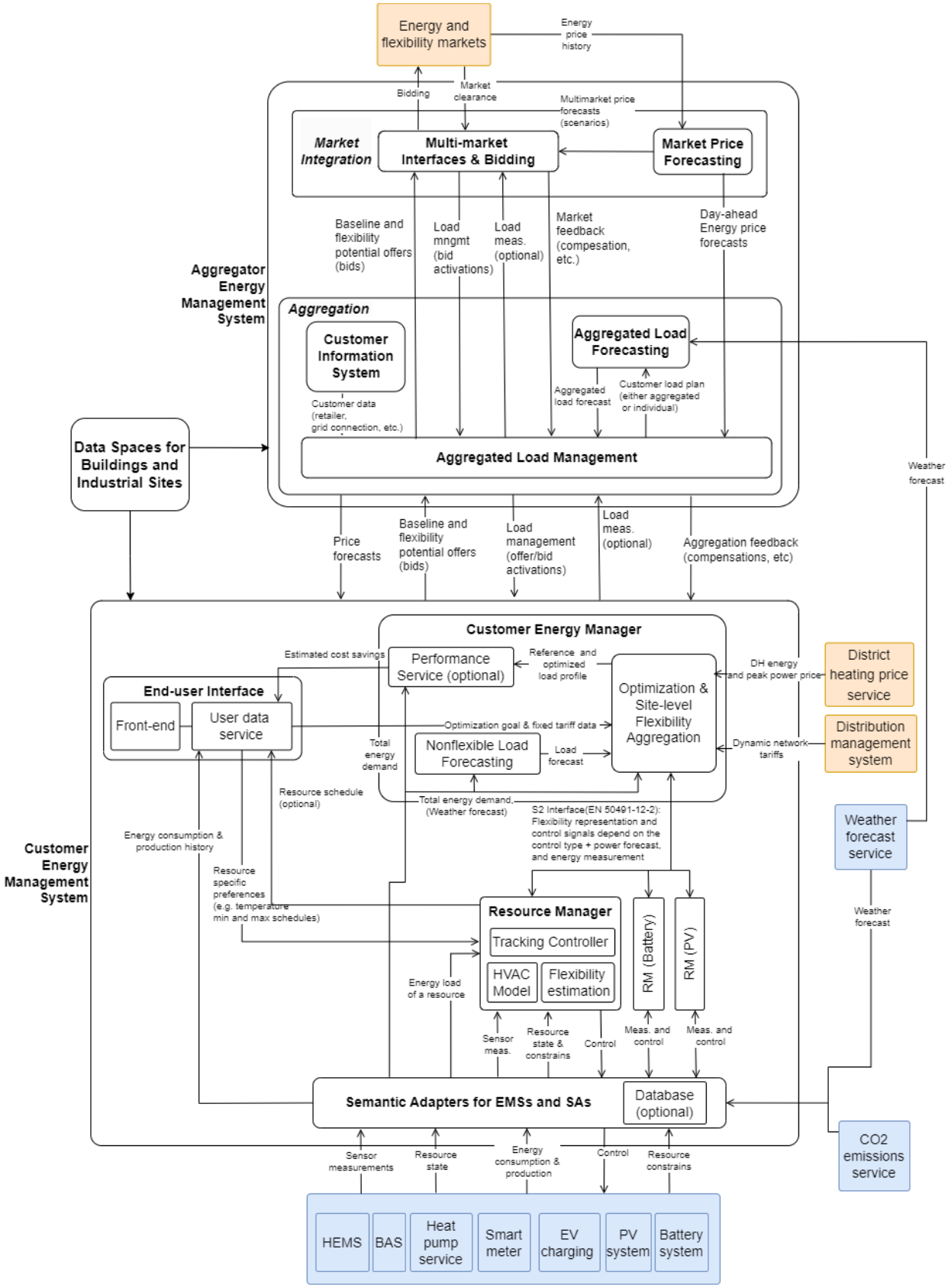


Figure 4: Functional view of the IDOP based system architecture.

Table 23 provides a detailed description of the five functional components of the AEMS. The AEMS components are divided thematically into two groups: Market Integration and Aggregation. This is to highlight that some AEMS can focus just on aggregation without direct interfaces with the markets and

can just include the functional components of the Aggregation group (i.e., these AEMS are called sub-aggregation platforms). The interface between the Aggregation and Market Integration parts is based on the same IEC 62746-4 standard (IEC, 2024) as the CEMS-AEMS interface.

Table 23: Functional components of Aggregator Energy Management System.

	Functional component	Description
Market integration	**Multi-market interfaces and Bidding**	The functional component is responsible for providing mechanism for maximizing the value of flexibility in multi-market operation. To this end, the functional component provides interfaces to energy and flexibility markets including TSO reserve and DSO local flexibility markets. Additionally, the component provides means to optimize aggregated flexibility bids/offers in multi-market setting using the probabilistic market price forecast provided by the Market Price Forecasting component.
	Market Price Forecasting	This functional component is responsible for providing probabilistic price forecasts for a wide variety of energy and flexibility markets.
Aggregation	**Customer Information System**	This component is responsible for providing access the customer related data and metadata required in the aggregation, including e.g. the retailer, metering point id and location in the network topology.
	Aggregated Load Forecasting	The purpose of this component is to provide aggregated baseline and flexibility forecasts. This is an optional component, and the idea is to improve the accuracy of the baseline and flexibility forecast which are initially constructed by the Aggregated Load Management component by adding together the CEMS-level forecasts.
	Aggregated Load Management	This component provides flexibility aggregation (and disaggregation) functionality. I.e., it is responsible for aggregating together the individual baseline and flexibility forecasts from CEMS and disaggregating the accepted flexibility bid for individual CEMS.

Table 24 describes the functional components of CEMS. The CEMS consists of four main functional components which are divided further into subcomponents as described in Table 24.

Table 24: Functional component of Customer Energy Management System.

Functional component	Description
End-user Interface - Front-end - User data service	The End-user Interface component is responsible for enabling consumers/prosumers (and their representatives) to interact with their CEM. The component consists of two subcomponents: Front-end and User data service.
Customer Energy Manager - Optimization & site-level flexibility aggregation - Nonflexible load forecasting - Performance service (optional)	The Customer Energy Manager component is the core of the CEMS as described in the (CENELEC, 2022). Its main function is to optimize energy and flexibility management within the site. The CEM consist of three subcomponents. First, the Optimization & site-level flexibility aggregation subcomponent is responsible for 1) optimizing energy management and 2) aggregating the flexibility provided by the Resource Managers at the site level. For optimization, the subcomponent utilizes Resource data provided via the S2 interface, inflexible load forecasts, and energy price and power tariff data. Second, the Nonflexible load forecasting subcomponent is responsible for providing the baseline forecast for the consumption that is not included to the individual resources. Third, the Performance Service is responsible for storing and providing access to the flexibility management performance data. This is an optional component that includes, for example, data about the estimated savings that have been obtained via flexibility management.

Resource Manager - Tracking Controller - Resource Model - Flexibility Estimation	The Resource Manager component is responsible for managing a single resource (device or logical group of devices) within the consumer premises. The main function of the RM is to control the flexible asset according to consumer preferences and expose the flexibility of the asset for the CEM as defined in the EN 50491-12 standard (CEN-CENELEC, 2022). The RM consist of three main subcomponents: Tracking Controller, Resource Model, and Flexibility Estimation. The Tracking Controller is responsible for following the control signals sent by the CEM while making sure that the consumer preferences are satisfied. To this end, it typically utilizes the Resource Model to perform Model Predictive Control (MPC). The Resource Model is also used by the Flexibility Estimation subcomponent that is responsible for representing the flexibility of the asset as defined in the S2 interface.
Semantic Adapters	The Semantic Adapters component provides a common interface for interfacing with building and home automation systems, metering infrastructure, weather forecast service, and other external systems providing information about resources. The idea is that there is a Semantic Adapter for each type of asset/protocol that maps the assets specific interface to a common SAREF aligned representation.

5.2.3 Information View

The information view describes the main information exchanged through the key interfaces of the IDOP-based system architecture. It complements the context view, which identifies the external actors and systems, and the functional view, which defines the main CEMS and AEMS components. The purpose of the information view is to clarify what information is exchanged, which components use it, and which standards or semantic models support interoperability.

In the IDOP architecture, demand-side flexibility management is supported through three main information boundaries. The first boundary is the CEM–AEMS interface, where baseline forecasts, flexibility offers, prices, activation instructions and performance data are exchanged for aggregation and market participation. The second boundary is the RM–CEM interface, where resource capabilities, measurements, forecasts, flexibility descriptions, constraints, control instructions and reception feedback are exchanged using the S2 interface. The third boundary is the Semantic Adapter Interface, where heterogeneous resource-side data from external systems and services is mapped into a common SAREF-aligned resource representation before it is used by RM or CEM components.

The following subsections describe these interfaces in more detail. Section 5.2.3.1 presents the information model of the CEM–AEMS interface, Section 5.2.3.2 presents the S2 information model between Resource Managers and the CEM, and Section 5.2.3.3 presents the SAREF-aligned Semantic Adapter Interface. Table 25 provides a compact summary of the main information categories identified from the context and functional views. It is used as an overview of the information exchanged in the architecture; the interface-specific data models are described in the subsections that follow.

Table 25: Main information categories identified for the IDOP-based system architecture.

Units	Data types	Resources	Systems	Information/ knowledge
•Power, energy, capacity •Temperature, humidity, CO_2	•Measurement data •Price data •Weather data •Report •State data •Constraint •Control data •Feedback data •CO2 estimates	•Sensors •Energy metering •Storages •Batteries	• Distribution management system •District heating management system •Energy management systems (BAS, HEMS) •Third party services (e.g., weather service, CO_2 emission service)	•Laws, standards •Identities •Bidding description

5.2.3.1 Interface between Customer Energy Manager and the Aggregator Energy Management System

The interface between the CEM and the AEMS, as well as the interface between market and sub aggregation platforms are based on the new IEC 62746-4 Demand-side Resource Interface (IEC, 2024). The standard is based on the Common Information Model (CIM) and defines data models for exchanging information between the Resource Role and the Operator Role. In the INDEPENDENT architecture, the CEM corresponds to the Resource Role, providing information about the flexible resources under its control, while the AEMS corresponds to the Operator Role, aggregating this information and using it for market-oriented flexibility management. The standard is designed to be generic and adaptable to different power-system and market structures, which makes it suitable for the INDEPENDENT pilots where flexibility may be used in wholesale energy markets, reserve markets, local flexibility markets, and emergency or congestion management contexts.

The CEM–AEMS interface can be understood as a set of message exchanges that support the flexibility management lifecycle. First, the AEMS may request or maintain information about the flexibility-providing resource or aggregation through the Inform exchange. This uses the MarketDER message to describe the market-level characteristics of a DER or an aggregation of DERs, including the resource profile, capabilities, and relevant baseline information.

Second, the AEMS may communicate price or incentive information to the CEM through the Incentivise exchange. This uses the CommodityPriceExchange message, which contains pricing information by time and product. The price information may be binding, for example when used for settlement, or indicative, for example as a price forecast used by the CEM to optimise its baseline operation and flexibility offers.

Third, the CEM communicates its intended operating plan and flexibility offers to the AEMS through the Plan exchange. This uses the MarketDERBidOffer message, illustrated in Figure 5. The message can represent either a fixed or intended operating schedule for non-dispatchable resources, or price-dependent bids and offers for price-dispatchable resources. Two alternative structures are available: BidSchedule for price-sensitive bids/offers and BidSelfSched for bids/offers that are not dependent on price. In the INDEPENDENT context, this message can represent the CEM baseline, upward and downward flexibility around the baseline, and the corresponding costs or compensation requirements. However, the representation is primarily schedule- and offer-oriented and does not fully capture all physical interdependencies or impacts of flexibility activation inside the site; these remain part of the CEM/RM-level optimisation and execution logic.

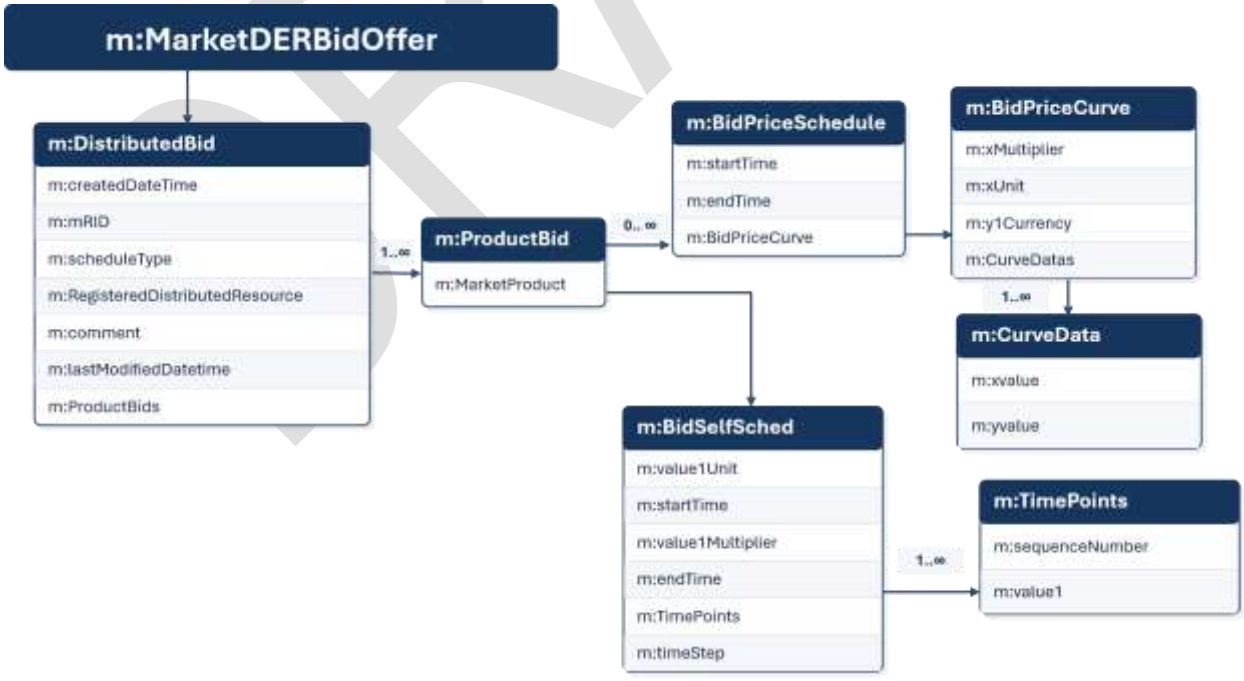


Figure 5. Data model of the MarketDERBidOffer message.

Fourth, after market clearing, portfolio optimisation, or another operator-side decision, the AEMS can communicate dispatch or activation instructions to the CEM using the MarketDERInstruction message, depicted in Figure 6. The message, depicted in represents the logical response to the planning

exchange by acknowledging a fixed schedule or selecting some or all of the offered flexibility. It can be used to communicate one or more setpoints to a DER or aggregated resource, either as individual dispatches or as a schedule. In the INDEPENDENT architecture, this means that the AEMS does not directly control individual assets; instead, it sends accepted schedules or flexibility activation instructions to the CEM, which then disaggregates and executes them through the local CEM–RM interface while respecting local constraints and user preferences.

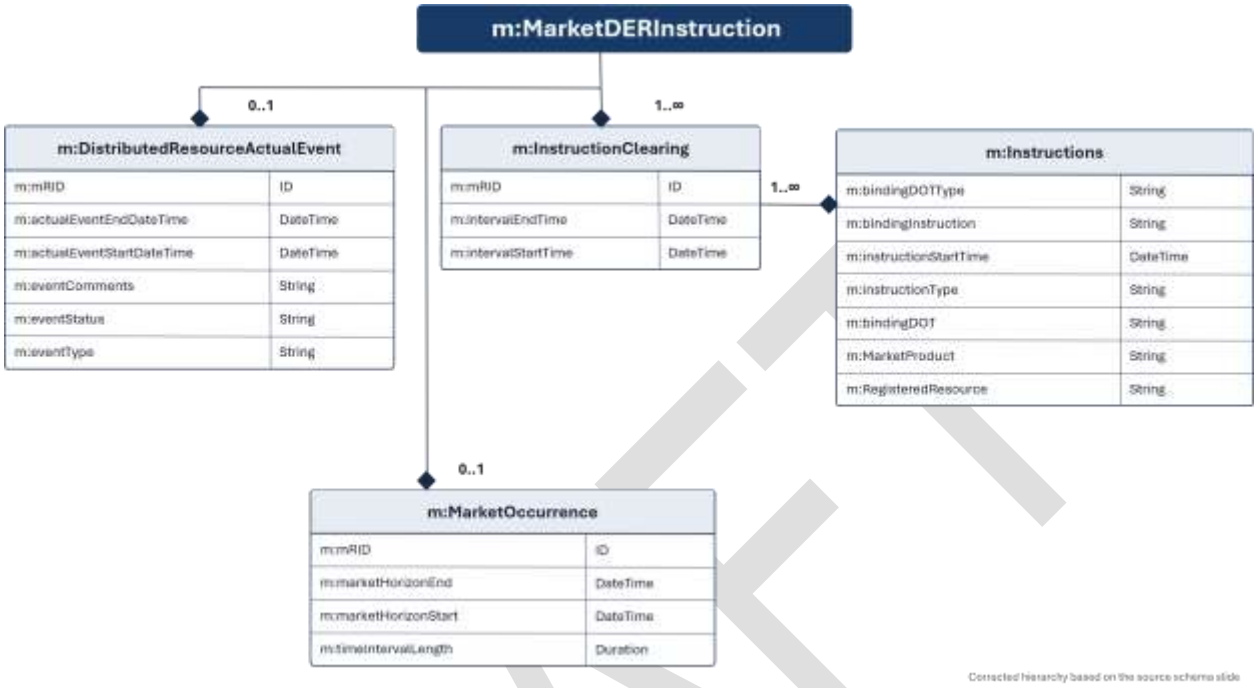


Figure 6. Data model for the MarketDERInstruction message.

Finally, the Report and Evaluate exchanges support post-event verification, settlement, and performance assessment. The CEM can use the ReferenceEnergyCurve message to report realised energy or power profiles, baseline values, and other agreed measurement data. The AEMS or operator-side function can then use the same message structure in the evaluation phase to communicate assessed performance or settlement-relevant information. This information provides the basis for compensation calculations and for evaluating whether delivered flexibility matched the agreed activation or market commitment.

Overall, the IEC 62746-4 data model separates the CEM–AEMS interface into resource description, price/incentive communication, flexibility planning, activation scheduling, and post-event reporting/evaluation. For the INDEPENDENT information view, the most important data objects are therefore: (i) resource and aggregation profiles, (ii) baseline/reference energy curves, (iii) prices and market-product information, (iv) flexibility bids/offers with quantities, time intervals, and costs, (v) accepted schedules or activation instructions, and (vi) realised measurements and evaluation data. This allows the AEMS to aggregate flexibility from multiple CEMS and interact with energy and flexibility markets, while the CEM remains responsible for local optimisation, resource-level control, and respecting site-specific constraints.

5.2.3.2 S2 interface between Resource Managers and Customer Energy Managers

The S2 interface defined in EN 50491-12-2 is used between Resource Managers (RMs) and the Customer Energy Manager (CEM) to exchange resource capabilities, measurements, forecasts, flexibility descriptions, control instructions and reception feedback. In the IDOP architecture, the interface realises the standardised RM-CEM communication required by IR1 and provides the resource-level information used by the CEM optimisation and site-level flexibility management functions.

The S2 information model contains common information objects and control-type-specific information objects. A resource announces the supported control types in ResourceManagerDetails, and the CEM activates an applicable type using SelectControlType. Different S2 control types provide different representations of resource flexibility, while reusing a set of common messages for resource identification, measurements, forecasts and acknowledgements.

Table 7 shows how these messages are exchanged over time. The RM first announces its identity and capabilities, after which the CEM selects a supported control type. During operation, the RM provides measurements, forecasts and control-type-specific flexibility information, while the CEM returns the corresponding control instructions, and both parties acknowledge the relevant message exchanges. The interaction pattern is common to the S2 control types; the control-type-specific flexibility description and instruction differ and are described in the subsections below. Within this exchange, the Resource Manager defines the feasible operating space and the CEM chooses within it; the Resource Manager may reject an instruction that would breach user comfort or safe operation of the resource.

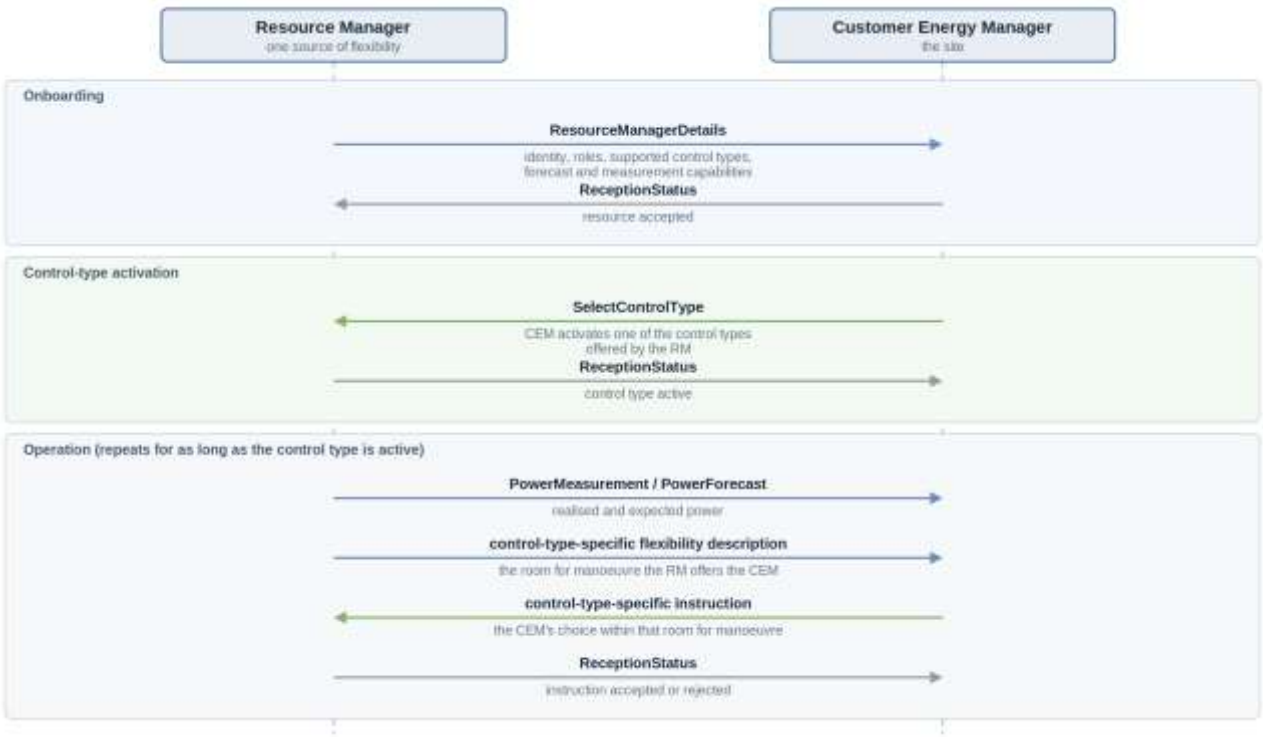


Figure 7: Message exchange between a Resource Manager and the CEM over the S2 interface.

Common S2 information objects

The common objects support onboarding, capability negotiation, operational data exchange and acknowledgements. ResourceManagerDetails communicates the resource identity, roles, available control types, processing delay, and forecast and measurement capabilities. PowerMeasurement and PowerForecast carry time-series information. SelectControlType activates the selected control model, while ReceptionStatus provides message reception and diagnostic feedback. InstructionStatusUpdate allows the RM to report whether a received instruction was accepted, started or rejected. Figure 8 shows the principal common information objects independently of a particular S2 control type.

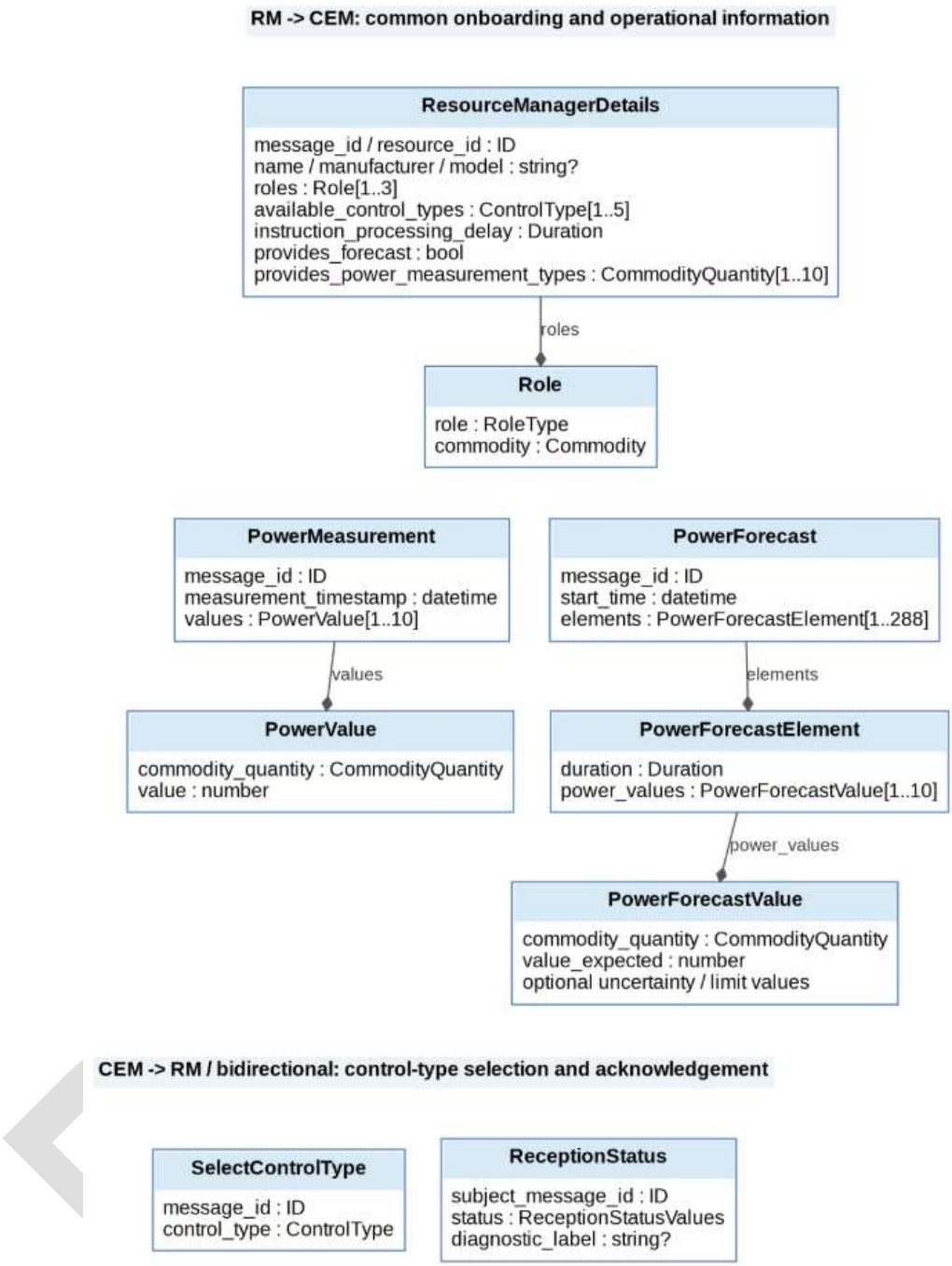


Figure 8: Common S2 information objects exchanged between Resource Manager and CEM.

Power Envelope Based Control (PEBC) data model example

PEBC represents resource flexibility as feasible power ranges over a validity interval and allows the CEM to return a scheduled power envelope. PEBC.PowerConstraints contains one or more allowed power bands expressed by PEBC.AllowedLimitRange. The range boundary is expressed as a NumberRange with start_of_range and end_of_range. PEBC.EnergyConstraint complements the power constraints with upper and lower average-power bounds for the validity period.

The CEM returns a PEBC.Instruction that references the applicable PowerConstraints through power_constraints_id. The instruction contains one or more PEBC.PowerEnvelope objects, each of which consists of time-ordered PowerEnvelopeElement objects with a duration and lower and upper power limits. This reference maintains the relationship between the flexibility description provided by the RM and the control decision produced by the CEM as illustrated in Figure 9.

Implementation example. The current heat-pump RM advertises PEBC as an available control type, which can subsequently be selected by the CEM using SelectControlType. The RM then provides

electrical power measurements, forecasts and PEBC flexibility constraints. Based on this information, the CEM determines a feasible schedule and returns the resulting control decision as a PEBC.Instruction.

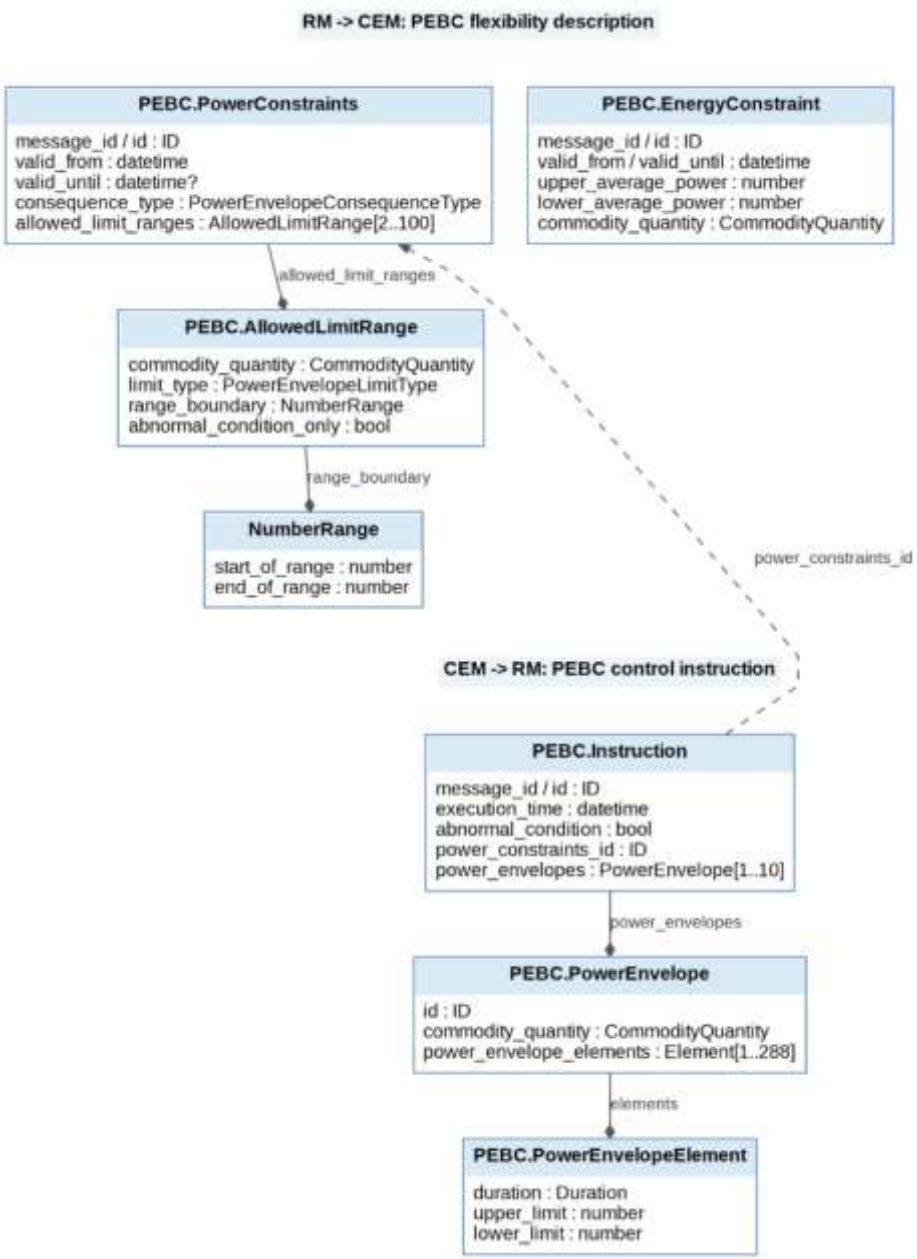


Figure 9: S2 PEBC information model for flexibility description and control instruction.

Fill-Rate Based Control (FRBC) data model example

FRBC uses a different information structure and is therefore shown separately from PEBC. It represents flexibility through a storage state, actuator descriptions and operation modes. FRBC.SystemDescription describes the available actuators and the associated FRBC.StorageDescription. Each actuator can expose operation modes whose elements relate fill-level ranges and fill rates to feasible power ranges. FRBC.StorageStatus communicates the present fill level of the resource.

The CEM controls an FRBC resource using FRBC.Instruction, which selects an actuator and operation mode together with an operation-mode factor and execution time. This representation is suitable for resources whose flexibility can be expressed by a fill level or state variable and by a set of controllable operating modes, as illustrated in Figure 10.

The current CEM implementation contains a dedicated FRBC scheduling handler in addition to the PEBC handler. FRBC is therefore a relevant second data-model example for the S2 interface, although the current heat-pump RM configuration advertises PEBC and does not activate FRBC.

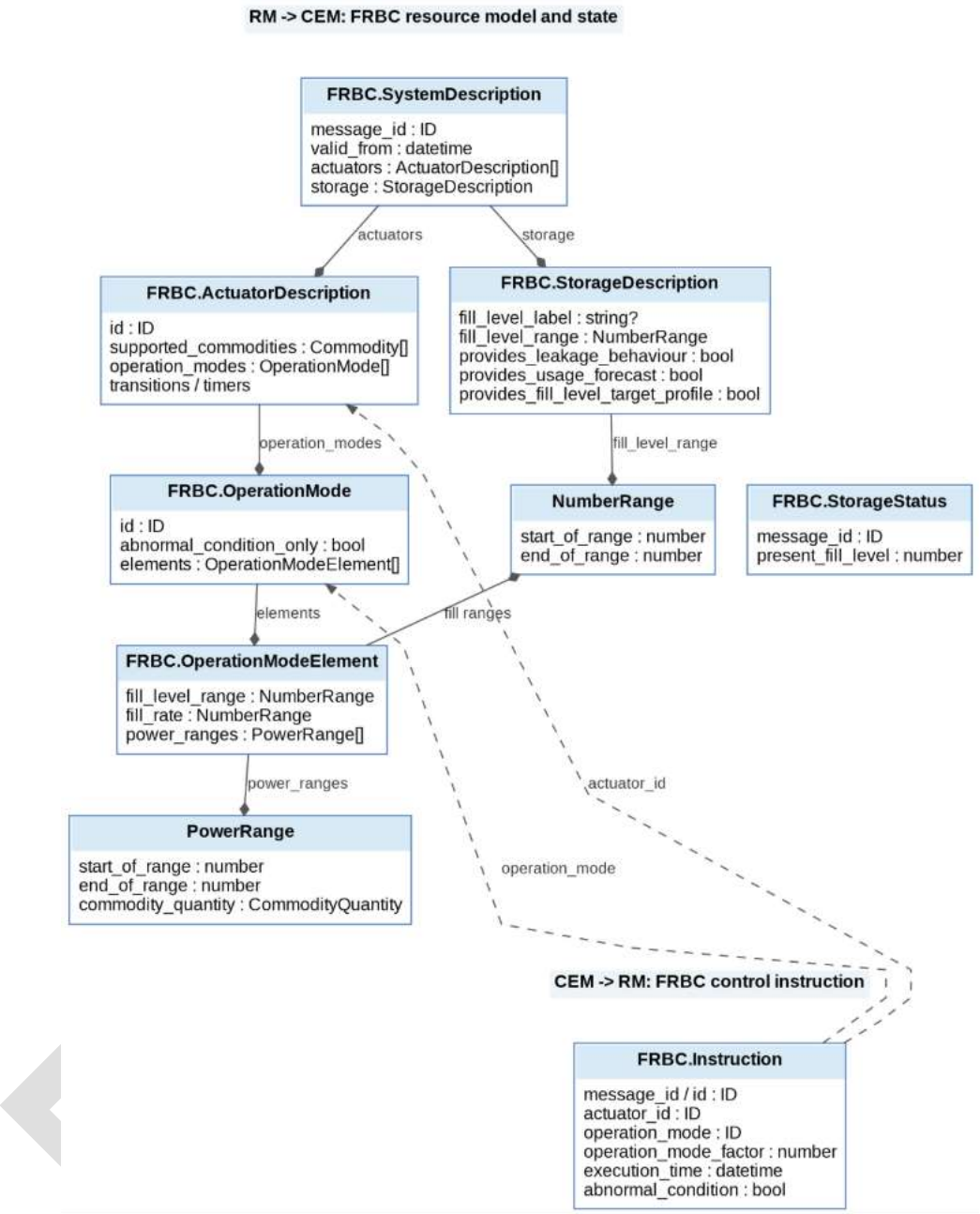


Figure 10: S2 FRBC information model for a storage-oriented resource.

Relationship between the S2 interface and the CEM scheduling backend

The S2 models above describe the information exchanged across the RM-CEM boundary; they do not prescribe how the CEM calculates a control decision. In the IDOP architecture, resource descriptions, measurements, forecasts and control-type-specific flexibility received through S2 are translated inside the CEM into the input required by the selected optimisation or scheduling backend, and the resulting schedule is translated back into the applicable S2 instruction before it is sent to the RM. The German cost-oriented energy system optimisation pilot currently uses FlexMeasures as one such backend, but its internal data model and the exact mapping are implementation-specific and are intentionally not part of this interface description. This keeps the S2 interface backend-independent, so future FlexMeasures versions or alternative scheduling backends can be introduced without changing the RM-facing S2 data model described here.

Coverage of the remaining S2 control types

The figures in this section show the common S2 objects and two control-type examples, PEBC and FRBC. EN 50491-12-2 also defines Power Profile Based Control (PPBC), Operation Mode Based Control (OMBC) and Demand Driven Based Control (DDBC), alongside NOT_CONTROLABLE and NO_SELECTION. All control types use the same ResourceManagerDetails and SelectControlType mechanism and reuse the common measurement, forecast and acknowledgement objects; only their flexibility descriptions and control instructions are type-specific. The architecture is therefore not limited to PEBC and FRBC, and the other S2 control types can be added without changing the common RM-CEM interface.

5.2.3.3 Semantic Adapter Interface

The Semantic Adapter Interface defines the data model used between external resource-side systems and the Resource Manager or Customer Energy Manager components. The purpose of the interface is to provide a common semantic representation for data originating from heterogeneous systems such as BAS, HEMS, smart meters, heat pump services, EV charging systems, PV systems, batteries, weather services and other pilot-specific data sources. In the IDOP information view, the interface is therefore focused on the semantic description of resource data, not on the internal implementation of adapter pipelines or communication protocols.

The Semantic Adapter Interface uses a SAREF-aligned data model. The core semantic concepts for devices, sensors, actuators, observable properties, measurements, units, states, commands and services follow the SAREF terminology. In this model, external resources are represented as SAREF devices or systems, sensors observe properties, measurements provide values for those properties with units and timestamps, and actuators expose commands that affect controllable properties. IDOP adds interface-level objects for information that is required by Resource Managers and Customer Energy Managers but is not fully covered by SAREF Core, including forecasts, capabilities, constraints, control endpoints and mapping metadata. These IDOP-specific objects are linked to the SAREF-based resource representation instead of being treated as native SAREF Core classes. The resulting interface data model is shown in Figure 11.

DRAFT

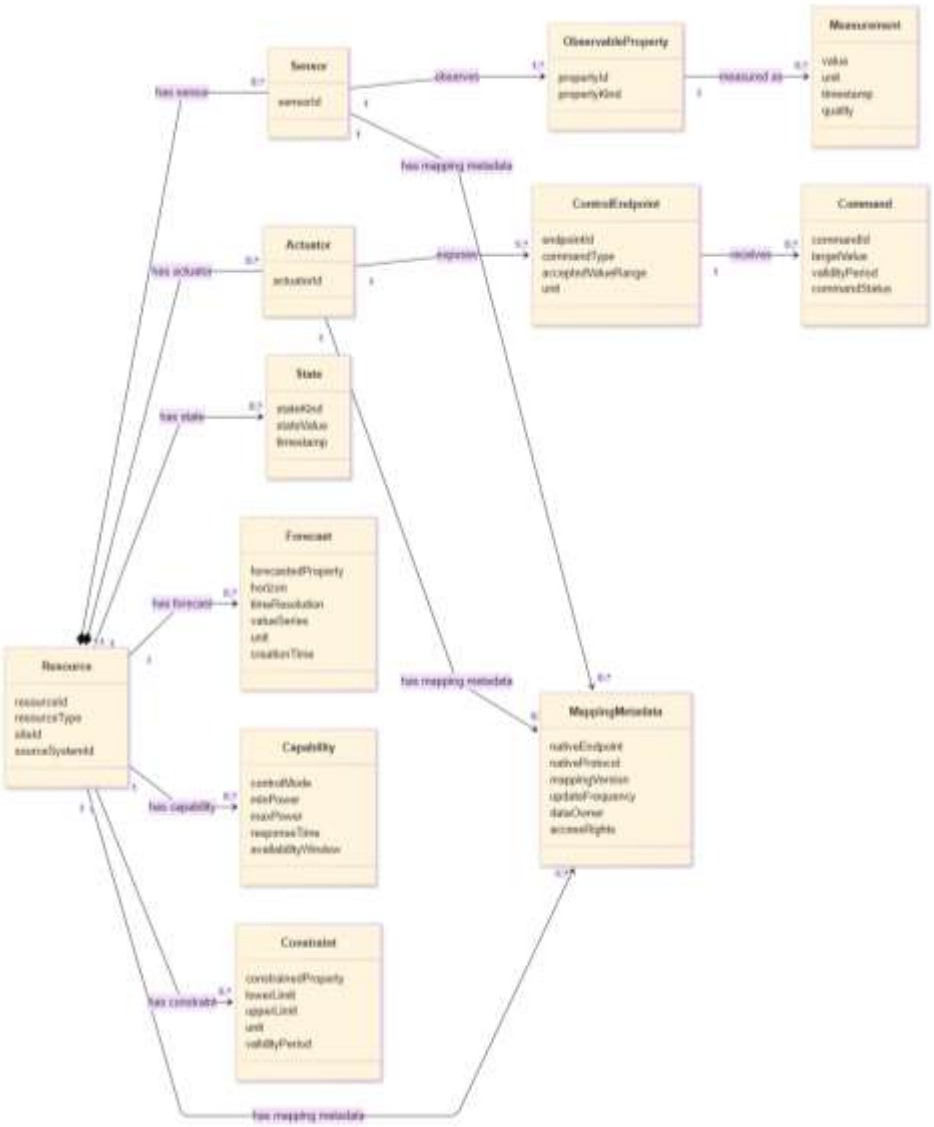


Figure 11. SAREF-aligned data model for the Semantic Adapter Interface. The model uses SAREF concepts for resources, devices, sensors, actuators, properties, measurements, states and commands, and extends them with IDOP-specific objects for forecasts, capabilities, constraints, control endpoints and mapping metadata.

The core object in the Semantic Adapter Interface is the resource representation. A resource represents a physical or logical asset that is monitored, modelled or controlled by the IDOP system. Examples include a heat pump, HVAC subsystem, battery, EV charger, PV inverter, smart meter, building zone, supermarket refrigeration unit or industrial process load. In SAREF terms, this resource is represented as a Device, System or Feature of Interest, depending on the level of abstraction. The resource is linked to Sensors, Actuators, observable Properties, Measurements, States and Commands using SAREF relationships. The IDOP representation extends this core with site-specific identifiers, source-system references, metering-point links and semantic mappings to the native data endpoints used in pilot systems.

Measurement and state data describe the observed behaviour of a resource. Measurements follow the SAREF observation pattern: a Sensor observes an observable Property of a resource, and the resulting Measurement or property value contains the value, unit, timestamp and quality information. Typical observed properties include electrical power, energy, temperature, humidity, CO2 concentration, state of charge, valve position, operating mode, availability state, PV production, EV charging power, indoor conditions and process-specific variables. State information is represented as the current condition of the resource or one of its relevant subsystems, such as availability, operating mode, alarm state or state of charge.

Forecast data describe expected future values of resource-related properties. Forecasts are treated as IDOP interface-level objects linked to the same SAREF resource and property concepts used for measurements. A forecast contains the predicted property, forecast horizon, time resolution, value series, unit, issuing component, creation time and uncertainty information when available. This structure allows measured and forecasted values of the same property to be interpreted consistently by RM and CEM components, while keeping the forecast object separate from the SAREF Core measurement concept.

Capability and constraint data describe how the resource can be operated. Capabilities define the controllable behaviour exposed by the resource, including supported control modes, minimum and maximum power, ramp limits, storage capacity, response time, availability windows and supported actuation commands. Constraints define operating limits that RM or CEM optimisation must respect, including minimum and maximum temperature, minimum state of charge, required dwell time, maximum peak power, comfort limits, process quality limits and safety boundaries. In the data model, capabilities and constraints are IDOP interface extensions linked to the relevant SAREF Device, Actuator, Property and Command concepts.

Control data describe the semantically meaningful control endpoints exposed by the adapter. A control endpoint represents a command, setpoint or schedule that the adapter translates into the native interface of the external system. Examples include temperature setpoint, charging limit, battery charge or discharge request, heat pump operating mode, ventilation mode, PV curtailment request and industrial process load limit. The SAREF relationship to commands and actuators is preserved by linking each control endpoint to the affected resource, actuator and property. The IDOP command object then captures the command type, target value, accepted value range, unit, validity period and command status used by RM or CEM components.

Mapping metadata is included in the Semantic Adapter Interface to make the semantic mapping traceable and maintainable. Each mapped resource, sensor, actuator or control endpoint is linked to the original pilot-system data point through metadata describing the source system, native endpoint name or tag, protocol or API, mapping version, update frequency, data owner, access rights and data quality information. This metadata is required because pilot integrations rely on legacy and vendor-specific systems where the same semantic concept can have different names, units and access mechanisms across sites.

5.2.4 Deployment View

Deployment view represents how the components of a system are implemented by software artifacts and how these software artifacts are deployed into different computing platforms. Figure 12 illustrates how the example IDOP based DSFM system is deployed.

DRAFT

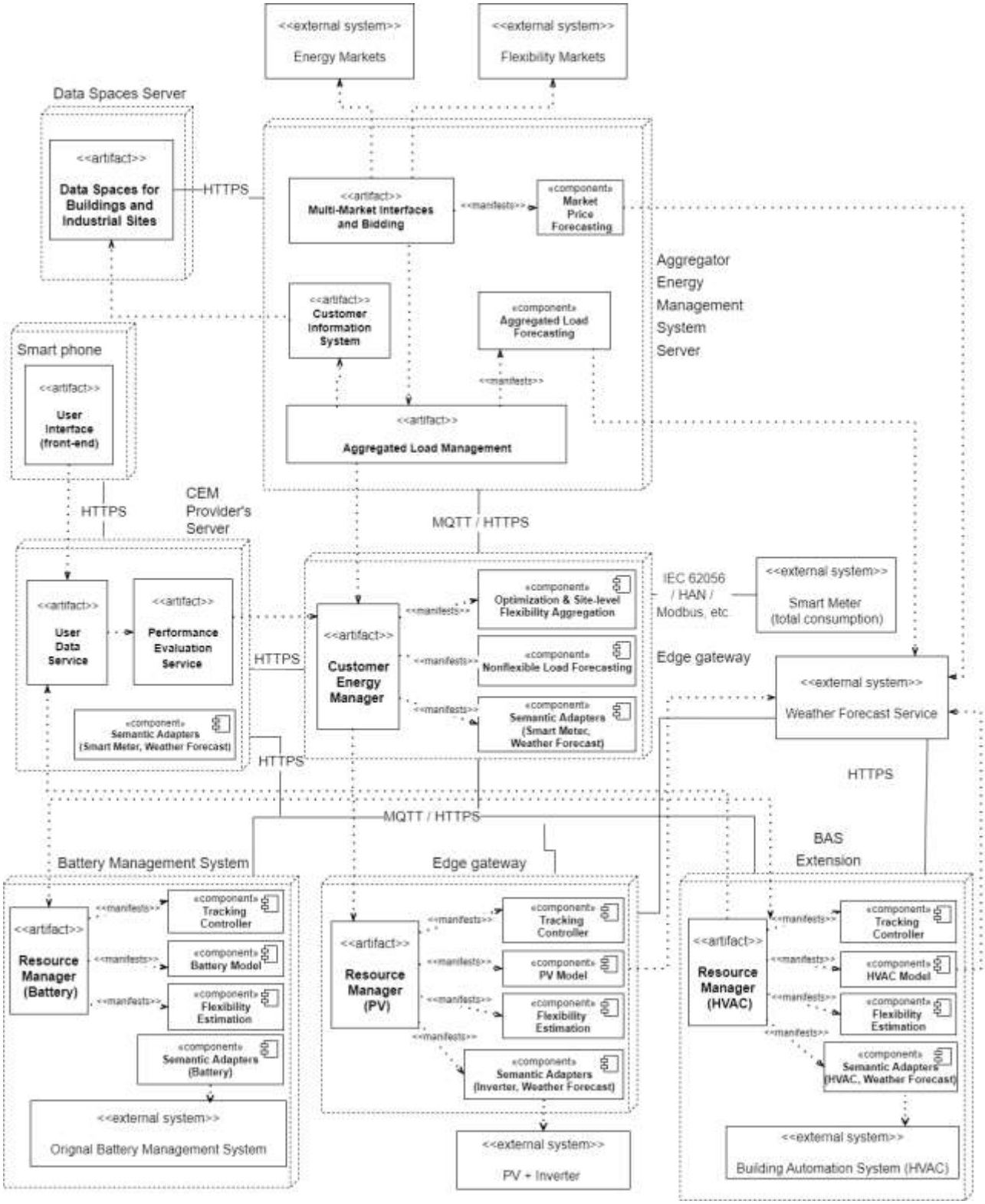


Figure 12: Deployment view of an IDOP based system.

The deployment example consists of a single CEMS (in practice there would be thousands) and AEMS. The CEMS consist of a Customer Energy Manager and three Resource Managers.

Starting from the bottom left, there is a RM integrated to a Battery Management System (BMS). In this example, the BMS system provider has extended their BMS system with standard-compliant RM. The RM consist of following subcomponents: Tracking Controller, Battery Model, Flexibility Estimation and Semantic Adapters for the BMS. The RM for the PVs in the middle in turn is implemented by a 3rd party

on an edge gateway. The third RM is implemented by the building automation system provider, and it is deployed in the same computing platform as the BAS.

The CEM in this example is deployed on an edge computing platform hosted in the consumer premises. It consists of following sub-components: Optimization & Site-level Flexibility Aggregation, Nonflexible load forecasting, and Semantic Adapters for smart meter and weather forecast integration. The deployment of the End-user interface component of CEMS is distributed. The front-end part is deployed in a smart phone whereas the User Data Service (i.e., back-end part) is deployed in a server. In this example the same server hosts the Performance Evaluation Service.

In this case there is a single aggregator providing aggregation and market integration services. The whole AEMS is therefore deployed into single server hosted by the AEMS provider. The deployment includes also Data Spaces that are deployed into as separate services.

Although not explicitly depicted in Figure 12 for clarity reasons, The DevSecOps module plays an important part in the deployment and operations of IDOP-based DSFM systems. The DevSecOps module provides tools and services that can be used in every stage from development to production deployment. It utilizes the “shift-left” philosophy, aimed at discovering potential vulnerabilities, bugs and misconfigurations as soon as possible. To achieve this, it combines dependency testing, image scanning, infrastructure scanning and compliance checking as an addition in the classic DevOps pipeline. This, in combination with tools for secure secret management, provides secure deployment capabilities to the project. The module also has a monitoring stack with alerting, as well as the means to securely deploy multiple cluster environments with all the required services.

5.2.5 Trust, security and privacy perspective

Trust, security, and privacy are of great importance for the proposed platform. Trust denotes a need in a system for stakeholders, actors, and entities to build relationships with each other, aiming to enable access to each other's data and resources. While doing so, access needs to be controlled and allowed only if all parties agree on the intended actions in the system. Security elements of the system are responsible for implementing access control in a way suitable for the system's scale and performance. The security elements also provide basic mechanisms for privacy provisioning in accordance with EU privacy regulations.

The trust, security and privacy (TS&P) provides a set of basic security services needed in the IDOP system. Entities in the system need to be properly authenticated, authorizations of the entities clearly defined and resulting policies decisively enforced. Communication between the entities needs to provide data integrity, authentication and confidentiality services. Non-repudiation of actions taken in the system should be provided. The DevSecOps module provides supporting services for secure deployment of the services and their operation but does not provide the basic security and privacy services for the end user. The cooperation between both sets of services is needed to deploy the TSP services securely. The DevSecOps can play a crucial role in trust and security bootstrap and provide means to distribute needed system entities credentials and basic policies in the IDOP system.

According to the functional view of the IDOP based system architecture, see Figure 4, the interface between the Aggregator and Customer Energy Manager (CEM) is the major interface in the system. The interface is planned to be compliant with the IEC 62746-4 standard (IEC, 2024). Besides the major interface there are important two additional interfaces: The interfaces between CEM and Resource Managers (RM) and between End User Interface and CEM and RMs. The interface between the CEM and RM follows recent EN 50491-12-2:2022 standard (CENELEC, 2022). No specific standards have been considered for interfaces between the EUI and the CEM and RMs.

Neither IEC 62746-4 nor EN 50491-12-2:2022 specifies any explicit TS&P requirements or normative references the standards should comply to. The IEC standard is part of a broader family of IEC 62756 standards that includes standards on use cases IEC TR 62746-2:2015 and IEC TS 62746-3:2015 on architecture (IEC, 2015). The architecture document lists some of the security requirements that are important for the implementation of the IEC 62746-4 standards as well:

- to avoid inbound connections and related security problems the architecture introduces a communication server the clients (VEN - Virtual End Node in the IEC 62746-4 nomenclature) connect through to the aggregator (VTN - Virtual Top Node),
- role based access control should be provided to manage privileges to access and manage the resources,

- the communication between the clients and the server should be secured, mutual authentication should be supported and non-repudiation should be provided,
- the communication server is a trusted entity for both clients and the server. Security services provisioning should take into account implications of key management for selected transport specific mapping (e.g. TLS, MQTT, etc.),
- the security burden on the client and server should be minimal though both, the client and the server need to provide security measures aligned with the devices with online Internet connection.

The EN 50491-12-2:2022 standard provides no information on how to handle TS&P issues related to the standard implementation. If the RMs are not integral part of the CEM process or if the entities communicate through open communication channels, like communication server mentioned beforehand, TS&P services need to be provisioned for the CEM and related RMs. The relationship between the entities, the CEM and RMs, needs to be established and managed properly.

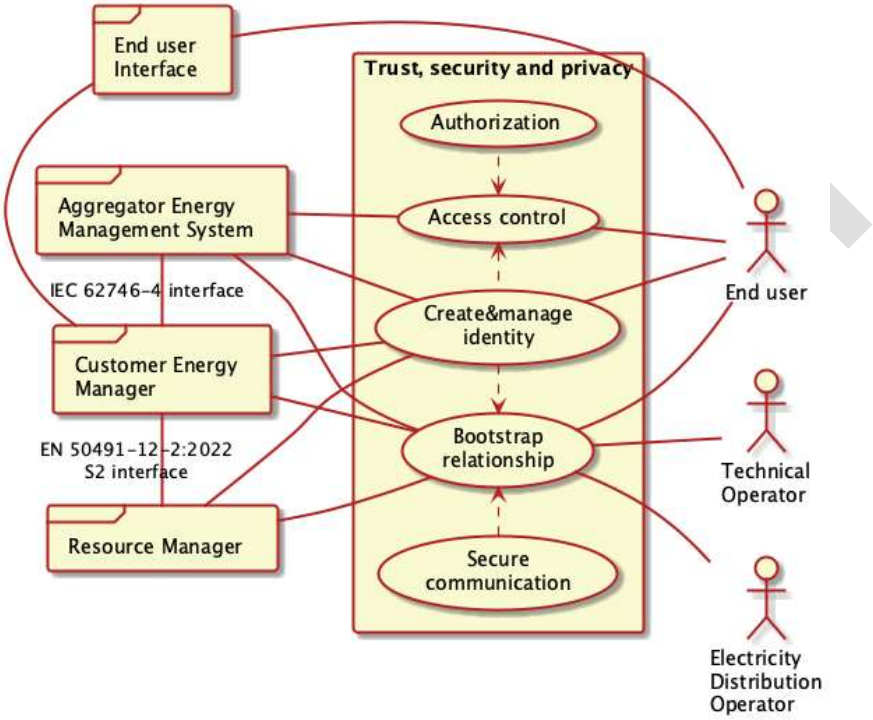


Figure 13: Trust, security and privacy system use case diagram

Figure 13 presents a TS&P system use case diagram. There are 3 actors and 4 system entities denoted in the diagram. The actors are the end user (either a household owner, an industrial plant owner, a building manager, etc.), the Technical Operator (TO) setting up the IDOP system for the end user and the Electricity Distribution Operator (EDO). The system entities are the Aggregator, the Customer Energy Manager, the Resource Manager and the End User Interface. The actor EDO is added to the use case diagram for two, trust establishing reasons. First, the EDO can vouch that somebody has a control over the end user network. For example, the EDO can issue a Digital ownership certificate for the smart meter owner, so everybody can validate if the identity stated in the certificate can manage the network behind the meter referred in the same certificate. Second, the EDO, or any other suitable entity under each particular country's legislation, can vouch by issuing a digital statement that some entity can perform aggregator operations in a particular electrical network or its part. These two digital statements can be used to boost up the use cases foreseen in the use case diagram.

The following TS&P use cases are foreseen for the IDOP system:

1) *Create and manage identities*: this is a central use case, needed for realization of all the other use cases. Each system entity and actor need its own identity to be able to start building relationship with other entities and actors. There is a number of possibilities how to manage identities. A hierarchical approach like X.509 based identity management is suitable for both small and large deployments. Nowadays, an approach oriented towards the end user like Self

Sovereign Identities (SSI) seems to be more practical and user friendly. Whichever approach is chosen each entity and actor should have one or more identities available that can be used in the following use cases;

2) *Bootstrap relationship*: there are a number of relationships that need to be established in a working IDOP system. From already mentioned relationship between the EDO, TO, aggregator and the end user, aggregator and CEMs, CEM and related RMs and End User Interface (EUI) and CEM. Some are purely technical relationships and some involve also the actors. The relationships can be boosted up with a proper distribution of digital statements and certificates as a kind of trust policies between the system entities. The DevSecOps framework can help to build proper and secure distribution of trust anchors so the system can start connecting securely and restrictively right away. Such solutions can be suitable for example for CEM and RMs bootstrap while for aggregator and CEM/end-user connection a simple web-based application can be helpful;

3) *Secure communication*: the identities are a cornerstone for secure communication. They are used to establish a secure, mutually authenticated communication channel. The TLS protocol in the case of X.509 framework or the DIDCOMM in case of SSI are examples of such secure communication channels. The entities can use the channels to exchange information, reach agreements, etc. When used over the communication server like MQTT a trust needs to be placed in the server to transmit the traffic between the entities securely and privately. The point-to-point connections terminate at the server and the information is at the server decrypted and encrypted again;

4) *Authorization*: the authorization is an approval that is granted to system entity to access a system resource. It also denotes a process of granting the approval. The mechanisms for implementing the authorizations are needed. Authorizations can be granted to identities through the system and resources naming design, by implementing role-based access control and by implementing delegation for access through authorization credentials. These mechanisms enable implementation of fine-grained access control. The authorizations should be designed to allow implementation of the principle of least privilege which implies that each system entity is granted the minimum system resources and authorizations that the entity needs to do its work;

5) *Access control*: access control provides both, availability for authorized entities as well the confidentiality service. Only entities allowed to access a certain piece of information are able to read or modify it. A simple implementation of role-based access control is when the identities are roles. In this case the identities are used to access the resources and govern who can change the set-point on HVAC or read the detailed smart meter measurements. The policies can be embedded in the naming of resources, e.g. identities can be parts of topics for communication (MQTT case) or URLs in the case of the REST API. If the access control involves more complex information, contained in the authorization credentials and obtained from the resource call environment, the access control process needs to obtain all the information and validate its integrity before using the information in the process of obtaining access control decision. The access control needs to provide an enforcement layer where the authorization and system policies are properly enforced.

DRAFT

6 System use cases

This section summarises the system use cases used to support and validate the IDOP-based system architecture. The detailed system use case descriptions are provided in Annex A (section 10.1), Annex B (section 10.2) and Annex C (10.3). The main text focuses on the architectural role of the system use cases and on the interactions between the relevant IDOP components, while the annexes provide the detailed step-by-step descriptions.

6.1 Demand-side flexibility aggregation for energy wholesale markets

This system use case focuses on exploiting the demand-flexibility provided by the CEMS in the energy wholesale markets. Figure 14 illustrates an example interaction between functional components in the given system use case. The example scenario starts with a price forecast for the day-ahead market provided by the Market Price Forecasting component. The Aggregated Load Management component forwards this message to the Customer Energy Management Systems connected to the Aggregator Energy Management System. The example scenario is simplified so that only two CEMS are depicted. Each CEMS will use the price forecast to optimize their energy consumption. In addition to the price forecast, various factors such as user preferences, power tariffs and coefficient of performance can influence the local optimization performed by CEMS. Please refer to section 6.3 for a detailed description of the local optimization SUC. In addition to the local optimization that produces a baseline load profile, the CEMS also estimates the flexibility and required compensations (i.e., possible deviation from the baseline at different time periods and the costs caused by this). Each CEMS then sends the baseline and flexibility potential offers to the AEMS.

DRAFT

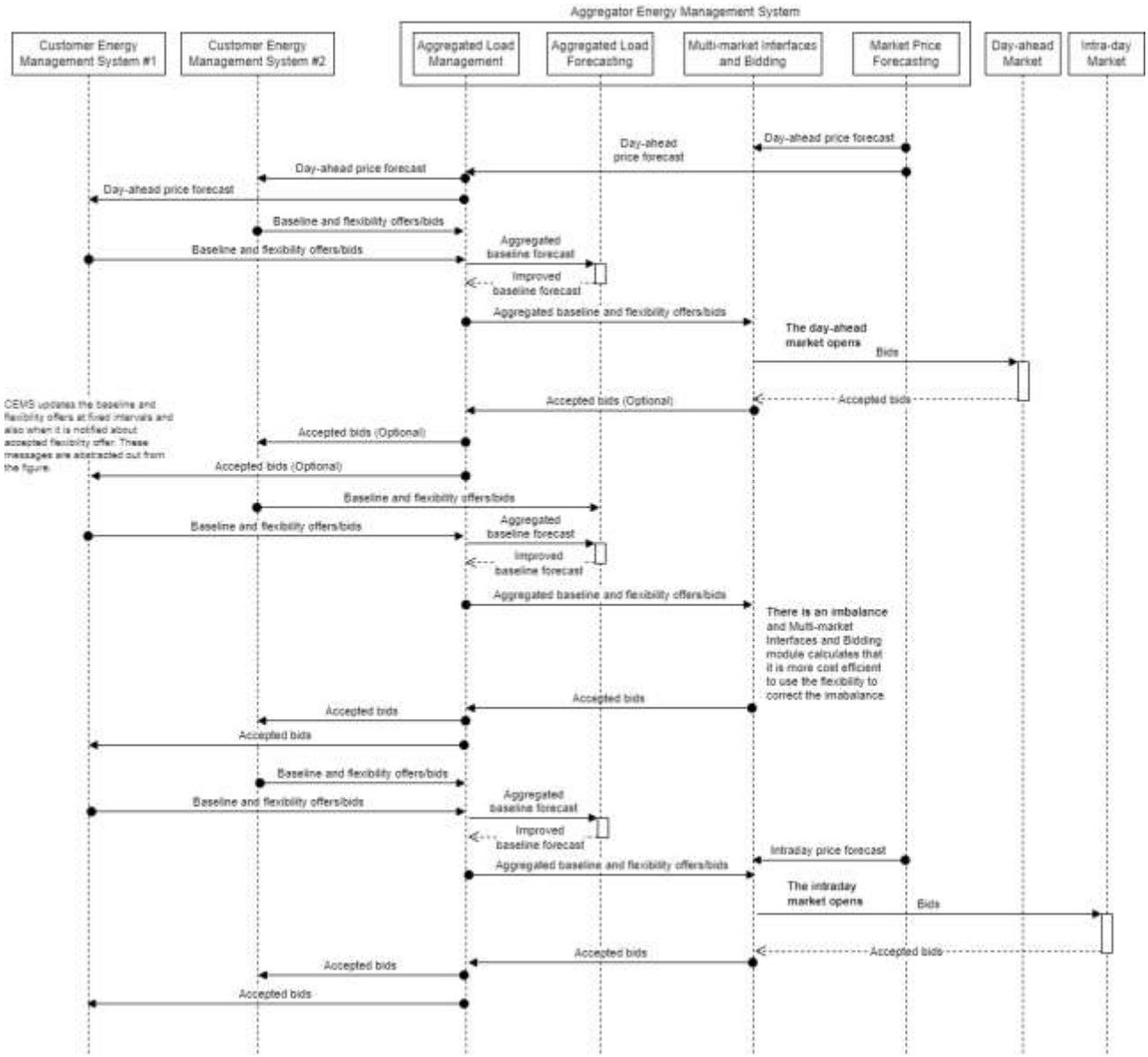


Figure 14: Sequence diagram of demand-side flexibility aggregation for energy wholesale markets.

Inside the AEMS, the Aggregated Load Management component aggregates the individual baselines. Then it passes the aggregated baseline load profile to the Aggregated Load Forecasting component to improve the accuracy of the forecast. The aggregated baseline and flexibility offers are sent to the Multi-Market Interfaces and Bidding module, which procures energy from the day-ahead market based on the aggregated baseline load profile. It should be noted that the scenario describes in this SUC is simplified as we do not perform proper multi-market optimization (if this would be the case the flexibility and price forecast for different markets would need to be considered in the optimization). Once the day-ahead market is cleared, the AEMS will be notified about the accepted bids. In this simplified scenario the price needs to be set so that all bids will be accepted. Therefore, it is not necessary to notify the CEMS about the accepted bids (i.e., CEMS can assume that they can follow the locally optimized baseline).

There are always some errors in the baseline load forecasts, which means that the energy acquired from the day-ahead market does not match with the actual consumption. This causes some costs to the aggregator (and eventually to the consumer). To this end, the CEMS will update their baseline (and flexibility offers) at fixed intervals (and when notified about accepted bids). Again, this data is first aggregated and then sent to the Multi-market Interfaces and Bidding module. Forecasts typically become more accurate as the time of energy usage approaches. Leveraging this improved accuracy, the aggregator estimates potential imbalances throughout the day and utilizes flexibility to correct them when it reduces overall costs—specifically, if flexibility offers from CEMS are cheaper than imbalance

costs. In this case the Multi-market Interfaces and Bidding module accepts the bids from the Aggregated Load Management module to shift energy demand so that imbalances are reduced. The Aggregated Load Management component then disaggregates the flexibility bid (based on the latest CEMS-level flexibility offers) and informs the CEMS about the accepted flexibility offers. After received notification about an accepted bid each CEMS will reoptimize the baseline and flexibility while making sure that the flexibility offered can be provided. The AEMS is then notified about the updated baseline and flexibility offers. There can be several iterations where the AEMS accepts flexibility offers and informs the CEMS about them if required to reach more optimal balance.

The final phase of the SUC focuses on using the flexibility to reduce costs by trading in the intra-day market. Similarly to the day-ahead market phase, this phase is initiated with the intra-day market price forecast. This time the information is only used by the Multi-market Interfaces and Bidding component to make bids and offers to the intra-day market. In addition to the market price forecast, the Multi-market Interface and Bidding component will utilize the latest flexibility offer data from the Aggregated Load Management component in the bidding process. After the Multi-market Interface and Bidding module has received a notification of the accepted bids and offers, it will notify the Aggregated Load Management module about the bids and offers. Similarly to the other scenarios, the Aggregated Load Management module will disaggregate the accepted bids and send individual accepted bid notification for each CEMS.

6.2 Demand-side flexibility aggregation for TSO reserve markets

This system use case, illustrated in Figure 15 below, focuses on aggregating demand-flexibility from CEMS for participation in TSO reserve markets (FCR-D, FCR-N, aFRR, mFRR). After the pre-study where the asset (e.g., heat pumps, batteries, or combinations) demonstrates capability for the specific reserve product we move to the pre-qualification, where the asset must demonstrate their technical capability to meet specific reserve product requirements like response time, duration, and accuracy. The AEMS maintains a registry of pre-qualified resources and their verified capabilities through the Customer Information System, establishing the maximum volume that can be bid into each reserve market.

The operational interaction between functional components starts with parallel forecasting streams:

- The Market Price Forecasting component provides price forecasts for the reserve products, considering historical clearing prices and market conditions.
- Within each CEMS:
    - The Resource Manager's Neural ODE models assess the asset's current state and dynamic response capabilities.
    - The Resource Manager predicts baseline consumption and available symmetric/asymmetric flexibility.
    - The Customer Energy Manager determines reserve capacity offers while ensuring operational constraints and user comfort requirements are maintained.

Each CEMS then sends its baseline and reserve capacity offers to the AEMS. The Aggregated Load Management component combines these individual offers with the validated customer data from the Customer Information System, ensuring that only prequalified resources are included in the aggregated portfolio. This combined data is used by the Aggregated Load Forecasting component to produce aggregated capacity forecasts at the portfolio level. The Multi-Market Interfaces & Bidding module uses these forecasts along with market price data to formulate reserve capacity bids that meet TSO product requirements.

DRAFT

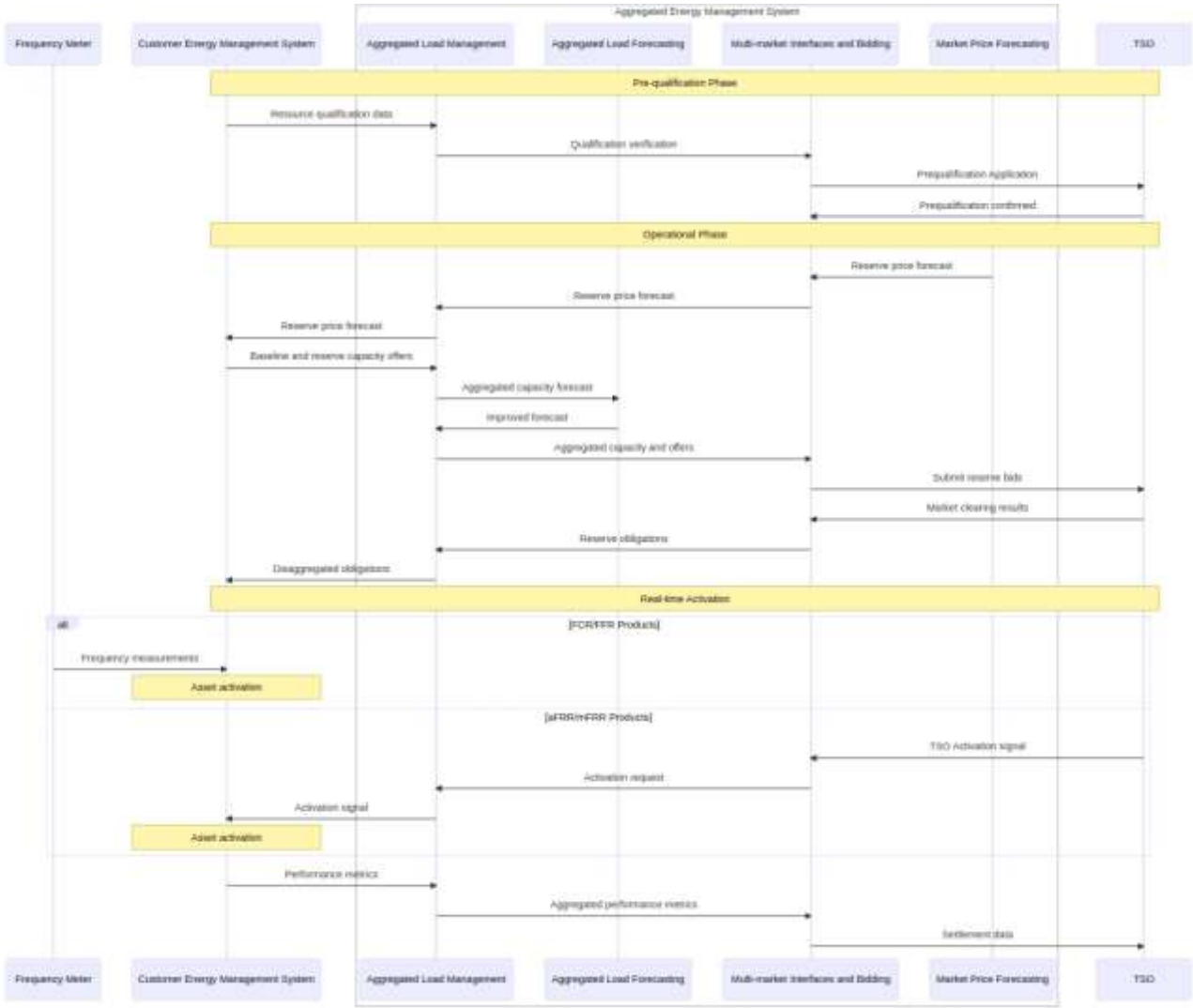


Figure 15: Sequence diagram of demand-side flexibility aggregation for TSO reserve markets.

When market clearing results are received, the reserve obligations flow through the Aggregated Load Management component to individual CEMS.

Delivery Period Management:

1. The Performance Service tracks activation performance based on:
    a. Frequency response (FCR, FFR) or,
    b. Activation signals (aFRR, mFRR) against TSO requirements.
2. Resource Managers monitor asset state and readiness for activation.
3. Updated reserve capacity and availability status flow through the system.
4. Aggregated Load Management maintains real-time view of available reserve capacity.
5. Multi-Market Interfaces & Bidding handles capacity adjustments if needed.

For real-time activation:

1. The Multi-Market Interfaces & Bidding component receives:
    a. Frequency deviation signals (FCR, FFR) from local frequency meters or,
    b. Activation signals from the TSO (aFRR, mFRR).
2. Activation signals flow through Aggregated Load Management to Customer Energy Managers.
3. Resource Managers execute asset/system response through their controllers.
4. The Performance Service component monitors response time and accuracy.
5. Settlement data flows through the system for verification and compensation based on reserve product performance metrics.

6.3 Local flexibility management

The local flexibility management system use case covers how individual end users manage their flexibility with the resources at their disposal. The end users can be households, apartment buildings, industrial plants and facilities, public buildings, retail establishments, etc. The SUC assumes that the end user resources are managed through a Customer Energy Management (CEM) system and each particular end user case can have multiple Resource Managers (RM) at their disposal, like HVAC RM, PV RM, Battery RM, etc. End users manage their resources to leverage flexibility for various goals, such as reducing costs, energy usage, CO2 emissions, and improving resource efficiency.

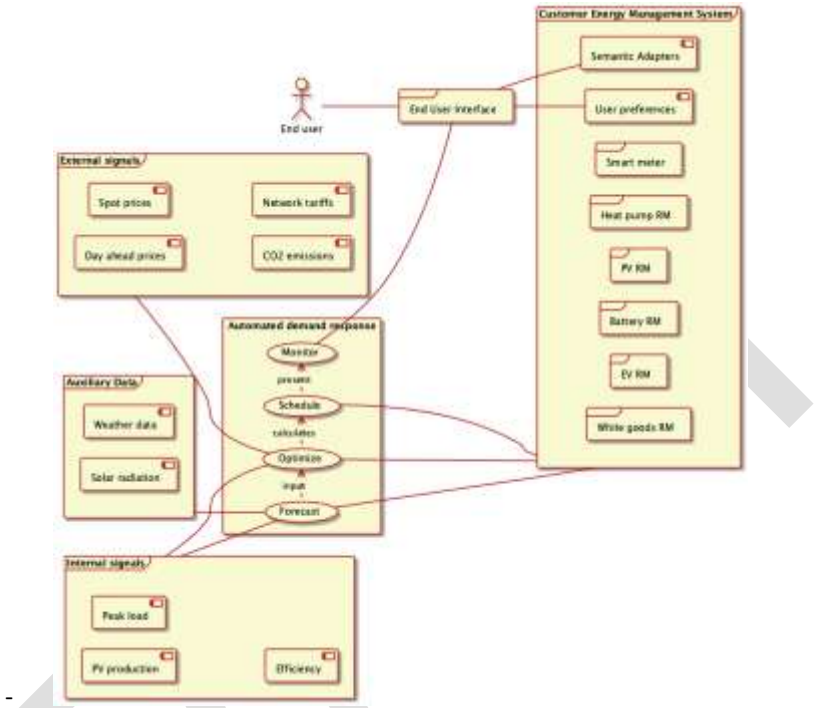


Figure 16: Local flexibility use case diagram

The use case diagram in Figure 16 presents essential elements of the use case and basic steps performed during use case execution. The end user accesses information about the system through the End-user Interface (EUI). The EUI is used to set the end user preferences and to monitor the system performance. The CEM encapsulates the RMs available at the end user premises and the smart meter (SM). Semantic adapters are used to enable unified access of the RMs to the Resources and for coherent EUI access to the monitoring data. The execution of the use case is guided by external or internal signals. The external signals can be, for example, day ahead prices, spot prices, CO2 emissions or network tariffs. As the internal signals a PV production at the premises, load profile with its peak load, or an efficiency of certain resources. Auxiliary data such as weather or solar irradiation is needed for the use case implementation.

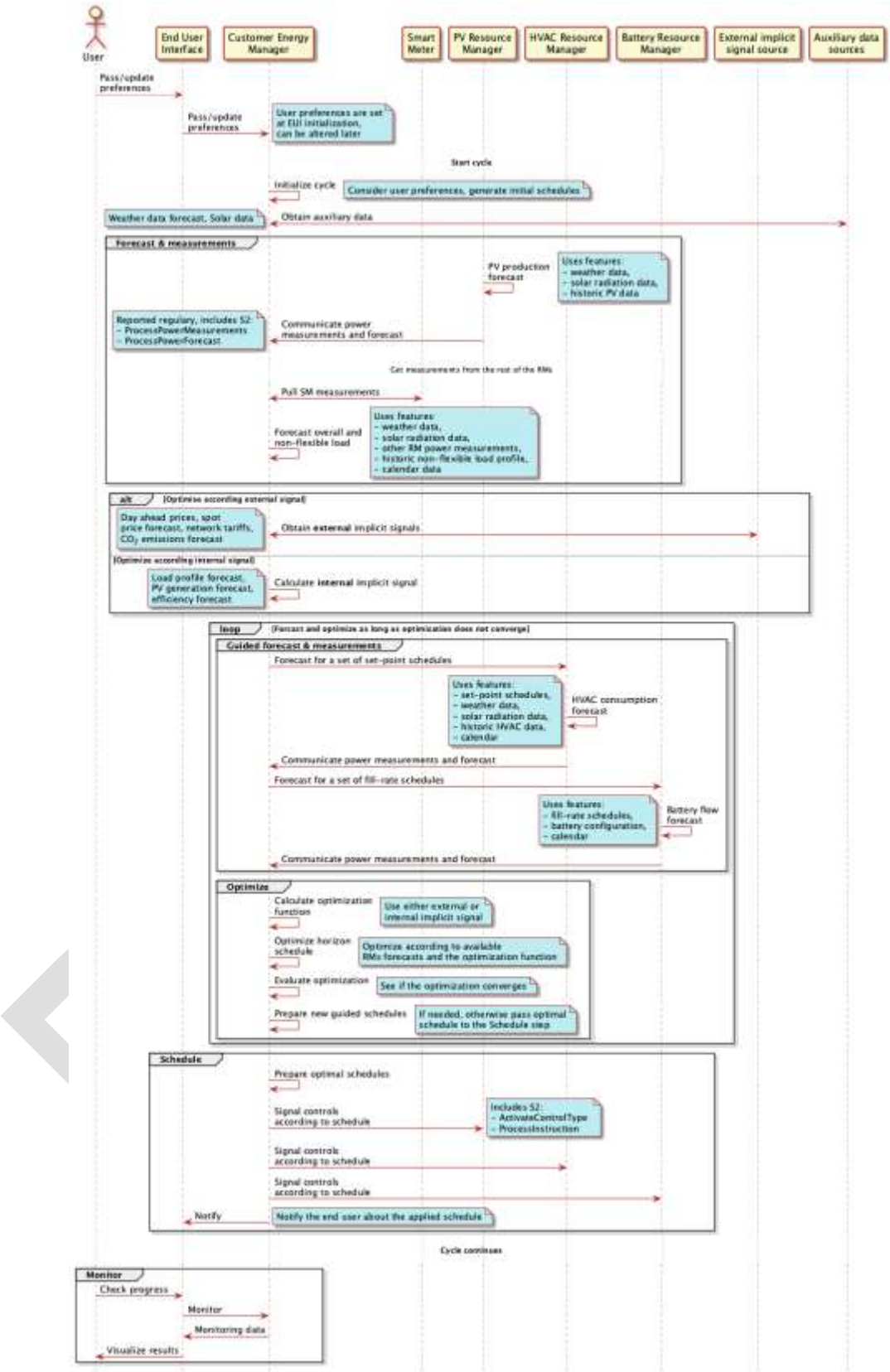


Figure 17: Local flexibility management use case sequence diagram

The basic steps of the use case are forecast, optimize, schedule and monitor. In the forecast step the internal signals employed in the use case are forecasted for foreseen time horizon. Most of the external signals, if employed, also need a forecast for the time horizon. We assume that external services are available that can provide suitable predictions for the use case needs. Similar assumption is held for

the auxiliary data. The forecasts for the individual RMs consumption in the horizon is provided by the RMs themselves. The forecast for the non-flexible loads is provided by the CEM based on smart meter measurements.

In the optimization step, based on end user goal, a selected signal is transformed into an optimization function. The optimization process, based on the function and individual RMs forecast calculates an optimal schedule for the RMs in the next time horizon. In the next step a schedule is prepared and communicated by the CEM to the RMs. The end user in notified about the schedule and can monitor its execution through the end user interface.

The details of the use case are presented in the use case sequence diagram in Figure 17. The diagram is split in three parts. In the first part the end user uses EUI to set its preferences regarding the system managed. The preferences are initialized at the EUI initialization and can be altered later. The preferences define the specific goal(s) of the end user as well operating conditions and limitations of the CEM and related RMs. In the second part is an operation cycle which can be triggered every hour or every 15 minutes. In the cycle the CEM calculates the optimal schedule for the next time horizon. The time horizon depends on horizon settings and available forecast needed for calculation. A typical time horizon is a day. The third part is monitoring of the progress of the operation of the system that is available for the end user at any time.

The management cycle begins with initialization, where the current user preferences are taken into account. Initial set of schedules for the controllable RMs are prepared. The schedules should adequately cover the controllable space of the RMs and the time horizon for initial optimization. The weather and solar irradiation data are obtained from auxiliary data sources.

The forecast and measurement part covers obtaining the measurements and next time horizon load and generation forecast from all the RMs the CEM controls. As an example, a Photo Voltaic (PV) RM case is presented in the diagram. The rest of the RMs follow the same pattern. The load and generation forecast are calculated by the particular RM. The communication of the RMs follows the S2 standard (CENELEC, 2022), the measurements and the forecasts are sent regularly to the CEM. The CEM calculates overall and non-flexible loads forecast based on the measurements pulled from the smart meter and the measurements sent by the RMs.

In the next step either external signal is obtained or internal signal calculated. The external signal forecasts are obtained from External implicit signal sources. In the case of day ahead prices, forecasted spot prices or network tariffs the system would aspire to minimize cost of energy consumed. The flexible loads consumption should be shifted to the periods when the costs are lower. The internal implicit signals are calculated from the forecasted smart meter or PV RM data. In the case of the smart meter forecast the system would, for example, shift the flexible loads consumption with an aim to lower the overall peak of the consumption. When the PV generation is used as the implicit signal the flexible loads should be shifted towards the times of high generation to optimize for self-consumption.

The next two steps, the controllable RMs forecast and optimization are performed in a loop. The loop continues until the evaluation of the optimization results is positive. The loop can be time limited. If the results of the evaluation are not satisfactory, the default schedule is used as a fallback for the cycle.

For the set of controllable RMs the schedules, prepared in the initialization step of the cycle, are used to get forecasts from each individual RM. In the diagram examples of features used for preparing the forecast are listed. The RMs return a set of load profiles forecasts associated with each input schedule together with the past measurements.

In the optimization step, an optimization function is created based on the user's goal(s) and the implicit signal. The optimization process uses the forecasted RM load profiles along with the optimization function to determine the optimal schedules for the RMs. The optimization is evaluated. If positive, the schedules are passed to the scheduling step otherwise new set of guided schedules are prepared for the next Guided forecast and optimization loop.

Based on the optimized schedules the CEM prepares the schedules for the RMs. The schedules are communicated to the RMs according to the S2 standard (CENELEC, 2022). The end user is notified through the EUI about the applied schedules.

DRAFT

7 Conclusion

This document describes the work done in three WP2 tasks: use cases and requirements engineering, common architecture of the IDOP based system, and trust, security, and privacy design for the IDOP based architecture.

The document provides the following:

- Business use cases and requirements engineering: The use cases emerged from large-scale pilots of four countries and are described from the business viewpoint. The use case analysis ended up with a set of common requirements associated to CEMS, AEMS, and DevSecOps & Investment Support Packages.
- Common architecture of the IDOP based system: The architecture of the IDOP consists of three main packages: CEMS, AEMS, and DevSecOps & Investment Support Package. The architecture design was an iterative process, following the relevant standards, such as ISO/IEC/IEEE 42010:2011 standard. The architecture of an IDOP based system is described from the context, functional, information and deployment viewpoints. The architecture was refined further with four system use cases that enabled to identify more detailed functionalities for the components.
- Trust, security and privacy design: The TS&P were addressed holistically from the start. Multiple TS&P dimensions were explored from the use cases, including trust and identity management, secure communication between components and entities, secure and privacy aware data spaces provisioning, and implementation and operations oriented DevSecOps. The trust, security, and privacy requirements for the INDEPENDENT Platform were outlined as a result.

DRAFT

8 List of figures and tables

8.1 Figures

Figure 1: Overview of the Integrated Development and Operations Platform. 27
Figure 2: IDOP based system. 29
Figure 3: Context view of an IDOP based system. 30
Figure 4: Functional view of the IDOP based system architecture. 33
Figure 5. Data model of the MarketDERBidOffer message. 36
Figure 6. Data model for the MarketDERInstruction message. 37
Figure 7: Message exchange between a Resource Manager and the CEM over the S2 interface. 38
Figure 8: Common S2 information objects exchanged between Resource Manager and CEM. 39
Figure 9: S2 PEBC information model for flexibility description and control instruction. 40
Figure 10: S2 FRBC information model for a storage-oriented resource. 41
Figure 11. SAREF-aligned data model for the Semantic Adapter Interface. The model uses SAREF concepts for resources, devices, sensors, actuators, properties, measurements, states and commands, and extends them with IDOP-specific objects for forecasts, capabilities, constraints, control endpoints and mapping metadata. 43
Figure 12: Deployment view of an IDOP based system. 45
Figure 13: Trust, security and privacy system use case diagram 47
Figure 14: Sequence diagram of demand-side flexibility aggregation for energy wholesale markets. 50
Figure 15: Sequence diagram of demand-side flexibility aggregation for TSO reserve markets. 52
Figure 16: Local flexibility use case diagram 53
Figure 17: Local flexibility management use case sequence diagram 54

8.2 Tables

Table 1: Business use case 1 of the German pilot. 11
Table 2: Business use case 2 of the German pilot. 12
Table 3: Business use case 3 of the German pilot 13
Table 4: Business use case 1 of the Finnish pilot. 14
Table 5: Business use case 2 of the Finnish pilot. 14
Table 6: Business use case 3 of the Finnish pilot. 15
Table 7: Business use case 1 of the Swedish pilot. 16
Table 8: Business use case 2 of the Swedish pilot. 17
Table 9: Business use case 3 of the Swedish pilot. 17
Table 10: Business use case 1 of the Slovenian pilot 18
Table 11: Business use case 2 of the Slovenian pilot 19
Table 12: Business use case 3 of the Slovenian pilot 19
Table 13: Requirements for Customer Energy Management Systems Package. 21
Table 14: Requirements for Aggregator Energy Management Systems. 21
Table 15: Requirements for investment planning support. 22
Table 16: Cross-cutting platform quality requirements. 22
Table 17: General TS&P IDOP design requirements 23
Table 18: Trust Requirements 23
Table 19: Security Requirements 24
Table 20: Privacy Requirements 25
Table 21: Interoperability requirements. 26
Table 22: Description of elements of the context view. 30
Table 23: Functional components of Aggregator Energy Management System. 34
Table 24: Functional component of Customer Energy Management System. 34

DRAFT

9 References

CEN-CENELEC. (2022). EN 50491-12-2. In *Smart grid - application specification - Interface and framework for customer - Interface between the Home/Building CEM and Resource manager(s) - Data model and messaging.* European Standard (EN): CEN-CENELEC.

CENELEC. (2018). EN 50491-12-1 - General requirements for Home and Building Electronic Systems (HBES) and Building Automation and Control Systems (BACS) - Smart grid - Application specification - Interface and framework for customer - Part 12-1: Interface between the CEM and Home/Building Resource manager - General Requirements and Architecture. 23.

CENELEC. (2022). *EN 50491-12-2: Part 12-2: Smart grid - application specification - Interface and framework for customer - Interface between the Home/Building CEM and Resource manager(s) - Data model and messaging*.

IEC. (2024). IEC 62746-4: Systems interface between customer energy management system and the power management system – Part 4: Demand Side Resource Interface. In (pp. 153): IEC.

IEC TS 62746-3-2015: System interface between customer energy management system and the power management system - Part 3: Architecture. (2015).

ISO/IEC/IEEE 42010:2011 - Systems and software engineering - Architecture description. (2011).

DRAFT

10 Appendices

10.1 Appendix A — SUC-WMA: Demand-side Flexibility Aggregation for Energy Wholesale Markets

Companion to INDEPENDENT D2.3 — Final Requirements and IDOP Architecture. Authored per IEC 62559-2 use case template [1]. Formal specification of the Demand-side flexibility aggregation for energy wholesale markets* system use case introduced in D2.1 D2.3 Section 5.1 and D2.3 Section 6.1 [2].*

10.1.1 Description of the use case

10.1.1.1 Name of use case

Name of the use case: SUC-WMA: Demand-side flexibility aggregation for energy wholesale markets

Area / Domain(s) / Zone(s): Energy Systems / Aggregator / Markets — Wholesale

10.1.1.2 Version management

Version	Date	Author(s)	Changes	Approval status
0.1	2026-08-26	Jožef Stefan Institute (IJS) for the INDEPENDENT consortium	Initial IEC 62559-2 formalisation of the D2.1/D2.3 Section 6.1 system use case.	Draft

10.1.1.3 Scope and objectives of use case

Scope: Aggregation of demand-side flexibility from a portfolio of Customer Energy Management Systems (CEMS) [3] by an Aggregator Energy Management System (AEMS) for participation in wholesale electricity markets — specifically the day-ahead (DA) and intra-day (ID) markets [4]. Each CEMS in the portfolio produces its baseline load profile and flexibility offers through its own local optimisation cycle; the AEMS aggregates these across the portfolio and bids into the markets on the aggregator's behalf. The CEMS ↔ AEMS interface follows IEC 62746-4 [5]; market-side exchanges are aligned with the IEC 62325 series [6].

Objective(s):

- **O1** — Monetise portfolio demand flexibility in the day-ahead energy market.
- **O2** — Reduce imbalance costs by activating cheaper CEMS flex offers when they are less expensive than the imbalance-settlement price.
- **O3** — Extract additional value in the intra-day market when refined forecasts reveal opportunities.
- **O4** — Provide a standards-conformant substrate (IEC 62746-4 [5] for CEMS ↔ AEMS; IEC 62325 [6] for market-facing exchanges) so that country- and market-specific specialisations (Nord Pool, EPEX, BSP SouthPool, …) are additive.

Related business case(s): Demand-side flexibility aggregation for energy wholesale markets as a system use case in INDEPENDENT D2.1 Section 5.1 [2] and D2.3 Section 6.1.

10.1.1.4 Narrative of use case

Short description:

An Aggregator Energy Management System aggregates demand-side flexibility from a portfolio of Customer Energy Management Systems and monetises it in wholesale energy markets. Each CEMS runs its own local optimisation (as specified in SUC-LFM's underlying pattern; see D2.3 Section 6.3) to

DRAFT

produce a baseline load profile and a set of flexibility offers. The AEMS collects these, aggregates them, and bids into the day-ahead market. During the delivery horizon it iteratively refines its baseline as forecasts improve, activating CEMS flex offers when they are cheaper than imbalance costs, and finally uses the remaining flexibility for intra-day trading. Interfaces between the AEMS and each CEMS follow IEC 62746-4 [5]; market-facing exchanges are aligned with IEC 62325 [6]; the underlying CEMS optimisation follows EN 50491-12-1 / -12-2 [3], [7].

Complete description:

The use case has three phases.

Day-ahead procurement. The Market Price Forecasting component emits a day-ahead price forecast. Aggregated Load Management (ALM) forwards this to each CEMS in the portfolio. Each CEMS uses the forecast in its own local optimisation (SUC-LFM pattern) to produce a baseline load profile and a set of flexibility offers (deviations from that baseline priced with the compensation the CEMS would need to accept them). Additional inputs to the CEMS-side optimisation include user preferences, power tariffs and the coefficient of performance of any thermal resource. CEMSs return baselines + flex offers to the AEMS; ALM aggregates baselines across the portfolio; Aggregated Load Forecasting (ALF) refines the aggregated baseline hierarchically. Multi-Market Interfaces and Bidding (MMIB) uses the aggregated baseline to procure energy from the day-ahead market. In the simplified scenario captured here, prices are set so that all bids clear and no per-CEMS notification is needed — CEMS proceed with their locally optimised baselines.

Baseline update and imbalance correction. Forecasts drift; the energy procured from the day-ahead market therefore does not exactly match delivered consumption. Imbalances cost the aggregator (and, downstream, the consumer). To limit this, CEMS emit updated baselines and updated flexibility offers at fixed intervals during the delivery horizon. ALM aggregates the updates; MMIB estimates residual imbalance. When flexibility is cheaper than imbalance settlement, MMIB accepts the aggregated flex bid; ALM disaggregates the bid using the latest CEMS-level flex offers and notifies the affected CEMS; each notified CEMS re-optimises and confirms deliverability; the loop repeats as forecasts continue to sharpen. This iterative refinement can run several rounds per delivery horizon.

Intra-day trading. An intra-day price forecast arrives; MMIB uses the latest flexibility offers from ALM to bid into the intra-day market. When bids clear, MMIB notifies ALM; ALM disaggregates the accepted bids and forwards per-CEMS acceptance notifications.

The AEMS-side split of responsibilities matches the CEMS ↔ AEMS architectural intent of IEC TS 62746-3 [8] and the profile of IEC 62746-4 [5]: MMIB owns market-facing bidding; ALM owns the portfolio-facing aggregation and disaggregation; ALF handles hierarchical forecast improvement; MPF is the price-forecast input. This use case does not commit to a specific optimisation algorithm inside MMIB — the concrete multi-market bidding model is a specialisation property of country- and market-specific child SUCs.

10.1.1.5 Key performance indicators (KPI)

ID	Name	Description	Refers to objectives
WMA_KPI_O1_da_value	Day-ahead procurement value	Net value of DA procurement across the portfolio horizon vs. a benchmark (flat / static procurement without CEMS baseline forecasts).	O1
WMA_KPI_O2_imb_reduction	Imbalance cost reduction	Reduction in imbalance settlement cost vs. a benchmark that does not activate CEMS flex offers during the delivery horizon.	O2
WMA_KPI_O3_id_value	Intra-day trading value	Net value captured in the ID market by trading against refined portfolio flexibility.	O3
WMA_KPI_O4_interop	Standards conformance	Share of CEMS ↔ AEMS transactions completing successfully under the IEC	O4

DRAFT

ID	Name	Description	Refers to objectives
		62746-4 profile [5] without out-of-band escalation.	

10.1.1.6 Use case conditions

Assumptions:

- Each CEMS in the portfolio can compute a **baseline load profile** and a set of **flexibility offers** (deviations priced with required compensation) as required by D2.1 Table 12 requirements CR3 and CR4 [2].
- The AEMS operates a functional decomposition into ALM, ALF, MMIB, MPF and Customer Information Systems modules per D2.1 Section 4.2.1 [2].
- Day-ahead and intra-day market gate-closure times are known and CEMS baseline / flex updates are cadenced to precede them.
- CEMS ↔ AEMS interoperability follows the IEC 62746-4 profile [5] for Customer Energy Manager ↔ Aggregator Energy Management System exchanges.

Prerequisites:

- Aggregator has market membership for the relevant DA and (where used) ID market venues.
- CEMS-side prerequisites for local flexibility production apply (see D2.3 Section 6.3): the CEMS is installed, RMs are commissioned, user preferences are configured.
- The AEMS and each CEMS share a secured communication substrate with mutual authentication.

10.1.1.7 Further information to the use case for classification/mapping

Relation to other use cases:

- **Parent context:** *Demand-side flexibility aggregation for energy wholesale markets* as introduced in D2.1 Section 5.1 [2] and D2.3 Section 6.1.
- **Uses:** the CEMS-side local flexibility management pattern of D2.3 Section 6.3 as an underlying sub-use-case — each CEMS in the portfolio produces its baseline and flex offers through that pattern.
- **Envisaged specialisations (child SUCs):** enumerated in Section 10.1.8.3.

Level of depth: System use case (SUC) — the generic wholesale-market aggregation layer that specialises into country- and market-specific child SUCs.

Prioritisation: High — the primary revenue path for demand-side aggregators in the internal electricity market.

Applicability: Any market area covered by the ENTSO-E CACM guideline [4]; illustrated at parent-SUC level, specialised per market venue in future child SUCs.

Nature of the use case: Technical and business — captures the aggregator-side control and communication flows, monetised via wholesale markets.

Further keywords for classification: Demand-side flexibility, aggregation, wholesale market, day-ahead, intra-day, imbalance, Aggregator Energy Management System, Customer Energy Management System, IEC 62746-4, IEC 62325.

10.1.1.8 General remarks

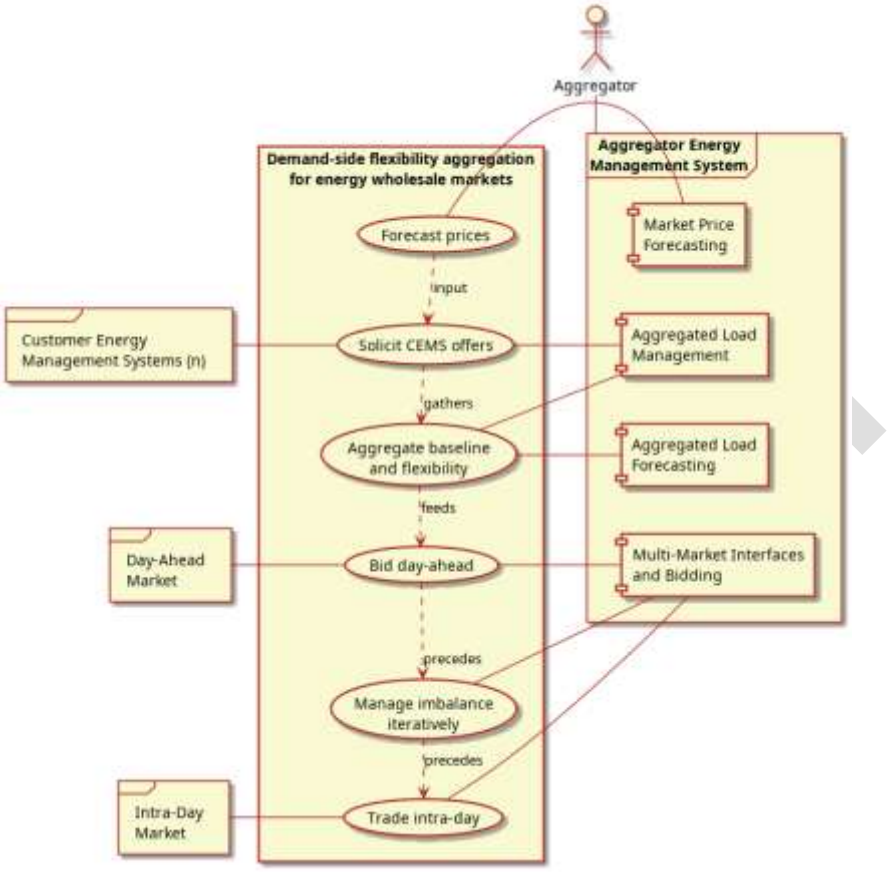
Country- and market-specific parameters (gate-closure times, bid granularity, minimum bid size, imbalance-settlement algebra) are properties of the market venue and are specialised in child SUCs (see Section 10.1.8.3). The parent SUC intentionally omits them so that the flow captured here transfers unchanged across market areas.

DRAFT

10.1.2 Diagrams of use case

10.1.2.1 Use Case Diagram

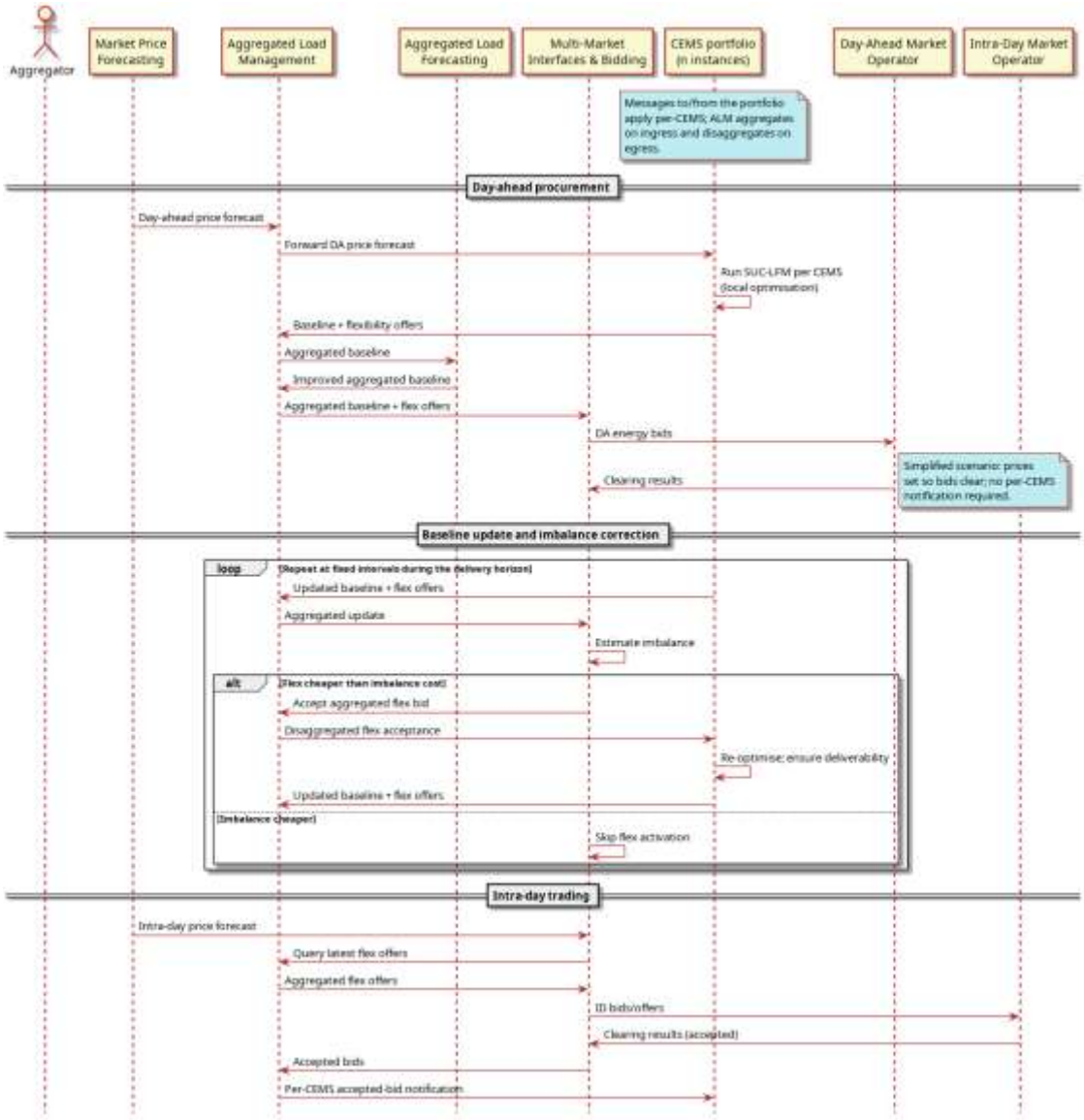
The actors and system boundary of SUC-WMA are shown below. The AEMS encapsulates the four functional components involved (ALM, ALF, MMIB, MPF); the CEMS portfolio is a single frame representing the *n* Customer Energy Management Systems participating in the aggregated portfolio; the two external market venues are drawn as separate frames.



SUC-WMA use case diagram. Adapted from the functional-component narrative in INDEPENDENT D2.1 Section 5.1 [2].

10.1.2.2 Sequence Diagram

The diagram below shows one full application of SUC-WMA covering the three phases delineated by == markers: *day-ahead procurement*, *baseline update and imbalance correction* (with an inner `loop` for iterative refinement), and *intra-day trading*. The `CEMS portfolio (n instances)` lifeline aggregates the per-CEMS interactions; a legend at the top of the diagram makes this compression explicit. The cyclic interactions are labelled by phase and match the phases in the Steps of the scenario table in Section 10.1.4.2.



SUC-WMA sequence diagram covering the three phases: day-ahead procurement, iterative baseline update and imbalance correction, and intra-day trading. Adapted from INDEPENDENT D2.1 Section 5.1 [2].

10.1.3 Technical details

10.1.3.1 Actors

Actor name	Actor type	Actor description
Aggregator	Business actor	Operator of the AEMS; participates in wholesale markets on behalf of the aggregated CEMS portfolio and passes value back to CEMS operators / end users through the contractual relationship.
Market Price Forecasting (MPF)	System	AEMS internal component that produces day-ahead and intra-day price forecasts, considering historical clearing prices and market conditions.
Aggregated Load Management (ALM)	System	AEMS internal component that aggregates CEMS-level baselines and flexibility offers on ingress and disaggregates accepted bids on egress. Implements the Operator Role of the CEMS interface as defined in IEC 62746-4 [5].

Actor name	Actor type	Actor description
Aggregated Load Forecasting (ALF)	System	AEMS internal component that provides hierarchical forecasting to refine aggregated forecasts by learning from residuals of CEMS-level forecasts.
Multi-Market Interfaces and Bidding (MMIB)	System	AEMS internal component that owns market-facing bidding for day-ahead and intra-day markets, estimates imbalance during the delivery horizon, and decides when to activate CEMS flex offers.
CEMS portfolio	System (n instances)	The n Customer Energy Management Systems that participate in the aggregated portfolio. Each CEMS produces its own baseline and flexibility offers through its own local optimisation cycle (D2.3 Section 6.3 pattern).
Day-Ahead Market Operator	System	External market venue for day-ahead energy products (nominal example: Nord Pool, EPEX SPOT, BSP SouthPool — specialised in child SUCs).
Intra-Day Market Operator	System	External market venue for continuous intra-day energy trading.

10.1.3.2 References

References cited throughout this Appendix are listed in the IEEE-style **Section 10.1.9 Bibliography** at the end of the document. The principal normative sources are the CEMS ↔ AEMS interface profile [5] and its enclosing architecture [8]; the market-side communication framework [6]; the EU capacity-allocation and congestion-management guideline that governs day-ahead and intra-day market design [4]; the use case methodology under which this Appendix is authored [1]; and the customer-side energy-management architecture that underpins each CEMS [3] and its flexibility-interface standard [7]. Project context and requirements sourcing come from INDEPENDENT D2.1 [2] and D2.3.

10.1.4 Step by step analysis of use case

10.1.4.1 Scenario: Aggregated wholesale-market participation over one delivery horizon

Field	Value
Scenario description	The AEMS aggregates CEMS-level baselines and flexibility across the portfolio and monetises them across the three wholesale-market phases: procurement in the day-ahead market, iterative baseline update and imbalance correction during the delivery horizon, and intra-day trading with the remaining flexibility.
Primary actor	Aggregator Energy Management System (AEMS)
Triggering event	DA gate-approach for the delivery horizon; subsequently, fixed-interval baseline / flex updates from CEMS during the delivery horizon; ID price-forecast update.
Pre-condition	All CEMS in the portfolio have completed their local optimisation prerequisites; AEMS has market membership; CEMS ↔ AEMS channel is authenticated.
Postcondition	DA and ID positions are settled; per-CEMS accepted-bid notifications have been dispatched; imbalance costs (if any) are attributed.

10.1.4.2 Steps of the scenario

Step	Phase	Name of process / activity	Description of process / activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (ID)	Requirement R-IDs
1	DA	Forecast DA price	MPF publishes a day-ahead price	Report	MPF	ALM	Inf.1	R-2.1

Step	Phase	Name of process / activity	Description of process / activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (ID)	Requirement R-IDs
			forecast for the delivery horizon.					
2	DA	Forward forecast to CEMS	ALM forwards the DA price forecast to each CEMS in the portfolio.	Send	ALM	CEMS portfolio	Inf.1	R-1.1
3	DA	CEMS local optimisation	Each CEMS runs its own local optimisation (D2.3 Section 6.3 pattern) using the price forecast plus user preferences, tariffs, resource states.	Calculate	CEMS portfolio	CEMS portfolio	—	—
4	DA	Emit baseline + flex offers	Each CEMS emits its baseline load profile and its set of flexibility offers (deviations priced with required compensation).	Report	CEMS portfolio	ALM	Inf.2	R-1.2, R-1.3
5	DA	Aggregate baseline	ALM aggregates CEMS-level baselines into a portfolio-level baseline; ALF refines the aggregation hierarchically.	Calculate	ALM, ALF	ALM	Inf.3	R-1.4
6	DA	Bid DA	MMIB submits DA energy bids	Send	MMIB	DA Market Operator	Inf.4	R-1.5

DRAFT

Step	Phase	Name of process / activity	Description of process / activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (ID)	Requirement R-IDs
			to the DA market.					
7	DA	Receive DA clearing	DA market operator returns clearing results.	Report	DA Market Operator	MMIB	Inf.5	R-2.1
8	Update	Update baseline + flex	Each CEMS re-emits updated baseline and flexibility offers at fixed intervals as forecasts sharpen. Loop.	Report	CEMS portfolio	ALM	Inf.2’	R-1.2, R-1.3, R-2.2
9	Update	Aggregate update	ALM aggregates CEMS updates and forwards to MMIB.	Calculate	ALM	MMIB	Inf.3’	R-1.4
10	Update	Estimate imbalance	MMIB estimates residual imbalance vs. cleared DA position; decides whether flex is cheaper than settlement.	Calculate	MMIB	MMIB	—	R-1.5
11	Update	Accept flex if beneficial	If flex is cheaper, MMIB accepts an aggregated flex bid; ALM disaggregates using latest CEMS flex offers and notifies affected CEMS; each notified CEMS re-optimises and confirms.	Send	MMIB, ALM	CEMS portfolio	Inf.6	R-1.5, R-3.1

DRAFT

Step	Phase	Name of process / activity	Description of process / activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (ID)	Requirement R-IDs
			Loop with step 8 until end of delivery horizon.					
12	ID	Forecast ID price	MPF publishes an intra-day price forecast.	Report	MPF	MMIB	Inf.7	R-2.1
13	ID	Trade ID	MMIB queries the latest aggregated flex offers from ALM and places ID bids/offers.	Send	MMIB	ID Market Operator	Inf.8	R-1.5
14	ID	Notify accepted bids	ID clearing results flow to MMIB → ALM → per-CEMS notifications.	Send	ID Market Operator, ALM	CEMS portfolio	Inf.9	R-1.5, R-3.1

10.1.5 Information exchanged

10.1.5.1 Information exchanged

The information objects catalogued below are exchanged across the three phases of SUC-WMA. CEMS ↔ AEMS exchanges follow the IEC 62746-4 profile [5]; market-facing exchanges are aligned with the IEC 62325 series [6].

Information ID	Requirement R-IDs	Name of information	Message type	Description
Inf.1	R-2.1	Day-ahead price forecast	AEMS-internal + AEMS → CEMS (IEC 62746-4 profile [5])	Forecast of clearing prices in the DA market over the delivery horizon.
Inf.2	R-1.2, R-1.3	CEMS baseline + flex offers	CEMS → AEMS (IEC 62746-4 profile [5])	Per-CEMS baseline load profile plus set of flexibility offers (deviations priced with required compensation).
Inf.2’	R-1.2, R-1.3, R-2.2	CEMS baseline + flex offers (update)	CEMS → AEMS (IEC 62746-4 profile)	Refreshed variant of Inf.2 emitted at fixed intervals during the delivery horizon.
Inf.3	R-1.4	Aggregated baseline	AEMS-internal	Portfolio-level aggregated baseline load profile, hierarchically refined by ALF.

DRAFT

Information ID	Requirement R-IDs	Name of information	Message type	Description
Inf.3’	R-1.4	Aggregated baseline (update)	AEMS-internal	Refreshed variant of Inf.3 emitted during the delivery horizon.
Inf.4	R-1.5	DA bid	MMIB → DA Market Operator (IEC 62325 [6])	DA energy bid based on the aggregated baseline.
Inf.5	R-2.1	DA clearing	DA Market Operator → MMIB (IEC 62325)	Clearing prices and accepted quantities.
Inf.6	R-1.5, R-3.1	Flex activation notification	AEMS → CEMS (IEC 62746-4 profile)	Per-CEMS notification of an accepted flex activation, disaggregated by ALM.
Inf.7	R-2.1	ID price forecast	AEMS-internal	Forecast of clearing prices in the ID market.
Inf.8	R-1.5	ID bid	MMIB → ID Market Operator (IEC 62325)	ID bid or offer based on aggregated latest flex offers.
Inf.9	R-1.5, R-3.1	ID accepted-bid notification	AEMS → CEMS (IEC 62746-4 profile)	Per-CEMS notification of accepted ID bid, disaggregated by ALM.

10.1.6 Requirements

The requirements in this section are the WMA-relevant subset of the common IDOP requirements from D2.1 Sections 3.5 and 4.6 [2], mapped onto the IEC 62559-2 R-ID scheme.

10.1.6.1 Requirements regarding configuration issues

Category ID: R-1

Category name for requirements: Requirements regarding configuration issues

Category description: Configuration of components, interfaces and integration paths required to operate the use case.

Requirement R-ID	Requirement name	Requirement description	Traceability to D2.1
R-1.1	Integration with energy and flexibility markets	The AEMS needs to be integrated with the relevant energy markets (day-ahead and intra-day) to perform automated bidding.	AR1
R-1.2	CEMS-side baseline power forecast	Each CEMS needs to provide the AEMS with a baseline power forecast (i.e. optimised load profile).	CR3
R-1.3	CEMS-side flexibility forecast/estimate	Each CEMS needs to provide the AEMS with a forecast/estimate of available flexibility and related costs.	CR4
R-1.4	Aggregated flexibility management	The AEMS needs to aggregate baseline and flexibility across the portfolio.	AR3
R-1.5	Flexibility bidding	The AEMS needs to optimise flexibility when bidding in energy markets.	AR4
R-1.6	User interaction (Aggregator side)	The AEMS provides the aggregator with a user interface to manage goals and preferences, and to view performance reports and system status information.	AR5

DRAFT

Requirement R-ID	Requirement name	Requirement description	Traceability to D2.1
R-1.7	Support for sub-aggregation	The AEMS Package supports decoupling of technical aggregation and market integration/bidding functionalities into independent AEMS instances.	AR6

10.1.6.2 Requirements regarding Quality of Service issues

Category ID: R-2

Category name for requirements: Requirements regarding Quality of Service issues

Category description: Availability, accuracy and latency requirements of the information flows that constitute the use case.

Requirement R-ID	Requirement name	Requirement description	Traceability to D2.1
R-2.1	Market price forecasting	The AEMS needs to provide CEMS with day-ahead price forecast; additional price forecasts for the intra-day and flexibility markets are required for multi-market bidding.	AR2
R-2.2	Baseline update cadence	CEMS-side baseline and flexibility offers are refreshed at fixed intervals during the delivery horizon; the cadence is set so that the AEMS can complete each imbalance-correction loop within the interval to the next update.	D2.1 Section 5.1
R-2.3	Availability of information flows	Market price forecasts, CEMS updates and market clearing notifications need to be available with sufficient timeliness to precede the corresponding market gate closures.	D2.1 Section 5.1

10.1.6.3 Requirements regarding trust, security and privacy

Category ID: R-3

Category name for requirements: Requirements regarding trust, security and privacy

Category description: Trust, security and privacy properties applicable to the use case, mapped from the D2.1 TSP requirements onto IEC 62559-2 R-ID form.

Requirement R-ID	Requirement name	Requirement description	Traceability to D2.1
R-3.1	Secure CEMS ↔ AEMS communication	Communication between each CEMS and the AEMS uses standardised secure channels; the IEC 62746-4 profile is applied with TLS-protected transport and mutual authentication.	SR1
R-3.2	Secure AEMS ↔ market communication	Communication between the AEMS and market operators uses standardised secure channels appropriate to each market venue.	SR1
R-3.3	Access control	Access to sensitive assets and data is guarded through authorisation policies enforced at CEMS, AEMS and market interfaces.	SR2
R-3.4	Manage identities	Identities of the system entities are managed in a privacy-preserving and scalable manner.	TR1

DRAFT

Requirement R-ID	Requirement name	Requirement description	Traceability to D2.1
R-3.5	Manage trust between entities	Relationships between system entities are bootstrapped in a secure and privacy-preserving manner.	TR2
R-3.6	Privacy compliance	Compliance with EU privacy regulations is ensured.	PR1
R-3.7	Explicit data flows	Explicit data flows document data origins, owners, nature and consumers.	PR2
R-3.8	Explicit consent	End users have given explicit consent for portfolio inclusion and for the flow of their baseline / flex data to the AEMS.	PR3
R-3.9	Data minimisation	Only the necessary data is collected and processed.	PR4
R-3.10	Transparency	Data collection, processing and sharing are transparent to end users.	PR5
R-3.11	Privacy by design	Privacy considerations are integrated from inception.	PR6

10.1.7 Common terms and definitions

10.1.7.1 Common terms and definitions

Term	Definition
AEMS	Aggregator Energy Management System
Aggregator	The business actor that operates the AEMS and holds market membership.
ALF	Aggregated Load Forecasting (AEMS internal component)
ALM	Aggregated Load Management (AEMS internal component)
Baseline	Optimised load profile a CEMS intends to follow absent flex activation.
Baseline update	Refreshed variant of a CEMS baseline emitted during the delivery horizon.
BSP	Balancing Service Provider
CEM	Customer Energy Manager (EN 50491-12-1 [3])
CEMS	Customer Energy Management System
CIS	Customer Information System (AEMS internal component)
DA	Day-Ahead (market)
Delivery horizon	The time interval covered by a market transaction, e.g. one delivery hour of the day-ahead market.
Flex offer	A priced deviation from a CEMS baseline that the CEMS is willing to serve if activated.
Gate closure	Deadline by which bids must be submitted to a market.
ID	Intra-Day (market)
Imbalance	Difference between the position acquired in a market and delivered consumption.
MMIB	Multi-Market Interfaces and Bidding (AEMS internal component)
MPF	Market Price Forecasting (AEMS internal component)
Portfolio	The set of CEMS instances aggregated by an AEMS.
RM	Resource Manager (EN 50491-12-1 [3])
S2	Energy-flexibility interface standard EN 50491-12-2:2022 [7]
SUC	System Use Case
Sub-aggregation	Decoupling of technical aggregation and market integration into independent AEMS instances.

DRAFT

Term	Definition
TLS	Transport Layer Security
TSP	Trust, Security and Privacy
TSO	Transmission System Operator

10.1.8 Custom information

10.1.8.1 Contributing institutions

Organisation name	Acronym	Country
Jožef Stefan Institute	IJS	Slovenia
(additional contributors from the INDEPENDENT consortium to be listed at publication time)		

10.1.8.2 Classification and provenance

- **Technologies addressed:** Aggregator Energy Management System, Customer Energy Management System, IEC 62746-4 profile, IEC 62325 market communication framework.
- **High-level use case classification:** HLUC 9 — *Flexibility provision by Buildings, Districts and Industrial Processes* (aggregated variant).
- **Funding context (traceability):** INDEPENDENT — Horizon Europe project on integrated energy demand-side flexibility [grant agreement no. 101172675]. Cordis link *(insert the official URL before publication)*.

10.1.8.3 Envisaged specialisations

SUC-WMA is intentionally market-venue-neutral. Concrete deployments are specialised as child SUCs in future work. Specialisations envisaged for the INDEPENDENT platform:

Child SUC ID	Market venue	Country / region	Status
(envisaged) WMA-Nord	Nord Pool DA + ID	Finland / Sweden pilots	Envisaged, not yet specified.
(envisaged) WMA-EPEX	EPEX SPOT DA + ID	German pilot	Envisaged, not yet specified.
(envisaged) WMA-BSP-SL	BSP SouthPool DA + ID	Slovenian pilot	Envisaged, not yet specified.

Cross-references between SUC-WMA and its published child SUCs (currently none) are maintained at project level in `D2_3-cross-reference-note.md`.

10.1.9 References

[1] IEC, “IEC 62559-2 – Use case methodology – Part 2: Definition of the templates for use cases, actor list and requirements list,” International Electrotechnical Commission (IEC), Geneva, 2015. Available: https://webstore.iec.ch/

[2] INDEPENDENT consortium, “D2.1 – Initial Requirements and IDOP Architecture,” INDEPENDENT (Horizon Europe project, grant agreement no. 101172675), Project deliverable D2.1, 2025.

[3] CENELEC, “EN 50491-12-1:2018 – General requirements for Home and Building Electronic Systems (HBES) and Building Automation and Control Systems (BACS) – Smart grid – Application specification – Interface and framework for customer – Part 12-1: Interface between the Customer Energy Manager and the resource,” European Committee for Electrotechnical Standardization (CENELEC), Brussels, 2018. Available: https://standards.cencenelec.eu/

[4] European Commission, “Commission Regulation (EU) 2015/1222 establishing a guideline on capacity allocation and congestion management.” Official Journal of the European Union, L 197, 25.7.2015, p. 24–72, 2015. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32015R1222

DRAFT

[5] IEC, “IEC 62746-4 – Systems interface between customer energy management system and the power management system – Part 4: Profile for direct flexibility communication between AEMS and CEMS,” International Electrotechnical Commission (IEC), Geneva, 2024. Available: https://webstore.iec.ch/
[6] IEC, “IEC 62325 series – Framework for energy market communications,” International Electrotechnical Commission (IEC), Geneva, 2019. Available: https://webstore.iec.ch/
[7] CENELEC, “EN 50491-12-2:2022 – Customer Energy Manager – Part 12-2: S2 interface,” European Committee for Electrotechnical Standardization (CENELEC), Brussels, 2022.
[8] IEC, “IEC TS 62746-3:2015 – Systems interface between customer energy management system and the power management system – Part 3: Architecture for systems for energy management in the demand side,” International Electrotechnical Commission (IEC), Geneva, Technical Specification, 2015. Available: https://webstore.iec.ch/

DRAFT

10.2 Appendix B — SUC-TRM: Demand-side Flexibility Aggregation for TSO Reserve Markets

Companion to INDEPENDENT D2.3 — Final Requirements and IDOP Architecture. Authored per IEC 62559-2 use case template [1]. Formal specification of the Demand-side flexibility aggregation for TSO reserve markets* system use case introduced in D2.1/D2.3 Section 6.2 [2].*

10.2.1 Description of the use case

10.2.1.1 Name of use case

Name of the use case: SUC-TRM: Demand-side flexibility aggregation for TSO reserve markets

Area / Domain(s) / Zone(s): Energy Systems / Aggregator / Markets — Reserves and Balancing

10.2.1.2 Version management

Version	Date	Author(s)	Changes	Approval status
0.1	2026-08-26	Jožef Stefan Institute (IJS) for the INDEPENDENT consortium	Initial IEC 62559-2 formalisation of the D2.1/D2.3 Section 6.2 system use case.	Draft

10.2.1.3 Scope and objectives of use case

Scope: Aggregation of demand-side flexibility from a portfolio of Customer Energy Management Systems (CEMS) [3] by an Aggregator Energy Management System (AEMS) acting as a Balancing Service Provider (BSP) [4] for participation in TSO reserve markets — specifically the frequency-containment (FCR-D, FCR-N, FFR) and frequency-restoration (aFRR, mFRR) products defined in the ENTSO-E System Operation Guideline [5]. The AEMS pre-qualifies its portfolio assets, bids reserve capacity into the market, and orchestrates real-time activation of the reserve when the TSO or local frequency meter demands it. CEMS ↔ AEMS interfaces follow IEC 62746-4 [6]; market-side exchanges follow the IEC 62325 series [7].

Objective(s):

- **O1** — Monetise portfolio demand flexibility in TSO reserve markets (FCR, aFRR, mFRR).
- **O2** — Meet product-specific technical requirements (response time, duration, accuracy) as verified during pre-qualification.
- **O3** — Deliver activated reserve reliably and demonstrably to enable settlement.
- **O4** — Provide a standards-conformant substrate for country- and product-specific specialisations (Fingrid, German TSOs, Slovenian TSO, …) as additive child SUCs.

Related business case(s): Demand-side flexibility aggregation for TSO reserve markets as a system use case in INDEPENDENT D2.1 Section 5.2 [2] and D2.3 Section 6.2.

10.2.1.4 Narrative of use case

Short description:

An Aggregator Energy Management System, acting as a Balancing Service Provider under the ENTSO-E Electricity Balancing Guideline [4], aggregates demand-side flexibility from a portfolio of CEMS and offers it into TSO reserve markets. Prior to any bid, each candidate asset undergoes pre-qualification: the asset (a heat pump, a battery, or a combination) must demonstrate technical capability for the specific reserve product — response time, duration, accuracy — against the product definition [5]. Once verified, the AEMS registers the resource in its Customer Information System, aggregates the pre-qualified capacity, and bids into the reserve market. During the delivery period, the AEMS's Performance Service monitors asset readiness and activation performance; adjustments flow through the AEMS as needed. Real-time activation is either frequency-driven (FCR-D, FCR-N, FFR) or TSO-signal-driven (aFRR, mFRR). Settlement follows product-specific metrics.

Complete description:

The use case has five phases.

Pre-qualification. Assets are pre-studied to establish capability for a specific reserve product, then pre-qualified by demonstrating that they can meet the product's response-time, duration and accuracy requirements per the ENTSO-E SO GL [5]. The AEMS's Customer Information System registers pre-qualified resources and their verified capabilities. Only pre-qualified resources may be included in aggregated reserve bids.

Forecast and bidding. The Market Price Forecasting component publishes reserve-product price forecasts using historical clearing prices and current market conditions. Each CEMS's Resource Manager (or equivalent) uses its resource models to assess asset state and dynamic response capability, and to predict baseline consumption together with symmetric or asymmetric flexibility. The Customer Energy Manager determines reserve capacity offers respecting comfort constraints and sends the baseline and reserve capacity offers to the AEMS. Aggregated Load Management combines these individual offers with the CIS-validated data, ensuring only pre-qualified resources enter the aggregation. Aggregated Load Forecasting produces portfolio-level aggregated capacity forecasts. Multi-Market Interfaces and Bidding formulates reserve capacity bids that meet the TSO product requirements and submits them to the reserve market.

Market clearing and obligation flow. When the reserve market clears, the results flow to MMIB → ALM → per-CEMS obligation notifications. Each notified CEMS updates its internal state so that the RM knows the committed reserve.

DRAFT

Delivery-period management. During the reserve availability window, the Performance Service tracks activation performance — frequency response for FCR / FFR, TSO activation signals for aFRR / mFRR — against product requirements. Resource Managers monitor per-asset readiness. Availability updates flow through ALM to MMIB, which handles capacity adjustments if the portfolio must reduce its committed reserve within the market's allowance for such adjustments.

Real-time activation and settlement. MMIB receives either a frequency deviation signal from a local frequency meter (FCR-D, FCR-N, FFR) or an activation signal from the TSO (aFRR, mFRR). The activation signal flows through ALM to the affected CEMS; the CEMS commands its RM to execute the response; the RM adjusts the asset. The Performance Service monitors response time and accuracy; settlement data flows through the system to the TSO for verification and compensation based on product performance metrics.

As with SUC-WMA, this parent SUC intentionally omits country- and product-specific parameters (exact response-time thresholds, ramp requirements, settlement algebra); those are properties of the market venue and are captured in future child SUCs (e.g. TRM-Fingrid).

10.2.1.5 Key performance indicators (KPI)

ID	Name	Description	Refers to objectives
TRM_KPI_O1_reserve_value	Reserve-market value	Net value captured from cleared reserve bids across the horizon.	O1
TRM_KPI_O2_prequal	Pre-qualification success ratio	Fraction of assets that pass pre-qualification for the target product.	O2
TRM_KPI_O3_activation	Activation delivery ratio	Fraction of activation events in which the aggregated response meets product requirements (response time, duration, accuracy).	O3
TRM_KPI_O4_interop	Standards conformance	Share of CEMS ↔ AEMS transactions completing successfully under the IEC 62746-4 profile [6].	O4

10.2.1.6 Use case conditions

Assumptions:

- The Aggregator is authorised as a Balancing Service Provider by the relevant TSO under EBGL [4].
- Reserve product definitions and technical requirements are known and stable during the SUC horizon; concrete parameters are property of child SUCs.
- CEMS-side flexibility production (baseline, symmetric / asymmetric flex) is available through the same pattern as SUC-LFM.
- Frequency-measurement infrastructure (a local frequency meter with the required accuracy and update rate) is available for frequency-driven products.
- TSO activation-signal channel is available and authenticated for TSO-signal-driven products.

Prerequisites:

- Assets in the aggregated portfolio have completed pre-qualification for their target reserve product per SO GL [5].
- CIS holds the current registry of pre-qualified resources and their verified capabilities.
- CEMS ↔ AEMS channel is secured per IEC 62746-4 [6]; AEMS ↔ TSO channel is secured per the TSO's rules.

10.2.1.7 Further information to the use case for classification/mapping

Relation to other use cases:

DRAFT

- **Parent context:** *Demand-side flexibility aggregation for TSO reserve markets* as introduced in D2.1 Section 5.2 [2] and D2.3 Section 6.2.
- **Uses:** the CEMS-side local flexibility management pattern of D2.3 Section 6.3 as an underlying sub-use-case — each CEMS in the portfolio produces its baseline and reserve capacity offers through that pattern, extended with symmetric / asymmetric flex characterisation for reserve products.
- **Envisaged specialisations (child SUCs):** enumerated in Section 10.2.8.3.

Level of depth: System use case (SUC) — the generic TSO-reserve aggregation layer that specialises into country- and product-specific child SUCs.

Prioritisation: High — reserve markets are a primary revenue path for aggregators of dispatchable demand.

Applicability: Any TSO reserve market covered by the ENTSO-E EBGL [4]; illustrated at parent-SUC level, specialised per TSO and per product in future child SUCs.

Nature of the use case: Technical and business.

Further keywords for classification: Demand-side flexibility, aggregation, TSO reserves, FCR, aFRR, mFRR, Balancing Service Provider, pre-qualification, Aggregator Energy Management System, Customer Energy Management System, IEC 62746-4, EBGL.

10.2.1.8 General remarks

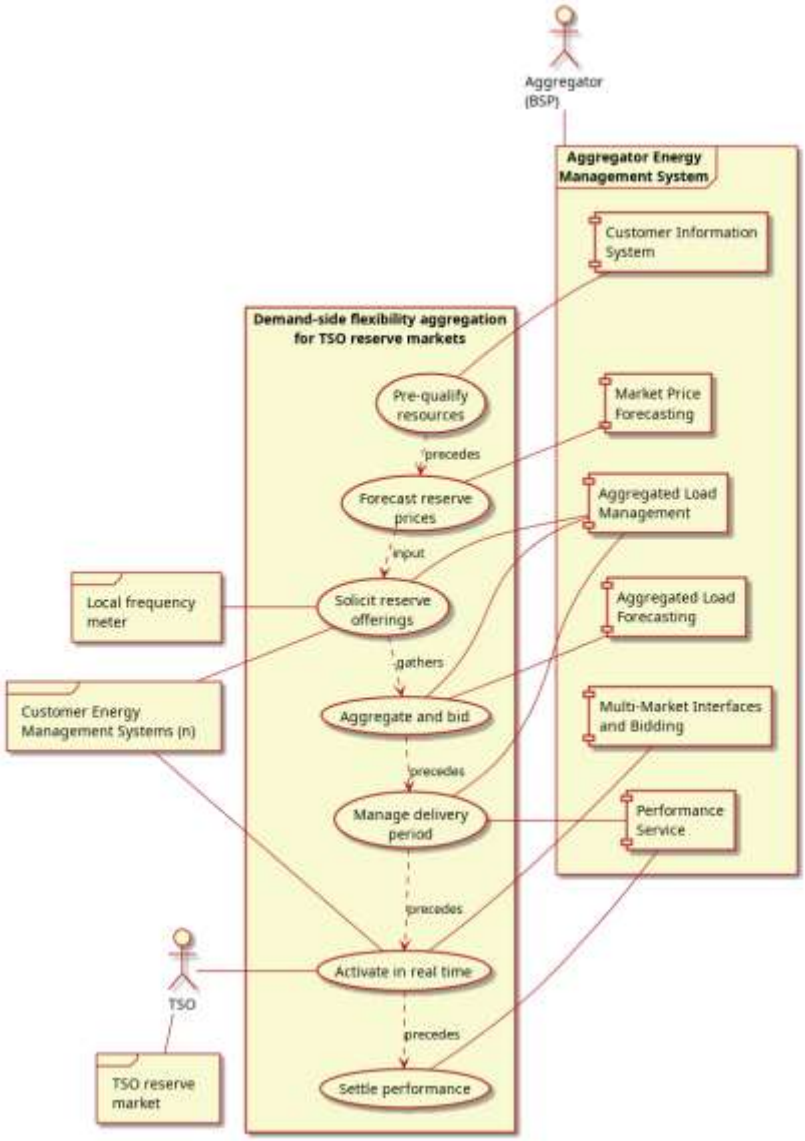
Product-specific parameters (response times per FCR-D / FCR-N / aFRR / mFRR; ramp requirements; minimum bid sizes) are properties of the reserve market and the TSO and belong in child SUCs rather than in this parent SUC. Frequency measurement accuracy and update rate similarly vary by product and jurisdiction.

10.2.2 Diagrams of use case

10.2.2.1 Use Case Diagram

The actors and system boundary of SUC-TRM are shown below. The AEMS encapsulates six functional components (ALM, ALF, MMIB, MPF, CIS, Performance Service). External to the AEMS are the CEMS portfolio, the TSO, the reserve market venue, and a local frequency meter (used for frequency-driven activation).

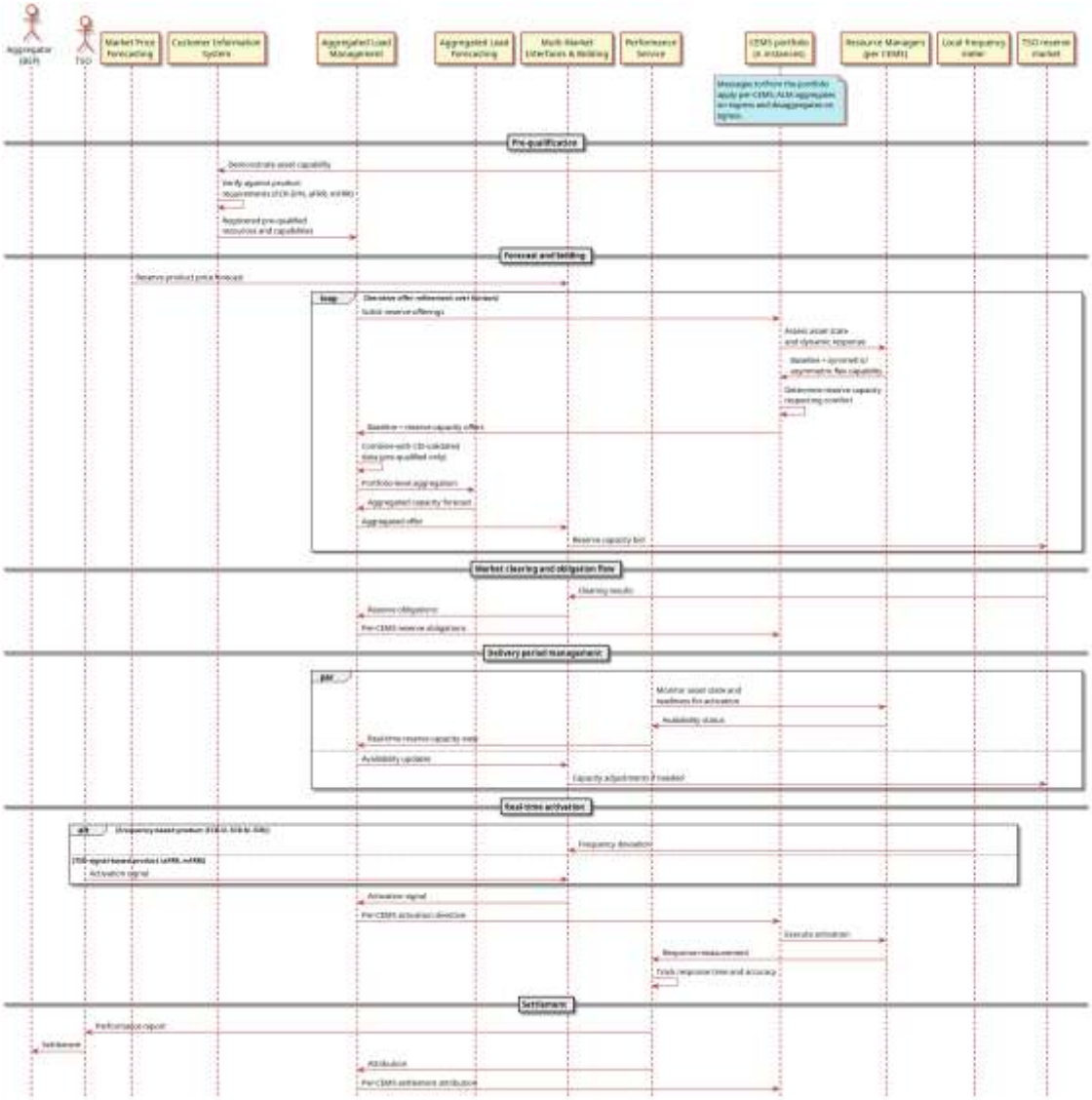
DRAFT



SUC-TRM use case diagram. Adapted from the functional-component narrative in INDEPENDENT D2.1 Section 5.2 [2].

10.2.2.2 Sequence Diagram

The diagram below shows one full application of SUC-TRM covering the five phases delineated by == markers: *pre-qualification*, *forecast and bidding* (with a `loop` for iterative offer refinement), *market clearing and obligation flow*, *delivery-period management* (a `par` block for parallel monitoring and capacity adjustment), and *real-time activation and settlement* (an `alt` between frequency-based and TSO-signal-based activation).



SUC-TRM sequence diagram covering the five phases: pre-qualification, forecast and bidding, market clearing, delivery-period management, and real-time activation and settlement. Adapted from INDEPENDENT D2.1 Section 5.2 [2].

10.2.3 Technical details

10.2.3.1 Actors

Actor name	Actor type	Actor description
Aggregator (BSP)	Business actor	Operator of the AEMS; authorised as a Balancing Service Provider under EBGL [4].
TSO	Business actor	Transmission System Operator; purchases reserves and dispatches activation signals for aFRR / mFRR products.
Market Price Forecasting (MPF)	System	AEMS internal component; produces reserve-product price forecasts.
Customer Information System (CIS)	System	AEMS internal component; registry of pre-qualified resources and verified capabilities.
Aggregated Load Management (ALM)	System	AEMS internal component; portfolio aggregation, obligation disaggregation, activation-signal routing.

Actor name	Actor type	Actor description
Aggregated Load Forecasting (ALF)	System	AEMS internal component; portfolio-level aggregated capacity forecasts.
Multi-Market Interfaces and Bidding (MMIB)	System	AEMS internal component; product-specific bidding, activation-signal ingress, capacity adjustment.
Performance Service	System	AEMS internal component; monitors activation performance during the delivery period; produces settlement input.
CEMS portfolio	System (n instances)	Customer Energy Management Systems in the aggregated portfolio; each produces its own baseline and reserve capacity offers.
Resource Managers (per CEMS)	System	S2 Resource Managers per asset (heat pump, battery, …); execute the physical response during activation.
Local frequency meter	System	Per-CEMS / per-asset measurement of grid frequency; drives activation for frequency-based products (FCR-D, FCR-N, FFR).
TSO reserve market	System	Market venue for reserve capacity bids and clearing.

10.2.3.2 References

References cited throughout this Appendix are listed in the IEEE-style **Section 10.2.9 Bibliography** at the end of the document. The principal normative sources are the ENTSO-E Electricity Balancing Guideline [4] and the System Operation Guideline that defines reserve products [5]; the CEMS ↔ AEMS interface profile [6] and its enclosing architecture [8]; the market-side communication framework [7]; the use case methodology [1]; and the customer-side energy-management architecture [3] and its flexibility-interface standard [9]. Country- and product-specific rules such as Fingrid's technical requirements for FCR / aFRR / mFRR [10] are cited only when a specific parameter is referenced.

10.2.4 Step by step analysis of use case

10.2.4.1 Scenario: Aggregated reserve-market participation over one delivery period

Field	Value
Scenario description	The AEMS pre-qualifies assets, bids aggregated reserve capacity into the reserve market for one delivery period, manages the delivery period, activates the reserve in real time when signaled, and produces settlement input.
Primary actor	Aggregator Energy Management System (AEMS)
Triggering event	Approach of the reserve-market gate closure for the next delivery period; subsequently, arrival of the frequency-deviation or TSO activation signal during the delivery period.
Pre-condition	Portfolio assets are pre-qualified in the CIS; CEMS ↔ AEMS and AEMS ↔ TSO channels are secured.
Postcondition	Reserve obligations are settled; per-CEMS activation and settlement notifications have been dispatched; performance metrics are recorded.

10.2.4.2 Steps of the scenario

Step	Phase	Name of process / activity	Description of process / activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (ID)	Requirement R-IDs
1	Pre-qual	Demonstrate capability	Asset (heat pump,	Execute	CEMS portfolio	CIS	Inf.1	R-1.1, R-2.1

Step	Phase	Name of process / activity	Description of process / activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (ID)	Requirement R-IDs
			battery, or combination) is tested against a reserve product's response-time, duration and accuracy requirements.					
2	Pre-qual	Verify and register	CIS verifies test results against product requirements; registers the resource and its verified capabilities.	Calculate	CIS	ALM	Inf.2	R-1.1
3	Bid	Forecast reserve prices	MPF publishes a reserve-product price forecast.	Report	MPF	MMIB	Inf.3	R-2.2
4	Bid	Solicit reserve offerings	ALM solicits reserve offerings from CEMS in the portfolio. Loop over iterative offer refinement.	Send	ALM	CEMS portfolio	Inf.4	R-1.2
5	Bid	Assess asset state	Each CEMS's RM assesses asset state and dynamic	Calculate	CEMS portfolio	CEMS portfolio	—	—

DRAFT

Step	Phase	Name of process / activity	Description of process / activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (ID)	Requirement R-IDs
			response capability.					
6	Bid	Emit reserve offer	CEMS emits baseline plus reserve capacity offer (symmetric or asymmetric) respecting comfort.	Report	CEMS portfolio	ALM	Inf.5	R-1.2, R-1.3
7	Bid	Combine and aggregate	ALM combines offers with CIS-validated data (only pre-qualified resources); ALF produces aggregated capacity forecast.	Calculate	ALM, ALF	MMIB	Inf.6	R-1.4
8	Bid	Bid reserve capacity	MMIB submits the reserve capacity bid to the TSO reserve market.	Send	MMIB	TSO reserve market	Inf.7	R-1.5
9	Clear	Receive clearing	Reserve market returns clearing results.	Report	TSO reserve market	MMIB	Inf.8	R-2.2
10	Clear	Distribute obligations	Clearing flows through MMIB → ALM → per-CEMS reserve obligations.	Send	MMIB, ALM	CEMS portfolio	Inf.9	R-1.5, R-3.1
11	Delivery	Monitor readiness	Performance Service	Report	RM, Performa	ALM	Inf.10	R-2.3

DRAFT

Step	Phase	Name of process / activity	Description of process / activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (ID)	Requirement R-IDs
			monitors per-asset readiness throughout the delivery period; RM reports availability.		nce Service			
12	Delivery	Capacity adjustment	If needed, ALM forwards availability updates to MMIB which negotiates capacity adjustment with the market.	Send	MMIB	TSO reserve market	Inf.11	R-1.5
13	Activation	Receive activation signal	MMIB receives frequency deviation from local frequency meter (FCR) OR activation signal from TSO (aFRR / mFRR). Alternate flows.	Report	Local frequency meter OR TSO	MMIB	Inf.12	R-2.4, R-3.2
14	Activation	Route to CEMS	ALM disaggregates the activation and routes per-CEMS activation directives.	Send	MMIB, ALM	CEMS portfolio	Inf.13	R-1.5, R-2.4, R-3.1
15	Activation	Execute response	Each activated CEMS commands its RM to execute the response; RM performs	Execute	CEMS portfolio, RM	RM	—	R-1.6

DRAFT

Step	Phase	Name of process / activity	Description of process / activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (ID)	Requirement R-IDs
			the asset action.					
16	Activation	Measure response	RM emits response measurement; Performance Service tracks response time and accuracy against product requirements.	Report	RM, Performance Service	Performance Service	Inf.14	R-2.4
17	Settlement	Report performance	Performance Service produces a performance report and attributes to individual resources.	Send	Performance Service	TSO, ALM	Inf.15	R-3.3
18	Settlement	Settle	TSO settles with the aggregator; ALM attributes per-CEMS.	Send	TSO, ALM	Aggregator, CEMS portfolio	Inf.16	R-3.3

10.2.5 Information exchanged

10.2.5.1 Information exchanged

The information objects catalogued below are exchanged across the five phases of SUC-TRM. CEMS ↔ AEMS exchanges follow the IEC 62746-4 profile [6]; market-facing exchanges are aligned with the IEC 62325 series [7]; TSO-facing activation channels follow TSO-specific rules.

Information ID	Requirement R-IDs	Name of information	Message type	Description
Inf.1	R-1.1, R-2.1	Asset capability test evidence	AEMS-internal; based on SO GL product definition [5]	Test data demonstrating the asset meets response-time, duration and accuracy requirements for the target product.

DRAFT

Information ID	Requirement R-IDs	Name of information	Message type	Description
Inf.2	R-1.1	Pre-qualified resource registration	AEMS-internal (CIS)	Registry entry for a pre-qualified resource with its verified capabilities.
Inf.3	R-2.2	Reserve-product price forecast	AEMS-internal	Forecast clearing prices for the reserve product.
Inf.4	R-1.2	Reserve-offering solicitation	AEMS → CEMS (IEC 62746-4 profile [6])	Solicitation of a reserve capacity offering from a CEMS.
Inf.5	R-1.2, R-1.3	CEMS baseline + reserve capacity offer	CEMS → AEMS (IEC 62746-4 profile)	Per-CEMS baseline plus symmetric or asymmetric reserve capacity offer.
Inf.6	R-1.4	Aggregated capacity forecast	AEMS-internal	Portfolio-level aggregated reserve capacity forecast filtered to pre-qualified resources only.
Inf.7	R-1.5	Reserve capacity bid	MMIB → TSO reserve market (IEC 62325 [7])	Aggregated reserve capacity bid meeting the TSO product requirements.
Inf.8	R-2.2	Reserve market clearing	TSO reserve market → MMIB (IEC 62325)	Clearing prices and accepted quantities.
Inf.9	R-1.5, R-3.1	Reserve obligation	AEMS → CEMS (IEC 62746-4 profile)	Per-CEMS reserve obligation flowing from clearing results.
Inf.10	R-2.3	Availability status	RM → Performance Service; Performance Service → ALM	Per-asset readiness status during the delivery period.
Inf.11	R-1.5	Capacity adjustment	MMIB → TSO reserve market (IEC 62325)	Reserve-capacity adjustment notification if the portfolio must reduce its committed reserve.
Inf.12	R-2.4, R-3.2	Activation signal	Local frequency meter → MMIB (site-local) OR TSO → MMIB (TSO-defined secure channel)	Frequency deviation (FCR-D, FCR-N, FFR) or TSO activation setpoint (aFRR, mFRR).
Inf.13	R-1.5, R-2.4, R-3.1	Per-CEMS activation directive	AEMS → CEMS (IEC 62746-4 profile)	Disaggregated activation directive dispatched to the affected CEMS instances.
Inf.14	R-2.4	Response measurement	RM → Performance Service	Measured asset response during activation (magnitude and timing).
Inf.15	R-3.3	Performance report	Performance Service → TSO; Performance Service → ALM	Delivered-performance report per activation event, attributed to individual resources.
Inf.16	R-3.3	Settlement	TSO → Aggregator; ALM → CEMS	Financial settlement for delivered reserve; per-CEMS attribution of the aggregate settlement.

DRAFT

10.2.6 Requirements

The requirements in this section are the TRM-relevant subset of the common IDOP requirements from D2.1 Sections 3.5 and 4.6 [2], mapped onto the IEC 62559-2 R-ID scheme.

10.2.6.1 Requirements regarding configuration issues

Category ID: R-1

Category name for requirements: Requirements regarding configuration issues

Category description: Configuration of components, interfaces and integration paths required to operate the use case.

Requirement R-ID	Requirement name	Requirement description	Traceability to D2.1
R-1.1	Pre-qualification registry	The AEMS maintains a registry (CIS) of pre-qualified resources and verified capabilities per SO GL product requirements [5]. Only pre-qualified resources are included in aggregated reserve bids.	D2.1 Section 5.2
R-1.2	CEMS-side reserve-offering capability	Each CEMS provides the AEMS with a baseline plus a symmetric or asymmetric reserve capacity offer respecting comfort constraints.	CR3, CR4
R-1.3	Product-response compliance	Each asset in an aggregated reserve bid meets the response-time, duration and accuracy requirements of the target product per SO GL [5].	D2.1 Section 5.2
R-1.4	Aggregated capacity management	The AEMS aggregates baseline and reserve capacity across the portfolio; ALF produces portfolio-level capacity forecasts.	AR3
R-1.5	Reserve-product bidding	The AEMS optimises reserve-capacity bidding across the applicable product portfolio.	AR4
R-1.6	Real-time activation execution	The AEMS routes activation signals through ALM to affected CEMS; each CEMS commands its RM to execute the physical response within product-specific timing bounds.	AR3, AR4
R-1.7	User interaction (Aggregator side)	The AEMS provides the aggregator with a user interface to manage goals, preferences, product participation and performance reports.	AR5

10.2.6.2 Requirements regarding Quality of Service issues

Category ID: R-2

Category name for requirements: Requirements regarding Quality of Service issues

Category description: Availability, accuracy and latency requirements of the information flows that constitute the use case, including activation-signal latency bounds.

Requirement R-ID	Requirement name	Requirement description	Traceability to D2.1
R-2.1	Pre-qualification test infrastructure	Test infrastructure and evidence recording are available to demonstrate product compliance per SO GL [5].	D2.1 Section 5.2

DRAFT

Requirement R-ID	Requirement name	Requirement description	Traceability to D2.1
R-2.2	Market price forecasting availability	Reserve-product price forecasts, portfolio updates and market clearing notifications are available with sufficient timeliness to precede the corresponding market gate closures.	AR2, D2.1 Section 5.2
R-2.3	Delivery-period availability monitoring	Availability status is refreshed at a cadence sufficient for the Performance Service to detect readiness degradations within the market's tolerance for capacity adjustments.	D2.1 Section 5.2
R-2.4	Activation-signal latency	End-to-end latency from activation-signal receipt at MMIB to executed asset response is bounded per the product category: sub-second class for FCR (FCR-D, FCR-N, FFR); seconds class for aFRR; minutes class for mFRR; concrete values are set by each TSO's product rules [5] and are deferred to child SUCs.	D2.1 Section 5.2

10.2.6.3 Requirements regarding trust, security and privacy

Category ID: R-3

Category name for requirements: Requirements regarding trust, security and privacy

Category description: Trust, security and privacy properties applicable to the use case, mapped from the D2.1 TSP requirements. TSO-facing activation channels have additional integrity requirements to protect against injection of spurious activation signals.

Requirement R-ID	Requirement name	Requirement description	Traceability to D2.1
R-3.1	Secure CEMS ↔ AEMS communication	Communication between each CEMS and the AEMS uses standardised secure channels; IEC 62746-4 profile with TLS-protected transport and mutual authentication.	SR1
R-3.2	Secure TSO ↔ AEMS activation channel	TSO-to-AEMS activation-signal channels use TSO-defined secure protocols with authentication and integrity protection to prevent spurious activation.	SR1
R-3.3	Signed performance reports	Performance reports submitted to the TSO for settlement are integrity-protected and non-repudiable.	SR1, SR2
R-3.4	Access control	Access to sensitive assets and data (registry, offers, obligations, activation directives) is guarded through authorisation policies enforced at CEMS, AEMS, TSO and market interfaces.	SR2
R-3.5	Manage identities	Identities of the system entities are managed in a privacy-preserving and scalable manner.	TR1
R-3.6	Manage trust between entities	Relationships between system entities are bootstrapped in a secure and privacy-preserving manner.	TR2
R-3.7	Privacy compliance	Compliance with EU privacy regulations is ensured.	PR1
R-3.8	Explicit data flows	Explicit data flows document data origins, owners, nature and consumers.	PR2
R-3.9	Explicit consent	End users have given explicit consent for portfolio inclusion in reserve-market	PR3

DRAFT

Requirement R-ID	Requirement name	Requirement description	Traceability to D2.1
		participation and for the flow of their measurement and offer data to the AEMS and, via performance reporting, to the TSO.	
R-3.10	Data minimisation	Only the necessary data is collected and processed.	PR4
R-3.11	Transparency	Data collection, processing and sharing are transparent to end users.	PR5
R-3.12	Privacy by design	Privacy considerations are integrated from inception.	PR6

10.2.7 Common terms and definitions

10.2.7.1 Common terms and definitions

Term	Definition
AEMS	Aggregator Energy Management System
aFRR	Automatic Frequency Restoration Reserve (SO GL [5])
Aggregator	The business actor that operates the AEMS.
ALF	Aggregated Load Forecasting (AEMS internal component)
ALM	Aggregated Load Management (AEMS internal component)
BSP	Balancing Service Provider (EBGL [4])
CEM	Customer Energy Manager (EN 50491-12-1 [3])
CEMS	Customer Energy Management System
CIS	Customer Information System (AEMS internal component); registry of pre-qualified resources.
Delivery period	Time interval during which reserve capacity is available for activation.
EBGL	Electricity Balancing Guideline (EU 2017/2195) [4]
FCR	Frequency Containment Reserve (SO GL)
FCR-D	Frequency Containment Reserve for Disturbances (Nordic naming)
FCR-N	Frequency Containment Reserve for Normal operation (Nordic naming)
FFR	Fast Frequency Reserve
mFRR	Manual Frequency Restoration Reserve (SO GL)
MMIB	Multi-Market Interfaces and Bidding (AEMS internal component)
MPF	Market Price Forecasting (AEMS internal component)
Performance Service	AEMS internal component that monitors activation performance during the delivery period.
Portfolio	Set of CEMS aggregated by an AEMS.
Pre-qualification	Verification that an asset meets a reserve product’s technical requirements (response time, duration, accuracy).
Reserve product	A specific reserve service defined by SO GL [5] (FCR-D, FCR-N, FFR, aFRR, mFRR, RR).
RM	Resource Manager (EN 50491-12-1 [3])
S2	Energy-flexibility interface standard EN 50491-12-2:2022 [9]
SO GL	System Operation Guideline (EU 2017/1485) [5]
SUC	System Use Case
Symmetric / asymmetric flexibility	Reserve capacity that can be delivered as upward-only, downward-only, or both directions symmetrically.
TLS	Transport Layer Security

DRAFT

Term	Definition
TSO	Transmission System Operator
TSP	Trust, Security and Privacy

10.2.8 Custom information

10.2.8.1 Contributing institutions

Organisation name	Acronym	Country
Jožef Stefan Institute	IJS	Slovenia

(additional contributors from the INDEPENDENT consortium to be listed at publication time)

10.2.8.2 Classification and provenance

- **Technologies addressed:** Aggregator Energy Management System, Customer Energy Management System, IEC 62746-4 profile, IEC 62325 market communication framework, ENTSO-E balancing framework.
- **High-level use case classification:** HLUC 9 — *Flexibility provision by Buildings, Districts and Industrial Processes* (reserve-market variant).
- **Funding context (traceability):** INDEPENDENT — Horizon Europe project on integrated energy demand-side flexibility [grant agreement no. 101172675]. Cordis link *(insert the official URL before publication)*.

10.2.8.3 Envisaged specialisations

SUC-TRM is intentionally TSO- and product-neutral. Concrete deployments are specialised as child SUCs in future work. Specialisations envisaged for the INDEPENDENT platform:

Child SUC ID	TSO / product	Country / region	Status
(envisaged) TRM-Fingrid	FCR-N, FCR-D, aFRR, mFRR	Finland	Envisaged, not yet specified.
(envisaged) TRM-Amprion	aFRR, mFRR	Germany (Amprion balancing area)	Envisaged, not yet specified.
(envisaged) TRM-50Hertz	FCR, aFRR, mFRR	Germany (50Hertz balancing area)	Envisaged, not yet specified.
(envisaged) TRM-SL	aFRR, mFRR	Slovenia	Envisaged, not yet specified.
(envisaged) TRM-SvK	FCR-N, FCR-D, aFRR, mFRR	Sweden (Svenska kraftnät)	Envisaged, not yet specified.

Cross-references between SUC-TRM and its published child SUCs (currently none) are maintained at project level in `D2_3-cross-reference-note.md`.

10.2.9 References

[1] IEC, “IEC 62559-2 – Use case methodology – Part 2: Definition of the templates for use cases, actor list and requirements list,” International Electrotechnical Commission (IEC), Geneva, 2015. Available: https://webstore.iec.ch/

[2] INDEPENDENT consortium, “D2.1 – Initial Requirements and IDOP Architecture,” INDEPENDENT (Horizon Europe project, grant agreement no. 101172675), Project deliverable D2.1, 2025.

[3] CENELEC, “EN 50491-12-1:2018 – General requirements for Home and Building Electronic Systems (HBES) and Building Automation and Control Systems (BACS) – Smart grid – Application specification – Interface and framework for customer – Part 12-1: Interface between the Customer Energy Manager and the resource,” European Committee for Electrotechnical Standardization (CENELEC), Brussels, 2018. Available: https://standards.cencenelec.eu/

DRAFT

[4] European Commission, “Commission Regulation (EU) 2017/2195 establishing a guideline on electricity balancing.” Official Journal of the European Union, L 312, 28.11.2017, p. 6–53, 2017. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32017R2195
[5] European Commission, “Commission Regulation (EU) 2017/1485 establishing a guideline on electricity transmission system operation.” Official Journal of the European Union, L 220, 25.8.2017, p. 1–120, 2017. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32017R1485
[6] IEC, “IEC 62746-4 – Systems interface between customer energy management system and the power management system – Part 4: Profile for direct flexibility communication between AEMS and CEMS,” International Electrotechnical Commission (IEC), Geneva, 2024. Available: https://webstore.iec.ch/
[7] IEC, “IEC 62325 series – Framework for energy market communications,” International Electrotechnical Commission (IEC), Geneva, 2019. Available: https://webstore.iec.ch/
[8] IEC, “IEC TS 62746-3:2015 – Systems interface between customer energy management system and the power management system – Part 3: Architecture for systems for energy management in the demand side,” International Electrotechnical Commission (IEC), Geneva, Technical Specification, 2015. Available: https://webstore.iec.ch/
[9] CENELEC, “EN 50491-12-2:2022 – Customer Energy Manager – Part 12-2: S2 interface,” European Committee for Electrotechnical Standardization (CENELEC), Brussels, 2022.
[10] Fingrid Oyj, “Technical requirements and prequalification for frequency-containment and frequency-restoration reserve products (FCR-N, FCR-D, aFRR, mFRR).” Fingrid technical rules, 2026. Available: https://www.fingrid.fi/

10.3 Appendix C — SUC-LFM: Local Flexibility Management

Companion to INDEPENDENT D2.3 — Final Requirements and IDOP Architecture. Authored per IEC 62559-2 use case template [1]. Formal specification of the Local flexibility management* system use case introduced in D2.1 Section 6.3 [2] and retained in D2.3.*

10.3.1 Description of the use case

10.3.1.1 Name of use case

Name of the use case: SUC-LFM: Local flexibility management

Area / Domain(s) / Zone(s): Energy Systems / Customer Premises / Operation

10.3.1.2 Version management

Version	Date	Author(s)	Changes	Approval status
0.1	2026-08-25	Jožef Stefan Institute (IJS) for the INDEPENDENT consortium	Initial IEC 62559-2 formalisation of the D2.1 Section 5.3 use case.	Draft

10.3.1.3 Scope and objectives of use case

Scope: Automated management of local electric-energy flexibility at an individual end-user premises, orchestrated by a Customer Energy Manager (CEM) [3] that coordinates one or more Resource Managers (RMs) [4] representing the controllable resources present at the premises — typically HVAC / heat-pump, PV, battery, EV, white-goods, and where present a smart-meter data feed. The end-user premises may be a single-family house, a multi-dwelling building, a tertiary building (offices, retail, public), or an industrial site. Optimisation is driven by *implicit* signals — either **external** (day-ahead prices, spot-price forecast, network tariffs, grid-mix CO2 emissions forecast) or **internal** (PV production

forecast, peak-load forecast, resource efficiency) — over a rolling horizon typically of one day and produces a schedule that is dispatched to the RMs over the S2 interface [4].

Objective(s):

- **O1** — Reduce end-user energy costs by shifting flexible loads into low-price intervals.
- **O2** — Increase local self-consumption of on-site generation (PV) by aligning flexible loads with generation windows.
- **O3** — Reduce operational CO2 emissions by scheduling against the grid-mix CO2 forecast.
- **O4** — Improve local resource efficiency (asset-utilisation, comfort-quality-of-service, peak-shaving) via coordinated multi-RM scheduling.
- **O5** — Provide a standards-conformant substrate (S2 over the CEM↔RM interface [4], CEM↔AEMS coordination via [5]) that specialises cleanly to any resource-mix present at the premises.

Related business case(s): Local flexibility management as a system use case in INDEPENDENT D2.1 Section 5.3 [2] and D2.3 Section 6.3.

10.3.1.4 Narrative of use case

Short description:

Local flexibility management (LFM) is the customer-side foundation on which every downstream flexibility service — direct implicit demand response, aggregated bidding into wholesale or reserve markets, DSO-local flexibility markets — is built. The end user sets preferences and goals through the End-User Interface (EUI); a Customer Energy Manager continuously forecasts the state of the premises, obtains an implicit signal (external or internal), computes an optimal schedule for the controllable resources, dispatches that schedule to the Resource Managers over S2 [4], and monitors execution. When the optimisation cannot converge within an operational time budget, the CEM falls back to a pre-configured default schedule so that the premises never runs uncontrolled.

Complete description:

The end users covered by this use case include households, apartment buildings, tertiary buildings (offices, retail, public) and industrial plants and facilities. In every case the assumption is the same: the controllable resources at the premises are managed through a **Customer Energy Manager** (CEM) [3] and each premises can have multiple **Resource Managers** (RMs) — typically HVAC RM, heat-pump RM, PV RM, battery RM, EV RM, white-goods RM — plus a **Smart-Meter** feed used to bound the non-flexible baseline. End users manage these resources to leverage flexibility for varying goals — reducing energy cost, increasing PV self-consumption, reducing operational CO2 emissions, improving resource efficiency — or for more than one goal at once. The concrete resolution of multiple goals is configured via the EUI and is not fixed by this use case.

The management cycle proceeds in three parts. First, in the **preferences setup** phase (once at initialisation and on user update), the end user configures goals, comfort bounds and operating limitations via the EUI; the EUI forwards the preferences to the CEM. Second, in the **operation cycle** (triggered every hour or every 15 min, depending on horizon settings), the CEM computes and dispatches the optimal schedule for the next horizon. Third, in the **monitoring** phase (continuously available to the end user), the CEM makes measurements, applied schedules, and performance rollups accessible through the EUI.

The operation cycle itself has a distinctive iterative structure. After initialisation (preferences resolved, initial guided schedules generated) and after collecting auxiliary data (weather, solar), the CEM obtains **either an external implicit signal** (day-ahead prices, spot prices, network tariffs, CO2 emissions forecast — pulled from external services) **or an internal implicit signal** (peak-shaving target, PV self-consumption target — derived from local measurements and forecasts). The CEM then enters a **guided-forecast optimisation loop**: it sends candidate schedules to each controllable RM; each RM computes the load profile that would result from following its input schedule and returns the forecast; the CEM aggregates these forecasts, evaluates its optimisation function, and either accepts the solution (loop exits) or prepares a new set of guided schedules (loop iterates). The loop is time limited. When it exits with a satisfactory result, the CEM dispatches the optimal schedule to the RMs via S2 and notifies the EUI; when it fails to converge within the time budget, the CEM falls back to a pre-configured default schedule and notifies the EUI that a fallback was applied.

The optimisation responsibility is split across two layers by design [6, Sec. 5.3]. At the **system level**, the CEM coordinates across multiple RMs and knows the signals that couple them (prices, tariffs, PV, non-flexible baseline). At the **resource level**, each RM knows its own physical asset (heat-pump dynamics, battery state of charge, EV connection state, HVAC thermal inertia) and, in S2 control types that allow it, retains autonomy inside CEM-issued constraints. The specific split — how much scheduling detail flows down as an envelope, an operation-mode sequence, or a full power profile — is a property of the chosen S2 control type and is specialised in the child SUCs (Section 10.3.8.3).

Data sourcing follows the same split. The CEM acquires implicit signals (external services) and auxiliary data (weather, solar radiation) and uses them in the objective and non-flexible-baseline forecast; RMs may independently subscribe to auxiliary data (for their own internal predictive models). Measurements and RM-side power forecasts flow from RM to CEM via S2 (`ProcessPowerMeasurements`, `ProcessPowerForecast`); optimised schedules and control instructions flow from CEM to RM via S2 (`ActivateControlType`, `ProcessInstruction`).

10.3.1.5 Key performance indicators (KPI)

ID	Name	Description	Refers to objectives
LFM_KPI_O1_cost	Cost reduction ratio	Ratio of energy cost under LFM scheduling vs. a flat-tariff / no-shifting baseline at identical comfort outcome.	O1
LFM_KPI_O2_self_cons	Self-consumption ratio	`E_gen_consumed_local / E_gen_total` over a billing period, compared against a no-shifting baseline.	O2
LFM_KPI_O3_co2	Operational CO2 reduction	Difference in operational CO2 emissions vs. flat-baseline scheduling, computed against the published grid-mix CO2 forecast.	O3
LFM_KPI_O4_util	Resource utilisation efficiency	Fraction of available flexibility of each RM effectively activated in the horizon (e.g. shifted energy / declared shiftable energy).	O4
LFM_KPI_O4_peak	Peak-shaving effectiveness	Reduction of premises peak demand vs. baseline over the horizon.	O4
LFM_KPI_O5_convergence	Optimisation convergence rate	Fraction of cycles in which the guided-forecast optimisation loop converges within the time budget (i.e. does not fall back to the default schedule).	O5

10.3.1.6 Use case conditions

Assumptions:

- A **Customer Energy Manager** is installed at the premises and conforms to the CEM/RM architecture standard [3].
- The controllable resources at the premises are exposed through **S2-capable Resource Managers** [4]. Legacy devices may be exposed through Semantic Adapters (see Section 10.3.6.1).
- At least one implicit signal is available for the horizon: either **external** (day-ahead prices, spot-price forecast, network tariffs, or CO2 emissions forecast, pulled from external services) or **internal** (derived locally from smart-meter or PV measurements and forecasts).
- Auxiliary data services (weather forecast, solar irradiation forecast) are available for the horizon.
- Each controllable RM is able to compute a load-profile forecast under a candidate schedule (“guided forecast” capability).

DRAFT

- A **default schedule** is pre-configured for every controllable RM as a safe fallback for cases where the guided-forecast optimisation loop does not converge within the time budget.

Prerequisites:

- The CEM and RMs share a secured communication substrate (typically an MQTT broker with TLS and mutual authentication) and have completed the one-time S2 handshake and control-type selection for every controllable RM as defined by EN 50491-12-2:2022 [4].
- The end user has configured preferences through the EUI: goal(s) or goal weights (cost / self-consumption / CO2 / efficiency), comfort bounds, operating limitations.
- For cost-objective scenarios (O1), the end user has a contract that exposes dynamic pricing (spot or day-ahead), or the CEM has access to a tariff schedule from the DSO / retailer.

10.3.1.7 Further information to the use case for classification/mapping

Relation to other use cases:

- **Parent context:** *Local flexibility management* as introduced in D2.1 Section 5.3 [2] and D2.3 Section 6.3.
- **Envisaged specializations (child SUCs):** specialization could be, for example, automated implicit demand response for single-family houses with a heat pump and PV over S2 interface, using PEBC or FRBC as a control type.
- **Upstream:** SUC-LFM is the customer-side substrate on which aggregated-flexibility use cases (wholesale-market participation, TSO reserve, DSO local flexibility) build via the CEM↔AEMS interface [5].

Level of depth: System use case (SUC) — the generic layer that specialises into resource-mix-specific child SUCs.

Prioritisation: High — foundational; every other CEMS-side use case in the INDEPENDENT platform builds on this substrate.

Applicability: Any end-user premises with a CEM and at least one S2-capable RM. Illustrated in this document with the residential and tertiary-building resource mix; industrial scope is retained through the same abstraction, with process-schedule constraints, safety interlocks and multi-vector coupling delegated to future industrial specialisations (see Section 10.3.8.3).

Nature of the use case: Technical — control and communication.

Further keywords for classification: Local flexibility management, implicit demand response, S2 protocol, EN 50491-12-2, Customer Energy Manager, Resource Manager, guided-forecast optimisation loop, default schedule fallback, two-level optimisation, external implicit signal, internal implicit signal, self-consumption, peak shaving.

10.3.1.8 General remarks

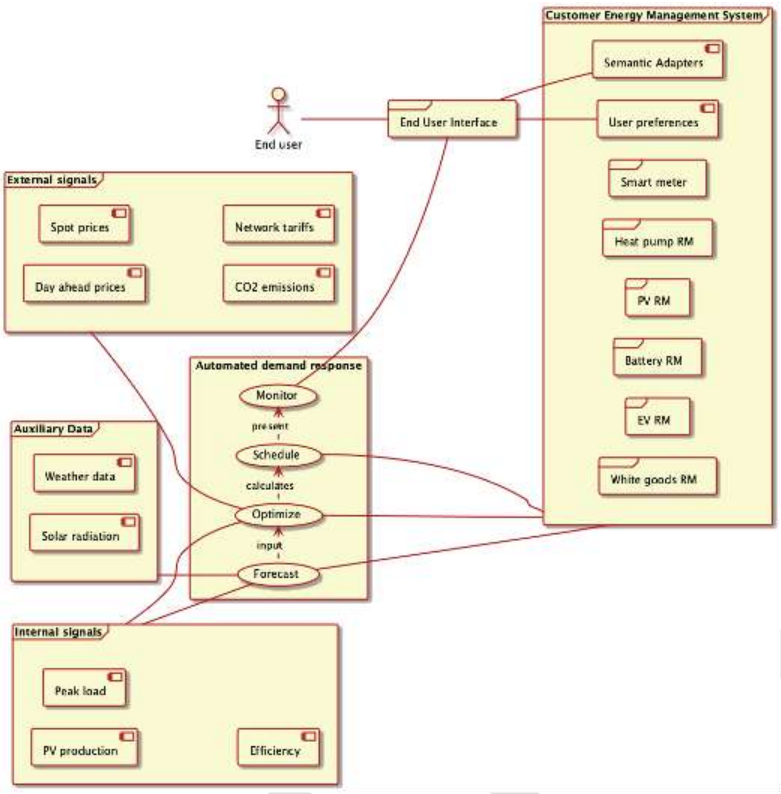
This SUC is intentionally control-type-neutral at the S2 layer: it does not commit to PEBC, FRBC, PPBC, OMBC or NC. The choice of S2 control type is a property of the child SUC that specialises SUC-LFM to a particular resource mix.

10.3.2 Diagrams of use case

10.3.2.1 Use Case Diagram

The actors and system boundary of SUC-LFM are shown below. The CEM encapsulates the RMs that manage the on-premises resources; External signals, Internal signals and Auxiliary data are outside the CEM boundary. The core activities (Forecast → Optimize → Schedule → Monitor) are shown as usecases inside the Local flexibility management boundary.

DRAFT

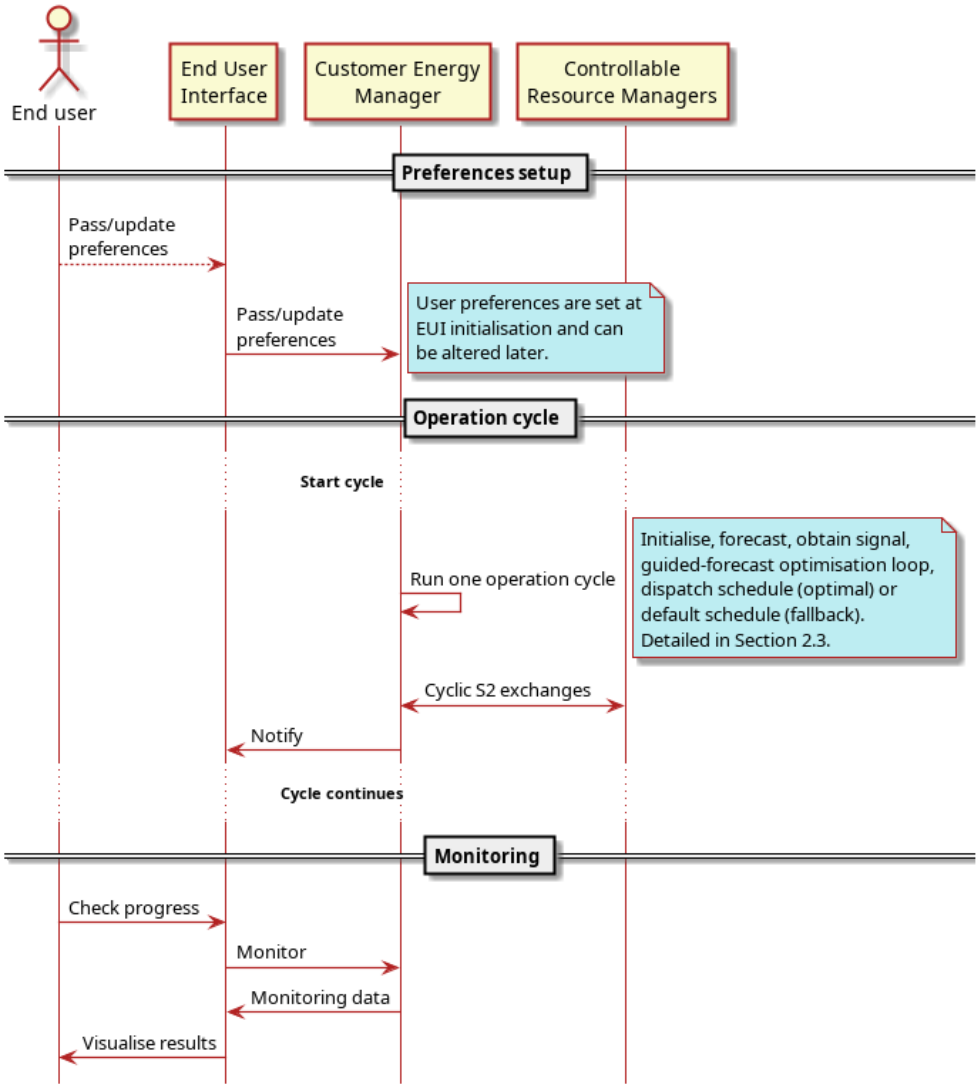


SUC-LFM use case diagram.

10.3.2.2 Sequence Diagram — Overview

The overview diagram below shows the three parts of SUC-LFM at a glance: the *preferences setup* (once at initialisation, updateable at any time), the *operation cycle* (in essential form — the details are deferred to Section 10.3.2.3), and the *monitoring* phase that is continuously available to the end user.

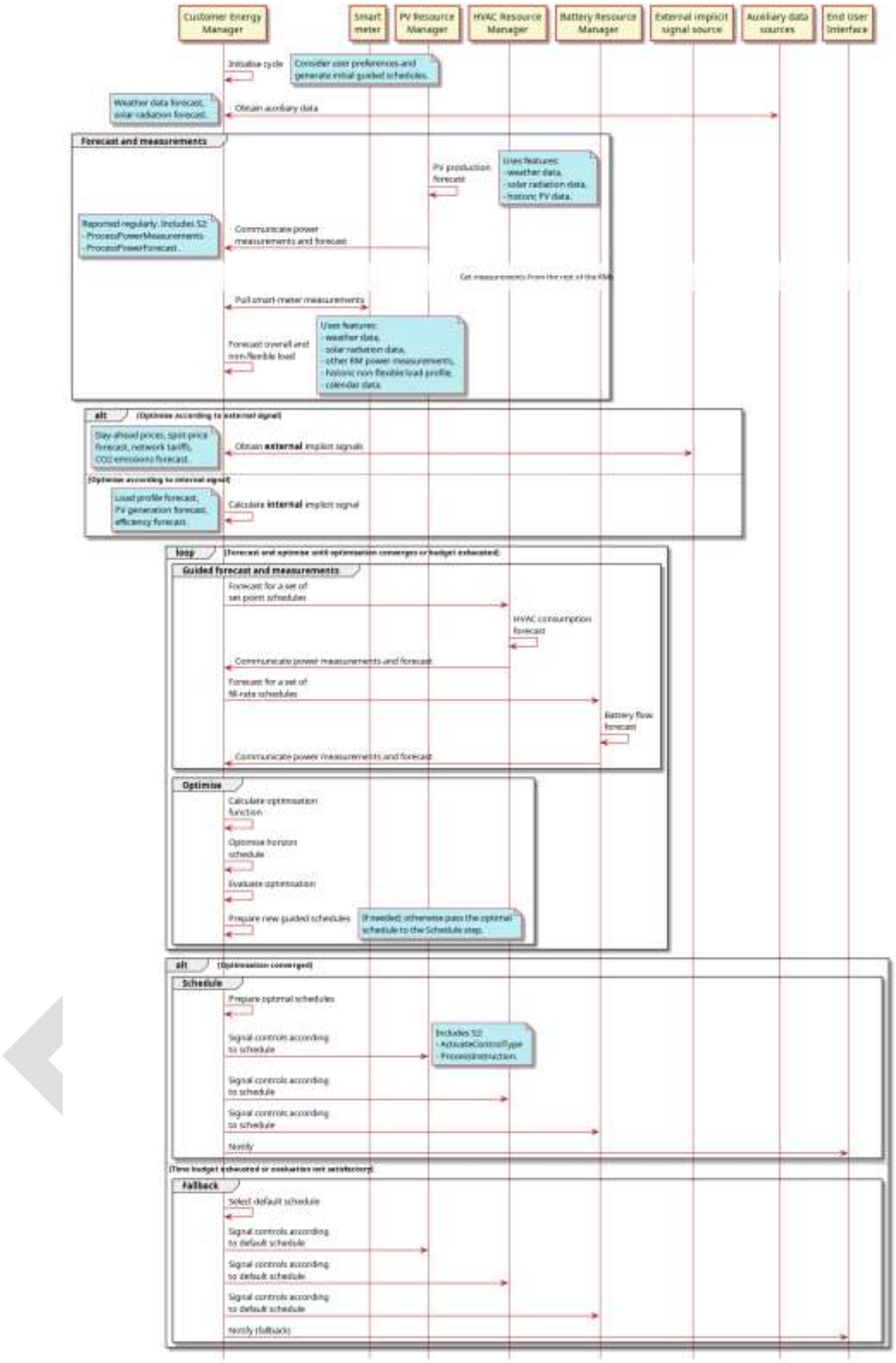
DRAFT



SUC-LFM overview sequence diagram covering preferences setup, operation cycle (in essential form) and monitoring.

10.3.2.3 Sequence Diagram — Operation Cycle Detail

The diagram below details one full operation cycle. It covers cycle initialisation, auxiliary-data acquisition, forecast-and-measurements from non-controllable / passive RMs (illustrated with SM and PV-RM), acquisition of the implicit signal (external OR internal; `alt` block), the **guided-forecast optimisation loop** (`loop` block; iterates until the optimisation converges or the time budget is exhausted), and either the **Schedule** step (on convergence) or the **Fallback** step (on non-convergence). The interactions are labelled with the step numbers from the Steps of the scenario table in Section 10.3.4.2.



SUC-LFM operation cycle detail: initialisation, forecast+measurements, external-vs-internal signal, guided-forecast optimisation loop, and schedule-vs-fallback dispatch. Adapted from INDEPENDENT D2.1 Section 5.3 [2].

10.3.3 Technical details

10.3.3.1 Actors

Actor name	Actor type	Actor description
End User	Business actor	The occupant, tenant, owner or operator of the premises. Configures preferences (goal(s), comfort bounds, operating limitations) and monitors performance via the EUI.
End-User Interface (EUI)	System	UI exposed to the End User for preference configuration, monitoring, and override. Forwards preferences to the CEM and displays monitoring rollups from the CEM.
Customer Energy Manager (CEM)	System	System-level orchestrator conforming to EN 50491-12-1 [3]; runs the operation cycle (initialise → forecast+measurements → obtain signal → guided-forecast optimisation loop → schedule OR fallback → notify), coordinates the RMs over S2 [4], and exposes monitoring to the EUI. Runs the CEM-side scheduler (in the INDEPENDENT reference architecture, a FlexMeasures-backed scheduler [7] per [6, Sec. 7.2.1]).
Semantic Adapters	System	CEM sub-component that provides a uniform interface between resources and RMs where legacy devices need to be wrapped; also provides coherent EUI access to monitoring data.
Smart Meter (SM)	System	Energy metering at the supply point; provides measurements that the CEM uses to forecast the non-flexible baseline load. Not necessarily an S2 RM.
Heat Pump / HVAC Resource Manager (HP-RM / HVAC-RM)	System	S2 RM for the space-heating / hot-water / HVAC resource; supports guided-schedule forecasting and accepts CEM-issued control instructions in the selected S2 control type.
PV Resource Manager (PV-RM)	System	S2 RM for the PV plant; typically operates in NC or a similar report-only control type, providing `ProcessPowerForecast` and `ProcessPowerMeasurements`.
Battery Resource Manager (Battery-RM)	System	S2 RM for the electrical battery / BESS at the premises; supports guided-schedule (fill-rate) forecasting and accepts CEM-issued control instructions.
EV Resource Manager (EV-RM)	System	S2 RM for the electric-vehicle charging point; supports guided-schedule forecasting and accepts CEM-issued control instructions.
White-Goods Resource Manager (WG-RM)	System	S2 RM for shiftable white-goods loads (washing machine, dishwasher, dryer); supports guided-schedule forecasting and accepts CEM-issued control instructions.
External Implicit Signal Source (EIS)	System	External source of external implicit signals: day-ahead prices, spot-price forecast, network tariffs, grid-mix CO2 emissions forecast.
Auxiliary Data Source (ADS)	System	External source of auxiliary data: weather forecast, solar irradiation forecast.

10.3.3.2 References

References cited throughout this Appendix are listed in the IEEE-style **Section 10.3.9 Bibliography** at the end of the document. The principal normative sources are the customer-side energy-management architecture [3], the S2 flexibility-interface standard [4], the use case methodology under which this Appendix is authored [1], the CEM↔AEMS profile that complements S2 upstream [5], and the CEM-

DRAFT

AEMS architecture that provides the surrounding functional context [8]. Project context and the two-level optimisation design are drawn from INDEPENDENT D3.1 [6]. The originating project use case is Local flexibility management in D2.1 Section 5.3 [2]. Security and privacy considerations reference the power-systems data-and-communications-security family [9] and the industrial-automation security family [10].

10.3.4 Step by step analysis of use case

10.3.4.1 Scenario: Nominal LFM operation cycle

Field	Value
Scenario description	The CEM runs one operation cycle: initialises against current user preferences, obtains auxiliary data and forecasts from non-controllable / passive RMs, obtains an implicit signal (external OR internal), runs the guided-forecast optimisation loop against the controllable RMs, and dispatches either the optimal schedule (on convergence) or a pre-configured default schedule (on non-convergence) to the RMs via S2. The end user is notified. Monitoring is continuously available.
Primary actor	Customer Energy Manager (CEM)
Triggering event	Cycle tick (typically hourly or 15-minutely, per horizon settings); or significant change in an implicit signal (configurable threshold); or user preferences update.
Pre-condition	S2 handshake with all controllable RMs completed; user preferences resolved; default schedules configured for every controllable RM.
Postcondition	A schedule (optimal or fallback) has been dispatched to every controllable RM; the end user has been notified of the applied schedule and, in the fallback case, that a fallback was applied. All exchanges are logged for audit.

10.3.4.2 Steps of the scenario

Step	Event	Name of process / activity	Description of process / activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (ID)	Requirement R-IDs
1	Cycle tick	Initialise cycle	CEM resolves current user preferences and generates the initial set of guided schedules for the controllable RMs covering the horizon.	Calculate	CEM	CEM	—	R-1.1, R-1.6
2	Cycle tick	Obtain auxiliary data	CEM retrieves weather forecast and solar-radiation forecast for the horizon	Report	Auxiliary Data Source	CEM	Inf.1	R-2.3

DRAFT

Step	Event	Name of process / activity	Description of process / activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (ID)	Requirement R-IDs
			from external data services.					
3	Cycle tick	Forecast and measurements from passive RMs	CEM collects power measurements and load / generation forecasts from non-controllable / passive RMs (illustrated: PV-RM, SM). CEM then forecasts the overall and non-flexible load using these inputs and historic-pattern models.	Report + Calculate	PV-RM, SM	CEM	Inf.2, Inf.3	R-1.1, R-2.5
4a	Cycle tick	Obtain external implicit signal	CEM retrieves the external implicit signal (day-ahead prices, spot-price forecast, network tariffs, CO2 emissions forecast) for the horizon. Alternative to step 4b.	Report	External Implicit Signal Source	CEM	Inf.4a	R-2.3
4b	Cycle tick	Calculate internal implicit signal	CEM derives an internal implicit signal (load-profile forecast,	Calculate	CEM	CEM	Inf.4b	R-1.1

DRAFT

Step	Event	Name of process / activity	Description of process / activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (ID)	Requirement R-IDs
			PV-generation forecast, efficiency forecast) from local measurements and forecasts. Alternative to step 4a.					
5	Signal available	Send guided-schedule forecast request	CEM sends a candidate guided schedule to each controllable RM (loop iteration). The concrete form of the guided schedule is control-type-specific and is defined by the child SUC — set-point schedule for HVAC, fill-rate schedule for a battery, appliance-run schedule for white-goods, etc.	Send	CEM	Controllable RMs	Inf.5	R-2.5, R-2.11
6	Guided schedule received	Compute guided forecast	Each controllable RM computes the load-profile forecast that would result from following its input guided	Report	Controllable RMs	CEM	Inf.6	R-1.1, R-2.5

DRAFT

Step	Event	Name of process / activity	Description of process / activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (ID)	Requirement R-IDs
			schedule and returns the forecast together with recent measurements to the CEM.					
7	RM forecasts collected	Optimise and evaluate	CEM constructs the optimisation function from the resolved user goal(s) and the implicit signal, and computes an optimal horizon schedule using the RM-returned load-profile forecasts. CEM evaluates convergence against a target tolerance and against a time budget.	Calculate	CEM	CEM	—	R-1.2
8	Not converged, budget remains	Prepare new guided schedules	CEM prepares a new set of guided schedules and returns to step 5. Loop iterates until convergence OR budget exhausted.	Calculate	CEM	CEM	—	R-1.2, R-1.9
9a	Converged	Dispatch optimal schedule	CEM converts the optimal horizon	Send	CEM	Controllable RMs	Inf.7	R-1.1, R-3.5, R-3.9

DRAFT

Step	Event	Name of process / activity	Description of process / activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (ID)	Requirement R-IDs
			schedule into per-RM control instructions and dispatches them to the controllable RMs over S2.					
9b	Budget exhausted	Dispatch fallback schedule	CEM selects the pre-configured default schedule for each controllable RM and dispatches it over S2.	Send	CEM	Controllable RMs	Inf.7’	R-1.9, R-3.5, R-3.9
10	Schedule dispatched	Notify end user	CEM notifies the EUI of the applied schedule and (in the fallback case) that a fallback was applied.	Notify	CEM	EUI	Inf.8	R-1.6
11	Continuous	Monitor	End user checks progress via EUI; CEM streams measurements, applied schedule and rollups to the EUI on demand.	Report	CEM	EUI, End User	Inf.9	R-1.6, R-3.15

10.3.5 Information exchanged

10.3.5.1 Information exchanged (cyclic flow)

The information objects catalogued below are exchanged in every operation cycle. Message identifiers are quoted at the S2 layer where the exchange is normative under EN 50491-12-2:2022 [4]; the concrete S2 message-type payload (e.g. `PEBC.PowerEnvelope` vs. `FRBC.Instruction` vs. `PPBC.PowerProfile`) depends on the S2 control type selected for the RM and is a specialisation property of the child SUC.

DRAFT

Information ID	Requirement R-IDs	Name of information	Message type	Description
Inf.1	R-2.3	Auxiliary data	Outside S2 — REST/HTTPS or similar	Weather forecast and solar-radiation forecast over the horizon, from an external auxiliary-data service.
Inf.2	R-2.5	Measurements + forecast from passive RM	S2: `ProcessPowerMeasurements`, `ProcessPowerForecast`	Recent power measurements and horizon load / generation forecast from a non-controllable / passive RM (illustrated: PV-RM).
Inf.3	R-2.5	Smart-meter measurements	Outside S2 (typically metering interface)	Recent smart-meter measurements at the supply point; used by the CEM to forecast the overall and non-flexible load.
Inf.4a	R-2.3	External implicit signal	Outside S2 — REST/HTTPS or similar	Day-ahead prices, spot-price forecast, network tariffs, and/or grid-mix CO2 emissions forecast over the horizon.
Inf.4b	R-1.1	Internal implicit signal	Internal CEM data	Load-profile forecast, PV-generation forecast, efficiency forecast — derived locally from smart-meter and RM measurements + forecasts.
Inf.5	R-2.5, R-2.11	Guided-schedule forecast request	S2 (control-type specific)	Candidate schedule for the horizon, sent from CEM to a controllable RM as the input to that RM's guided forecast. The concrete payload (set-point schedule / fill-rate schedule / power envelope / power profile / appliance-run schedule) is defined by the

DRAFT

Information ID	Requirement R-IDs	Name of information	Message type	Description
				child SUC and its selected S2 control type.
Inf.6	R-2.5	Guided-forecast response	S2: `ProcessPowerMeasurements`, `ProcessPowerForecast` (+ control-type-specific status)	Load-profile forecast that would result from following the input guided schedule, together with recent measurements, from a controllable RM back to the CEM.
Inf.7	R-3.5, R-3.9	Optimal schedule dispatch	S2: `ActivateControlType`, `ProcessInstruction` (with control-type-specific instruction payload)	Per-RM control instructions covering the horizon, dispatched from CEM on convergence of the guided-forecast optimisation loop. The concrete instruction payload is defined by the child SUC and its selected S2 control type.
Inf.7’	R-3.5, R-3.9	Fallback schedule dispatch	S2: `ActivateControlType`, `ProcessInstruction` (with default-schedule payload)	Per-RM control instructions corresponding to the pre-configured default schedule, dispatched from CEM on non-convergence of the guided-forecast optimisation loop within the time budget.
Inf.8	R-1.6	Applied-schedule notification	Outside S2 — internal CEM ↔ EUI protocol	Human-readable rollup of the applied schedule (optimal or fallback) and expected KPIs, pushed to the EUI.
Inf.9	R-1.6	Monitoring stream	Outside S2 — internal CEM ↔ EUI protocol	Measurements, applied schedule, RM status and performance rollups streamed

DRAFT

Information ID	Requirement R-IDs	Name of information	Message type	Description
				to the EUI on demand.

10.3.5.2 Preferences setup (once at initialisation, updateable at any time)

Setup-ID	Direction	Message	Purpose
Pref.1	End User → EUI	Preference bundle	End user sets or updates goal(s), goal weights, comfort bounds and operating limitations via the EUI.
Pref.2	EUI → CEM	Preference bundle	EUI forwards the resolved preference bundle to the CEM for use in cycle initialisation.

10.3.6 Requirements

The requirements in this section are the LFM-relevant subset of the common IDOP requirements from D2.1 Sections 3.5 and 4.6 [2], mapped onto the IEC 62559-2 R-ID scheme.[2]

10.3.6.1 Requirements regarding configuration issues

Category ID: R-1

Category name for requirements: Requirements regarding configuration issues

Category description: Configuration of components, interfaces, integration paths and user-facing controls required to operate the use case.

Requirement R-ID	Requirement name	Requirement description	Traceability to D2.1
R-1.1	Integration with legacy automation and metering infrastructure	The CEM and RMs need to be able to collect measurement data and send control signals to building and home automation systems, smart meters, and other metering infrastructure at the premises.	CR1
R-1.2	Optimise energy consumption	The CEM needs to be able to optimise energy consumption taking into account user preferences and limits, dynamic energy and network prices, local production from PVs, and energy efficiency of the building / site. The CEM controls resources (flexible assets) according to the optimised schedule.	CR2
R-1.3	Baseline power forecast	The CEM needs to be able to provide the AEMS with a baseline power forecast (i.e. optimised load profile).	CR3
R-1.4	Flexibility forecast / estimate	The CEM needs to be able to provide the AEMS with a forecast or estimate of the available flexibility and related costs.	CR4
R-1.5	React to explicit flexibility activations	The CEM needs to be able to activate the offered flexibility when requested by an AEMS.	CR5
R-1.6	User interaction	The CEM needs to be able to collect user preferences, limits and goals; and to provide the end	CR6

[2] R-IDs in Section 10.3.6 are formed by mapping the D2.1 requirement identifiers (CR-series for CEMS, TR-series for Trust, SR-series for Security, PR-series for Privacy) onto the IEC 62559-2 R-{category}.{index} scheme, with the traceability column listing the source identifier. IDs introduced for this SUC that are not present verbatim in D2.1 (R-1.7, R-1.8, R-1.9, R-2.11, R-2.12) are marked as sourced from D2.1 Section 5.3. The host document INDEPENDENT D2.3 uses a separate letter-prefixed requirement-ID series for its main body; mapping between the two series, if needed, is a publication-time reconciliation task.

DRAFT

Requirement R-ID	Requirement name	Requirement description	Traceability to D2.1
		user with visualisations on energy consumption, system state, and results of DSFM actions (e.g. cost savings and CO2 emission reductions).	
R-1.7	Semantic-adapter coverage	Where legacy devices need to be wrapped, the CEM provides a Semantic Adapter that exposes them through the S2 interface without altering the S2-facing contract.	D2.1 Section 5.3
R-1.8	Default schedule availability	A default schedule is pre-configured for every controllable RM as the fallback when the guided-forecast optimisation loop does not converge within the time budget.	D2.1 Section 5.3
R-1.9	Time-budgeted optimisation	The guided-forecast optimisation loop is subject to a time budget; on exhaustion the CEM falls back to the default schedule (Inf.7' in Section 10.3.5.1).	D2.1 Section 5.3

10.3.6.2 Requirements regarding Quality of Service issues

Category ID: R-2

Category name for requirements: Requirements regarding Quality of Service issues

Category description: Availability, accuracy, latency and recovery requirements of the information flows that constitute the use case.

Requirement R-ID	Requirement name	Requirement description	Traceability
R-2.3	Availability of information flows	Implicit-signal services and auxiliary-data services need to be available with sufficient horizon coverage that the CEM can complete each operation cycle. Day-ahead prices, where used, need to be available before market gate closure for the next horizon.	IEC 62559-2 template + D2.1 Section 5.3
R-2.5	Accuracy of data	Smart-meter energy-reading accuracy ≤ 1 %; weather-forecast temporal granularity ≤ 1 h; CO2-forecast granularity ≤ 1 h; RM `PowerForecast` updated at least once per cycle.	IEC 62559-2 template
R-2.11	Guided-forecast turnaround	Each RM's response to a guided-schedule forecast request (Inf.5 → Inf.6) needs to complete within a time bound that allows the CEM to run the guided-forecast optimisation loop within its total time budget (see R-1.9). Recommended: ≤ 1 s on a local MQTT broker under nominal network conditions per iteration.	D2.1 Section 5.3
R-2.12	RM handshake recovery	After a broker disconnect, the S2 handshake is re-established and the RM's full descriptor is re-emitted within 30 s of reconnect, per EN 50491-12-2:2022 [4].	D2.1 Section 5.3

10.3.6.3 Requirements regarding trust, security and privacy

Category ID: R-3

Category name for requirements: Requirements regarding trust, security and privacy

Category description: Trust, security and privacy properties that apply to the use case, mapped from the D2.1 TSP requirements onto IEC 62559-2 R-ID form. Detailed treatment of the CEM ↔ RM secure-channel and identity model is in D2.1 Section 4.6 and in the surrounding standards families [9], [10].

DRAFT

Requirement R-ID	Requirement name	Requirement description	Traceability to D2.1
R-3.1	Manage identities	Manage identities of the system entities (CEM, RMs, EUI, external services) in a privacy-preserving manner and in a scalable way fit for LFM deployment.	TR1
R-3.2	Manage trust between entities	Bootstrap the relationships between system entities and actors in a secure and privacy-preserving manner.	TR2
R-3.5	Secure communication	Ensure secure communication channels between different entities in the LFM system, using standardised security protocols; concretely, S2 exchanges between CEM and RMs run over TLS-protected transport with mutual authentication.	SR1
R-3.9	Access control	Implement access-control mechanisms suitable to the scale and performance of the deployment; guard access to sensitive assets and data (measurements, preferences, schedules, control instructions) through authorisation policies enforced at the CEM, RM, EUI and external-service interfaces.	SR2
R-3.10	Privacy compliance	Ensure compliance with EU privacy regulations.	PR1
R-3.11	Explicit data flows	Establish explicit data flows to provide information about data origins, rightful owners, data nature and data consumers.	PR2
R-3.12	Explicit consent	Require end-user explicit consent for data processing and ensure the presence of the intended data processor among authorised processors.	PR3
R-3.13	Data minimisation	Implement data-minimisation techniques to collect and process only the necessary data.	PR4
R-3.14	Transparency	Provide transparency for end users about data collection, processing and sharing.	PR5
R-3.15	Privacy by design	Develop novel mechanisms through privacy-by-design and privacy-by-default principles, ensuring privacy considerations are integrated into the system from its inception.	PR6

10.3.7 Common terms and definitions

10.3.7.1 Common terms and definitions

Term	Definition
ACL	Access Control List
AEMS	Aggregator Energy Management System
BESS	Battery Energy Storage System
BMS	Building Management System
CEM	Customer Energy Manager (EN 50491-12-1 [3])
CEMS	Customer Energy Management System
CO2	Carbon dioxide; in this document, the grid-mix CO2 emission factor
Controllable RM	An RM whose associated resource can be scheduled by the CEM through S2 (as opposed to a passive / report-only RM such as a smart-meter feed or an NC-mode PV-RM).
Default schedule	A pre-configured safe schedule for each controllable RM, dispatched by the CEM when the guided-forecast optimisation loop does not converge within the time budget.
DHW	Domestic Hot Water

DRAFT

Term	Definition
DR	Demand Response
DSFM	Demand-Side Flexibility Management
DSO	Distribution System Operator
EIS	External Implicit Signal (source)
EUI	End-User Interface
EV	Electric Vehicle
Guided schedule	A candidate schedule sent from CEM to a controllable RM as the input to that RM's guided forecast. The concrete form (set-point schedule, fill-rate schedule, power envelope, power profile, appliance-run schedule) is control-type specific.
Guided-forecast optimisation loop	The iterative CEM ↔ RM exchange within one operation cycle in which the CEM sends candidate guided schedules to the controllable RMs, receives their load-profile forecasts, optimises against the objective, evaluates convergence, and either exits with an optimal schedule or prepares a new set of guided schedules and iterates.
Horizon	The look-ahead window over which the CEM optimises; typically one day.
HVAC	Heating, Ventilation and Air-Conditioning
HP	Heat Pump
Implicit signal	A signal that motivates flexibility indirectly through price / cost / carbon-intensity information (as opposed to an explicit dispatch command). May be *external* (e.g. day-ahead prices, tariffs, CO2 forecast) or *internal* (e.g. peak-shaving target, PV self-consumption target).
LFM	Local Flexibility Management (this system use case)
MPC	Model Predictive Control
MQTT	Message Queuing Telemetry Transport
Operation cycle	One end-to-end pass of initialise → forecast+measurements → obtain signal → guided-forecast optimisation loop → schedule or fallback → notify, typically triggered every hour or every 15 min.
PV	Photovoltaic
RM	Resource Manager (EN 50491-12-1 [3])
S2	Energy-flexibility interface standard EN 50491-12-2:2022 [4]
SFH	Single-Family House
SM	Smart Meter
SoC	State of Charge
SUC	System Use Case
Time budget	The wall-clock allowance for the guided-forecast optimisation loop within one operation cycle; on exhaustion the CEM falls back to the default schedule.
TLS	Transport Layer Security
TOU	Time-of-Use (tariff)
TSO	Transmission System Operator
TSP	Trust, Security and Privacy
White goods	Shiftable household appliances (washing machine, dishwasher, dryer, etc.)

10.3.8 Custom information

10.3.8.1 Contributing institutions

Organisation name	Acronym	Country
Jožef Stefan Institute	IJS	Slovenia
(additional contributors from the INDEPENDENT consortium to be listed at publication time)		

DRAFT

10.3.8.2 Classification and provenance

- **Technologies addressed:** Customer Energy Manager, Resource Manager, S2 interface, End-User Interface, external implicit-signal services, auxiliary-data services.
- **High-level use case classification:** HLUC 9 — *Flexibility provision by Buildings, Districts and Industrial Processes*.
- **Funding context (traceability):** INDEPENDENT — Horizon Europe project on integrated energy demand-side flexibility [grant agreement no. 101172675]. Cordis link *(insert the official URL before publication)*.

10.3.8.3 Envisaged specialisations

SUC-LFM is intentionally control-type-neutral at the S2 layer and resource-mix-neutral at the premises layer. Concrete deployments are specialised as child SUCs. The first published child specialisation, and other specialisations envisaged for the INDEPENDENT platform:

Child SUC ID	Scope	S2 control type(s)	Status
SI-SUC01	Single-family house with heat-pump and PV	PEBC (primary), FRBC (alternative), NC (PV)	**Published** — see companion Appendix.
(envisaged) SFH-BAT	Single-family house with battery, PV and heat-pump	Mix of FRBC (battery, thermal storage) + NC (PV) + PEBC (HP)	Envisaged, not yet specified.
(envisaged) MDU-HVAC	Multi-dwelling / apartment-building HVAC and shared services	To be selected per building	Envisaged, not yet specified.
(envisaged) TER-HVAC	Tertiary building (offices / retail / public) with HVAC and PV	To be selected per building	Envisaged, not yet specified.
(envisaged) IND-PROC	Industrial site with process-schedule constraints and multi-vector coupling	To be selected per site	Envisaged, not yet specified. Includes additional actors (process controller, safety interlock) and additional constraints (batch schedule, safety envelope) that specialise Section 4.2.

The cross-reference between SUC-LFM and its published child SUCs (currently SI-SUC01) is maintained at project level; see the project cross-reference note `D2_3-cross-reference-note.md`.

10.3.9 References

[1] IEC, “IEC 62559-2 – Use case methodology – Part 2: Definition of the templates for use cases, actor list and requirements list,” International Electrotechnical Commission (IEC), Geneva, 2015. Available: https://webstore.iec.ch/
[2] INDEPENDENT consortium, “D2.1 – Initial Requirements and IDOP Architecture,” INDEPENDENT (Horizon Europe project, grant agreement no. 101172675), Project deliverable D2.1, 2025.
[3] CENELEC, “EN 50491-12-1:2018 – General requirements for Home and Building Electronic Systems (HBES) and Building Automation and Control Systems (BACS) – Smart grid – Application specification – Interface and framework for customer – Part 12-1: Interface between the Customer Energy Manager and the resource,” European Committee for Electrotechnical Standardization (CENELEC), Brussels, 2018. Available: https://standards.cencenelec.eu/
[4] CENELEC, “EN 50491-12-2:2022 – Customer Energy Manager – Part 12-2: S2 interface,” European Committee for Electrotechnical Standardization (CENELEC), Brussels, 2022.
[5] IEC, “IEC 62746-4 – Systems interface between customer energy management system and the power management system – Part 4: Profile for direct flexibility communication between AEMS and CEMS,” International Electrotechnical Commission (IEC), Geneva, 2024. Available: https://webstore.iec.ch/

DRAFT

[6] INDEPENDENT consortium, “D3.1 – Initial Customer Energy Management Systems Package,” INDEPENDENT (Horizon Europe project, grant agreement no. 101172675), Project deliverable D3.1, 2026.
[7] Seita B.V., “FlexMeasures: Open-source energy flexibility platform.” Linux Foundation Energy, 2025. Available: https://flexmeasures.io/
[8] IEC, “IEC TS 62746-3:2015 – Systems interface between customer energy management system and the power management system – Part 3: Architecture for systems for energy management in the demand side,” International Electrotechnical Commission (IEC), Geneva, Technical Specification, 2015. Available: https://webstore.iec.ch/
[9] IEC, “IEC 62351 series – Power systems management and associated information exchange – Data and communications security,” International Electrotechnical Commission (IEC), Geneva, 2020. Available: https://webstore.iec.ch/
[10] IEC, “IEC 62443 series – Security for industrial automation and control systems,” International Electrotechnical Commission (IEC), Geneva, 2018. Available: https://webstore.iec.ch/

DRAFT