



D2.2 – DIGITISE Evaluation Protocol, Novel Market Models and Architecture Design

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Preface

Funded by the European Commission under Grant Agreement number 101160671, DIGITISE is a project focused on enhancing the digital literacy and empowerment of consumers and prosumers in the energy sector. By integrating advanced technologies and fostering active engagement in digital energy activities and markets, DIGITISE aims to play a crucial role in the global energy transition.

Executive Summary

This deliverable presents the DIGITISE D2.2 – DIGITISE *Evaluation Protocol, Novel Market Models and Architecture Design* presents a comprehensive framework that integrates performance evaluation methodologies, market model assessments, and the system architecture design of the DIGITISE platform. The work laid out in this deliverable is fundamental for guiding the technical implementation, evaluation processes, and long-term scalability of the project’s digital solutions.

The document is structured into three major sections. The first focuses on the definition of a performance measurement and verification framework, introducing a wide set of Key Performance Indicators (KPIs) derived from literature, past projects, and internal project use cases. These KPIs are classified into five categories—energy, social, business/economic, technical and environmental—and are tailored to reflect the multi-dimensional impact of DIGITISE innovations. Each use case is linked to relevant KPIs, ensuring traceability between the platform's functionalities and the outcomes to be monitored. Furthermore, the definition of the measurement and verification framework is presented as an outcome of the review analysis, to establish the basis for evaluating the different KPIs using standards-based methodologies, and reflecting the needs specified in the DoA for a comprehensive evaluation framework.

The second section provides an in-depth analysis of existing and emerging energy market models across Europe, with a particular focus on balancing markets and local flexibility markets. This assessment helps identify integration challenges, regulatory gaps, and innovation opportunities within the current market landscape. The findings are summarised as follows. The European balancing markets allow countries to maintain in real time the balance between generation and electricity demand by activating flexible resources. These mechanisms are mainly managed through common platforms such as FCR Cooperation, PICASSO (aFRR), MARI (mFRR) and TERRE (RR), coordinated by ENTSO-E. Most European countries actively participate in these platforms, conducting daily auctions to secure reserve capacity and promote cross-border exchange of balancing energy. France, for example, is part of FCR Cooperation and must procure at least 30% of its reserve through regional cooperation. Estonia, Ireland, and Croatia have developed internal FCR markets, while others such as Spain and Greece do not compensate for the activation of this reserve, as it is considered a natural response of synchronous generators. Ireland and Cyprus are the only major exceptions in Europe. As island systems, they face greater technical difficulties in fully integrating into these platforms. For this reason, both countries are excluded from comparative analyses on the operation of balancing and balancing markets and participation in European platforms. All other countries are already integrated or in the process of integration into these common platforms, demonstrating a

widespread commitment to regional cooperation, system efficiency and the development of flexible solutions at the continental level. Local flexibility markets (LFMs) are at different stages of development in Europe. France is the only country with a fully operational LFM, while Portugal, Ireland and Estonia are driving programs led by industry players. Spain and Croatia are in the pilot phase and Cyprus lacks any flexibility market. These markets allow distributed resources to participate in grid management, favouring a more decentralized energy model. Although they are based on European regulations, national differences in their application, requirements and technologies make their comparison and cross-border expansion difficult. Following the review analysis and the identification of key bottlenecks hindering the penetration of flexibility services, several observations are made regarding the structure of flexibility markets, along with a preliminary definition of flexibility products relevant to the project's context. It is important to highlight that a co-creation process is being applied, with demo partners directly contributing to the early definition of these flexibility products.

Finally, the third part of the deliverable outlines the DIGITISE architecture design, providing both a high-level conceptual framework and a detailed component-based technical structure. It describes the Data Space environment, AI-powered analytics modules, and a range of energy and non-energy applications integrated into the DIGITISE platform. The architecture follows a modular approach that supports scalability, interoperability, and privacy-by-design principles. It also includes a development and deployment roadmap aligned with project milestones and use case requirements, ensuring a coherent technical evolution across work packages.

Altogether, this deliverable ensures that the DIGITISE platform is built on a solid foundation of performance metrics, aligned market integration, and cutting-edge digital architecture. These elements will support the project's goals of empowering users, enhancing system flexibility, and accelerating the energy transition through secure, intelligent, and human-centric digital solutions.

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Abbreviations

Abbreviation	Full Name
aFRR	automatic Frequency Restoration Reserve
ATC	Available Transmission Capacity
BESS	Battery Energy Storage System
BM	Balancing Market
BM	Balancing Markets
BSP	Balancing Service Provider
CBMP	Cross Border Marginal Prices
CNMC	Spanish National Commission on Markets and Competition
CRE	French Energy Regulation Commission
DoA	Description of Action
DR	Demand Response
DRR	Dynamic Reactive Response
DSO	Distribution System Operator
EBGL	Electricity Balancing Guideline
EC	European Commission
ERSE	Redes Energéticas Nacionais
ESCO	Energy Service Companies
EU	European Union
FCR	Frequency Containment Reserve
FO	Flexibility Off-taker
FO	Flexibility Off-takers
FSP	Flexibility Service Providers
GDPR	General Data Protection Regulation
HVAC	Heating, ventilation, and air conditioning
IMO	Independent Market Operator
KPIs	Key Performance Indicators
LEC	Local Energy Community
LFC	Load-Frequency Control
LFM	Local Flexibility Market
LL	Living Lab
LV	Low Voltage
mFRR	manual Frequency Restoration Reserve
MV	Medium Voltage
NECP	National Energy and Climate Plans
PV	Photovoltaic

REE	Red Eléctrica de España
RR	Replacement Reserve
RTE	Réseau de Transport d'Électricité
SO	System Operator
SOGL	System Operation Guideline
SRAD	Active Demand Response Service
TSO	Transmission System Operator

1 Introduction

1.1 Scope of the Document

The scope of this deliverable is threefold: to provide the details of a comprehensive evaluation framework that serves as a cornerstone for validating the impact and effectiveness of the project's activities; to incorporate a review of flexibility markets and offer an early definition of the project's flexibility products; and to support the definition of the DIGITISE project's architecture.

In more details and building upon standards-based methodologies for baseline assessment and verification, the KPI framework will ensure that all energy-related aspects are evaluated with rigor and in alignment with recognized industry practices. At the same time, it expands beyond traditional energy metrics to include additional quantifiable Key Performance Indicators (KPIs) spanning technical, economic, environmental, social, and business domains. This broader scope is critical for capturing the project's holistic impact, especially regarding enhancing digital services for household customers. A key focus of this work lies in addressing the evaluation of non-energy benefits, such as improvements in health, financial resilience, and social well-being. Furthermore, as part of the work we initiate an early mapping between the defined project use cases and the various KPI sub-groups. This alignment ensures that the evaluation approach remains tailored to the specific characteristics and objectives, while maintaining a coherent structure for assessing project-wide outcomes.

This document also outlines the outcomes of Task 2.4, which aims to assess the implications of the energy and flexibility markets. The scope centers on proposing modifications to existing flexibility services and related processes to better align with the evolving digital landscape. As part of this work, the document provides a detailed analysis of current market practices, focusing on how flexibility is currently defined, contracted, and activated within established energy systems.

Moving beyond the Sota analysis, special attention is given to the definition of discrete flexibility and demand response products suitable for use in overlay flexibility and balancing markets. These products are designed with consideration for the technical characteristics of the flexible assets involved—such as ramp-up/down times, service durations, and operational constraints—while also aligning with the technical requirements imposed by the markets they aim to serve. These insights are intended to inform the development of digital tools and functionalities under WP5, specifically those supporting consumer enrollment in flexibility marketplaces and enabling the execution of associated transactions.

Finally, this document builds on the outcomes of previous WP2 activities and relevant reference architectures (i.e. DERA 3.0) to define the overall architecture of the DIGITISE project, specifying the key technical components, their functionalities, and integration principles. The approach systematically translates requirements into modular features while ensuring a structured and comprehensive technical design.

The architecture incorporates tools, interfaces, and components, using a graphical notation language such as UML to illustrate integration logic. A key focus is on interoperability, leveraging existing, validated solutions from the past and ongoing EC projects. This strategy optimizes development efforts and ensures alignment with standard-based communication protocols and data models, fostering seamless semantic interoperability across the DIGITISE ecosystem.

1.2 Relevance to other Deliverables

This deliverable closely interacts with several tasks and work packages across the DIGITISE project to ensure alignment with overall project goals, stakeholder needs, and consistent technical development. It builds on the outcomes of Task 2.1 by incorporating both functional and non-functional requirements into the architectural design and evaluation framework. In this way, it ensures that DIGITISE architecture responds to both general and pilot-specific business needs. The Key Performance Indicators (KPIs) defined in this deliverable are derived from the business objectives outlined in T2.1, providing a foundation for the measurable validation of project outcomes. In addition, the regulatory analysis from T2.1, including aspects such as data governance and market rules, is integrated into both the flexibility market review and the architectural design to ensure compliance and relevance. The systematic mapping of requirements to architectural components enhances clarity in design and supports consistency, interoperability, and scalability across project activities.

The deliverable also draws from Task 2.2 to strengthen the societal relevance and user-centric focus of the project. Insights from T2.2's social impact evaluations have informed the early design of flexibility products and contributed to shaping the architectural approach, ensuring that user needs and social considerations are embedded from the outset.

Beyond Tasks 2.1 and 2.2, this deliverable is linked with several additional components of the project. The definition of KPIs directly supports the demonstration and evaluation activities to be conducted in WP6, enabling a structured and consistent assessment of the project's impact. The flexibility products and services proposed herein are aligned with the business and implementation work carried out in WP5, ensuring a coherent development of flexibility-related offerings. Furthermore, the architectural design presented in this document serves as a key reference point for the technical work in WP3,

WP4, and WP5, bridging the gap between high-level requirements, market insights, and the practical implementation of the DIGITISE platform.

In this way, the deliverable functions as an integrative element within the project, ensuring that requirements, market conditions, social impact, and technical execution are fully aligned and therefore drive the implementation activities in the next phase of the project.

1.3 Structure of the Document

This document is organized as follows:

- Chapter 1: This chapter provides an overview of the deliverable, outlining its objectives, scope, and the motivation behind the deliverable. It also introduces the structure of the document and summarizes the key themes addressed in the subsequent chapters.
- Chapter 2: In this chapter, we define the Key Performance Indicators that will be used to evaluate the impact and effectiveness of the project's activities. The rationale behind the selection of each KPI is discussed, along with the methodologies for their measurement and assessment.
- Chapter 3: This chapter presents a comprehensive review of the existing balancing and flexibility markets in each country represented by the project partners. It examines the regulatory frameworks, market mechanisms, and the current status of flex markets, providing comparative insights and identifying best approaches for new flexibility products in the project.
- Chapter 4: This chapter details the proposed architecture for the DIGITISE project. It describes the system components, their interactions, and the overall design principles. This section also discusses how architecture supports the development and deployment of the different solutions.

The document concludes with a summary and key takeaways, providing a roadmap for the next steps in the DIGITISE project.

2 Performance Measurement, verification framework, and KPIs

This task aims at developing a tool for performance measurement, verification framework, and quantified key performance indicators (KPIs). It is expected to be useful in tracking and evaluating the efficiency and effectiveness of DIGITISE actions through various metrics and data points, assessing the extent to which the project is meeting its objectives. For the verification framework, it is critical to apply a structured approach to ensure data accuracy and reliability. For KPIs, it is essential to define specific, measurable metrics that capture the most important aspects of the project. The performance measurement requires a structured methodology for data collection and verification to enhance accuracy and reliability.

Our approach to developing this task is highlighted in Figure 1. We began by conducting a comprehensive review of the current state of the art, carefully selecting and listing relevant KPIs, including some predefined in the DoA and others sourced from the literature. These KPIs spanning various domains, are thoroughly quantified and are well-documented with detailed descriptions. Moving forward, our focus will shift towards the careful selection of KPIs tailored specifically to the unique characteristics and objectives of each use case within the demos/pilots. This customization ensures that the evaluation of project outcomes remains pertinent and effective across different contexts by aligning KPIs with the specific goals of each scenario.

Apart from the KPIs, the process to set the M&V methodology with baseline data collection to establish a reference point prior project implementation is needed. Standardized approaches are considered in the analysis to tackle the different use cases examined in the project. By setting the M&V methodology and the KPIs selection we pave the way for the support of the demonstration activities of the project in WP6.

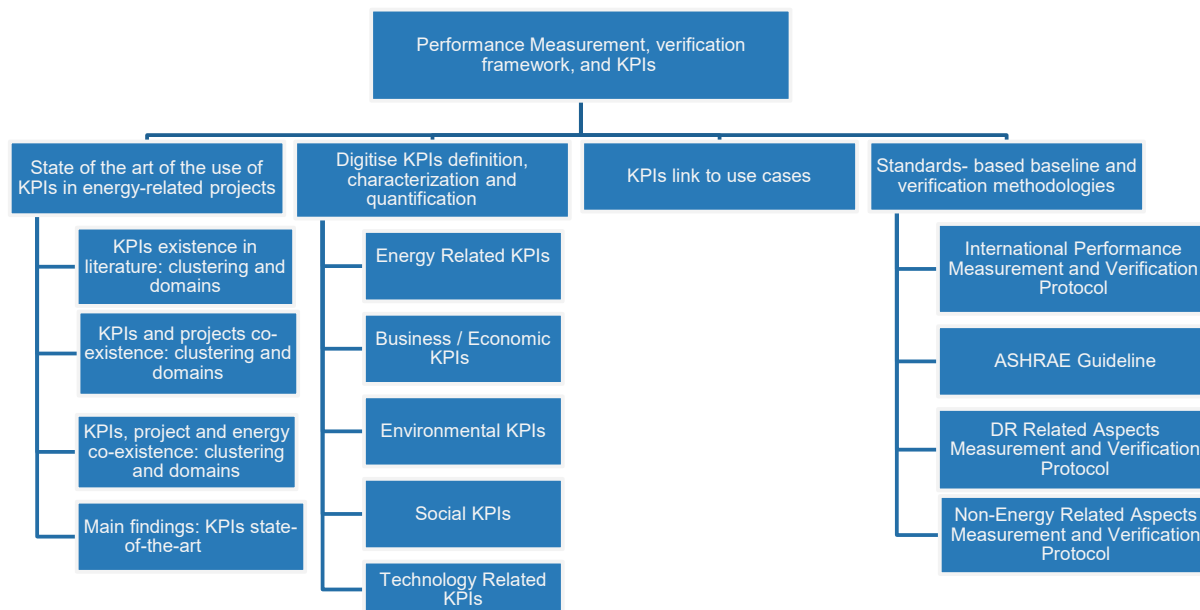


FIGURE 1. PERFORMANCE MEASUREMENT, VERIFICATION FRAMEWORK, AND KPIs

2.1 State of the art of the use of KPIs in energy-related projects

The methodology of this study involved a systematic search within the SCOPUS database, aimed at uncovering the prevalence and application of Key Performance Indicators (KPIs) across various domains. The process was structured into three distinct phases, as illustrated in Figure 2. In the first phase, a broad query (Query 1) was used to retrieve all documents where the term "KPI" appeared up to the end of 2023. This general search provided an overview of how KPIs are utilized across different fields, forming the foundation for further analysis. The results were then categorized into five primary domains: Technic, Economic, Environmental, Business, and Social, ensuring a structured approach to understanding the distribution of KPI-related research. The second phase refined the search to focus on documents where both "KPI" and "Project" co-exist. This query (Query 2) was designed to highlight the relevance of KPIs specifically within the context of project management. By targeting documents that integrate these two key terms, the study aimed to identify the intersection where KPIs play a critical role in project outcomes across the previously identified domains. In the third and final phase, the focus was further narrowed using Query 3 to include documents where "KPI," "Project," and "Energy" are all present. This specialized query was formulated to explore the application of KPIs within energy-related projects, recognizing the unique challenges and opportunities in this sector. The documents retrieved through this query were then categorized across the same five domains, providing a detailed view of how KPIs are used in energy projects.

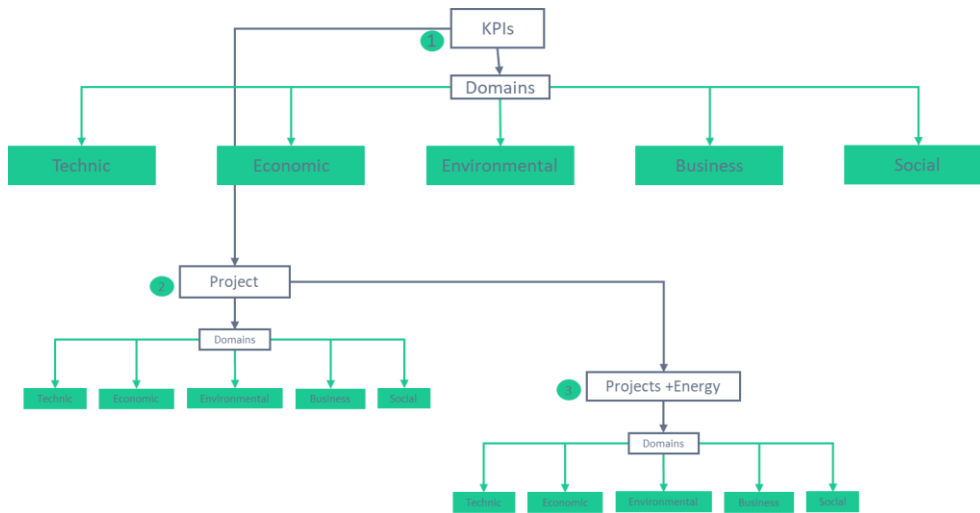


FIGURE 2. STATE-OF-THE-ART METHODOLOGY

2.1.1 KPIs existence in literature: clustering and domains

From the analysis, the general KPI query, *Query 1; TITLE-ABS-KEY ("kpi*") AND (EXCLUDE (PUBYEAR, 2024))* returned 10,467 documents. The results were then visualized in Figure 3, where a network of 108 keywords is presented out of 52,215 identified keywords with a criterion of 100 minimum occurrences. The visualization reveals interconnected clusters that demonstrate the central role of KPIs in driving performance and decision-making. The central green cluster highlight terms such as "benchmarking," "key performance indicators," and "decision making," emphasizing their importance in measuring performance and guiding strategic decisions. This cluster also includes terms related to business efficiency, such as "supply chain management" and "sustainable development," illustrating KPIs' broad application in enhancing organizational effectiveness. The yellow cluster pertains to healthcare, featuring terms like "health care quality," "human," and "demographic descriptors", highlighting KPIs' role in improving healthcare outcomes and understanding population dynamics. The blue cluster emphasizes technology, with keywords like "5G mobile communication," "Internet of Things," and "machine learning," showing KPIs' importance in evaluating technological innovation. Lastly, the red cluster which centres on operational efficiency and risk management, with terms like "quality control," "process control," and "energy management," underscoring KPIs' role in optimizing processes and managing risks across industries.

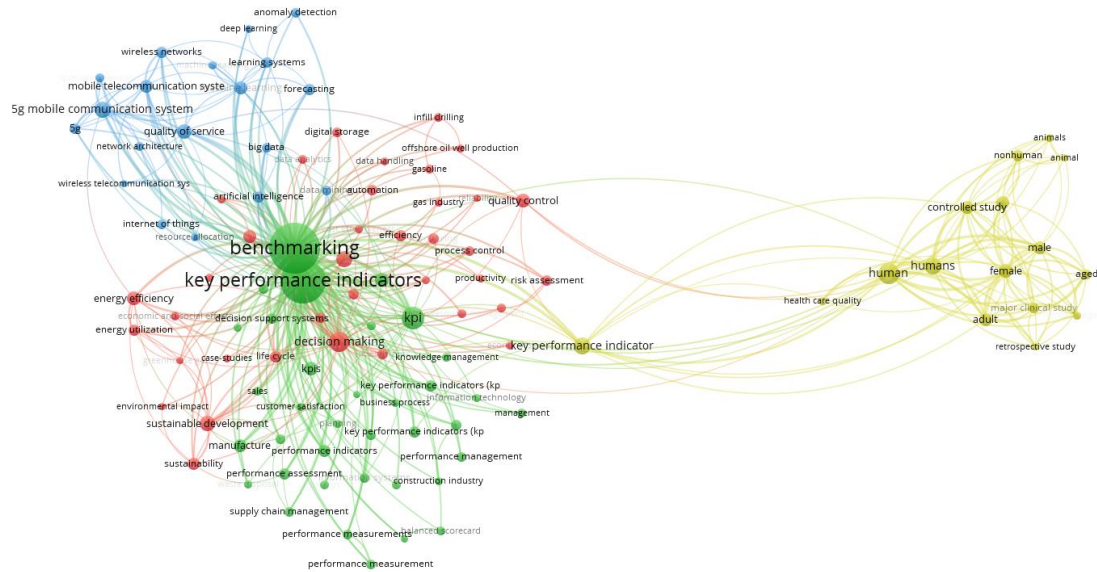


FIGURE 3. KEYWORDS NETWORK OF DOCUMENTS WHERE THE TERM KPI EXISTS.

When characterizing KPIs across diverse domains, we found that business KPIs dominate with 1,862 documents, underscoring their extensive use in business management (see Table 1). To provide a clearer comparison, the number of documents in other domains has been normalized against the business domain, and the corresponding percentages are included. This percentage column quantifies the deviation from the domain with the highest output. Economic KPIs follow with 1,133 documents, representing 61% of the business domain. Environmental and technical KPIs have 850 (46%) and 695 (37%) documents, respectively. Social KPIs, with 775 documents (42%), show the least representation, indicating a potential research gap in this area.

Category	Query	Results	Normalized
Technic	TITLE-ABS-KEY ("kpi*" AND "technic*") AND (EXCLUDE (PUBYEAR, 2024))	695	37%
Economic	TITLE-ABS-KEY ("kpi*" AND "economic*") AND (EXCLUDE (PUBYEAR, 2024))	1,133	61%
Environmental	TITLE-ABS-KEY ("kpi*" AND "environmental*") AND (EXCLUDE (PUBYEAR, 2024))	850	46%
Business	TITLE-ABS-KEY ("kpi*" AND "business*") AND (EXCLUDE (PUBYEAR, 2024))	1,862	100%
Social	TITLE-ABS-KEY ("kpi*" AND "social*") AND (EXCLUDE (PUBYEAR, 2024))	775	42%

TABLE 1. QUERY SEARCH STRINGS: KPIs USE PER DOMAIN

2.1.2 KPIs and projects co-existence: clustering and domains

A similar analysis was conducted using the second query, Query 2: TITLE-ABS-KEY ("kpi*" AND "project*") AND (EXCLUDE (PUBYEAR, 2024)), which returned 1,593 documents.

The distribution per domain is presented in Table 2. Here, business domain leads significantly with 345 documents (100% normalized), indicating a strong focus on KPIs in business projects. The Economic domain follows with 248 documents (72%), highlighting the importance of KPIs in economic projects. The Technic domain has 199 documents (58%), showing a moderate focus on technical project KPIs. Environmental projects have 186 documents (54%), reflecting considerable attention to environmental KPIs. The Social domain, with 165 documents (48%), indicates the least focus on social project KPIs.

Category	Query	Results	Normalized (%)
Technic	TITLE-ABS-KEY ("kpi*" AND "technic*" AND "project*") AND (EXCLUDE (PUBYEAR, 2024))	199	58%
Economic	TITLE-ABS-KEY ("kpi*" AND "economic*" AND "project*") AND (EXCLUDE (PUBYEAR, 2024))	248	72%
Environmental	TITLE-ABS-KEY ("kpi*" AND "environmental*" AND "project*") AND (EXCLUDE (PUBYEAR, 2024))	186	54%
Business	TITLE-ABS-KEY ("kpi*" AND "business*" AND "project*") AND (EXCLUDE (PUBYEAR, 2024))	345	100%
Social	TITLE-ABS-KEY ("kpi*" AND "social*" AND "project*") AND (EXCLUDE (PUBYEAR, 2024))	165	48%

TABLE 2. DOMAINS SPECIFIC QUERY STRINGS FOR KPIs IN VARIOUS PROJECTS

2.1.3 KPIs, project and energy co-existence: clustering and domains

The network visualization of keywords from documents where "KPI," "energy," and "project" co-exist highlights the key connections among these concepts. Using Query 3: TITLE-ABS-KEY ("kpi*" AND "energy*" AND "project*") AND (EXCLUDE (PUBYEAR, 2024)), we retrieved 255 documents. The keywords identified from these documents were then visualized and clustered similarly to previous analyses.

Several thematic clusters emerge in the visualization, with "benchmarking" again as the central term. The yellow cluster focuses on "benchmarking," "energy management," and "renewable energy resources," underscoring the importance of KPIs in optimizing energy resources and integrating renewables into projects. The green cluster centers on "energy utilization" and "conservation," reflecting efforts to optimize energy use while incorporating economic considerations such as "investments" and "cost-benefit analysis" in project management. The red cluster highlights environmental concerns, including "greenhouse gases," "carbon dioxide," and "emission control," illustrating how KPIs are used to monitor

and mitigate the environmental impact of energy projects. Lastly, the blue cluster emphasizes "decision making," "energy efficiency," and "smart city," showcasing the application of KPIs in enhancing energy efficiency and addressing global challenges like climate change.

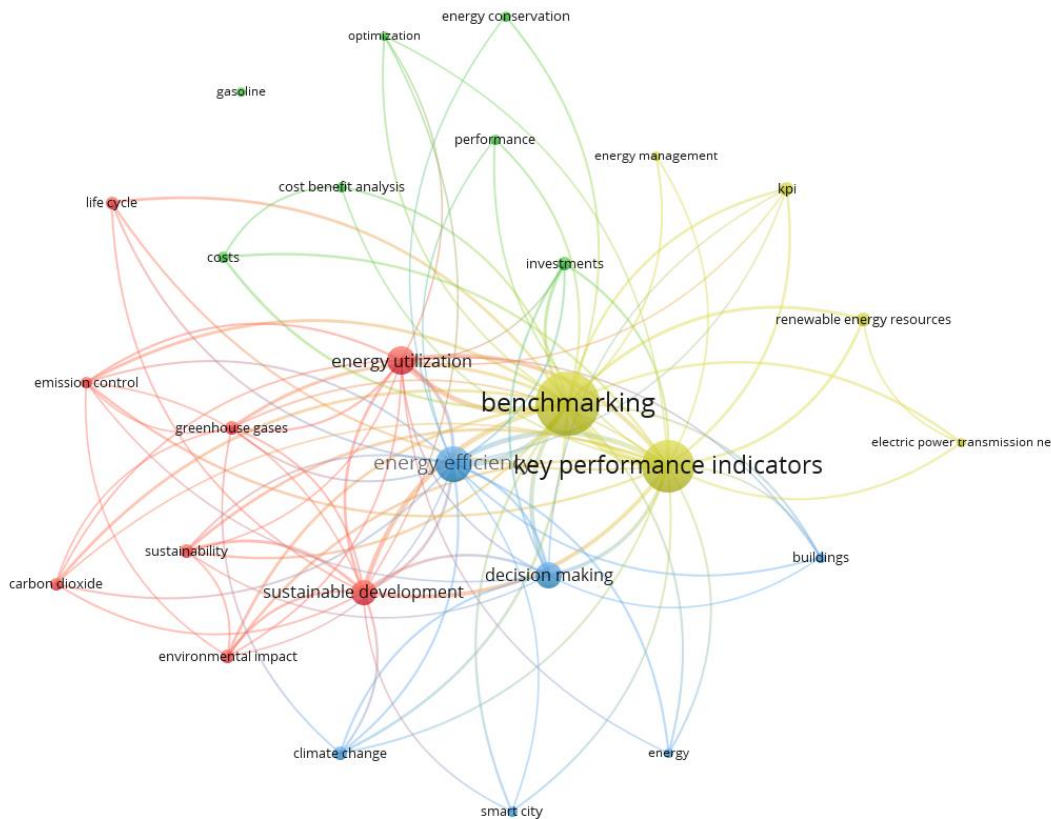


FIGURE 5. KEYWORDS NETWORK OF DOCUMENTS WHERE KPI, ENERGY, AND PROJECT CO-EXIST

A similar analysis was carried out to identify distribution per domain. Here, the Economic and Environmental categories lead with 78 (100%) and 72 (92%) documents respectively, focusing on financial and environmental metrics. Technic follows with 45 documents (58%), while business and social categories trail with 38 (49%) and 31 (40%) results respectively, indicating less focus on business and social KPIs in current energy literature.

Category	Query	Results	Normalized
Technic	TITLE-ABS-KEY ("kpi*" AND "energy*" AND "project*" AND "technic*") AND (EXCLUDE (PUBYEAR , 2024))	45	58%
Economic	TITLE-ABS-KEY ("kpi*" AND "energy*" AND "project*" AND "economic*") AND (EXCLUDE (PUBYEAR , 2024))	78	100%

Environmental	TITLE-ABS-KEY ("kpi*" AND "energy*" AND "project*" AND "environmental*") AND (EXCLUDE (PUBYEAR , 2024))	72	92%
Business	TITLE-ABS-KEY ("kpi*" AND "energy*" AND "project*" AND "business*") AND (EXCLUDE (PUBYEAR , 2024))	38	49%
Social	TITLE-ABS-KEY ("kpi*" AND "energy*" AND "project*" AND "social*") AND (EXCLUDE (PUBYEAR , 2024))	31	40%

TABLE 3. DOMAINS SPECIFIC QUERY STRINGS FOR KPIS IN THE ENERGY SECTOR, VARIOUS PROJECTS

2.1.4 Main findings: KPIS state-of-the-art

This study the literature through bibliometric analysis offers critical insights into the application of Key Performance Indicators (KPIs) across various fields, particularly in business, economic, and energy project contexts. The findings highlight the dominant use of KPIs in business and economic settings, where they effectively measure performance, profitability, and efficiency, guiding strategic decisions and resource allocation. However, this focus has resulted in a significant underrepresentation of KPIs in environmental and social domains, signalling a gap that needs to be addressed, especially as sustainability and social responsibility become increasingly important. In project-oriented contexts, the study confirms the widespread use of KPIs to track progress and outcomes, particularly in technical and environmental projects. However, the lack of emphasis on social KPIs in projects with societal impacts reveals a critical area for development. Integrating social KPIs is essential for a more comprehensive and holistic approach to project assessment, ensuring that projects contribute positively to social welfare and community needs. The study also underscores the interdisciplinary application of KPIs, especially in energy-related projects, where economic, environmental, and technical factors intersect. While economic and environmental KPIs are well-represented in these projects, the absence of social KPIs points to a significant gap in current frameworks. Addressing this gap is crucial for developing more inclusive and comprehensive evaluation methods that consider the full range of impacts, including social dimensions such as community impact and equity.

2.2 KPIS definition, characterization and quantification

The DIGITISE project is designed to create a robust evaluation framework that validates the project's activities, impacts, and outcomes. This approach involves the standardized collection and quantification of Key Performance Indicators (KPIs) across multiple domains, which play a crucial role in measuring the success of the project during its pilot implementations.

The KPIs have been carefully defined and refined based on the project’s Description of Action (DoA). The initial list of KPIs, as specified in the DoA, has been updated to reflect the objectives derived from the various use cases examined within the project, while also incorporating insights from the literature review presented above. Each KPI corresponds to specific objectives that align with the broader goals of the DIGITISE project, enabling a thorough evaluation of parameters such as energy savings, market penetration, consumer engagement, system reliability, and environmental impact.

All in all, to support a comprehensive assessment of the project's overall effectiveness, the KPIs—spanning energy, technical, economic, environmental, social, and business dimensions—are categorized into distinct groups. The following section presents the detailed list of KPIs identified in the project, along with their classification into these groups

2.2.1 Energy Related KPIs

Energy KPIs measure aspects to the core of the energy services examined in the project, namely energy savings, self-consumption related aspects, flexibility related parameters etc... We need to point out that there is a clear linkage of the energy KPIs with the different use cases to be examined in the project, this correlation is clearly reflected in the following section.

KPI: 01	Energy savings (ES)
Definition	Energy Savings for Consumers/Prosumers
Formula	$ES = \text{Baseline Energy Consumption} - \text{Post Implementation Energy Consumption (kWh)}$
Details	Measures the energy savings achieved by consumers or prosumers by comparing baseline energy consumption with post-implementation consumption. It reflects the effectiveness of energy-saving initiatives and the impact on reducing overall energy use.
KPI: 02	Target Demand flexibility (TDF)
Definition	Target Demand Flexibility as Percentage of Peak Load
Formula	$TDF = \frac{\text{Target Flexible load}}{\text{Peak load}} \times 100 \text{ [%]}$
Details	Assesses the flexibility of demand as a percentage of peak load, indicating how much of the peak load can be adjusted or shifted in response to market signals. It is crucial for optimizing energy distribution and enhancing grid stability.
KPI: 03	Energy Efficiency Improvement (EEI)
Definition	Efficiency of energy saving
Formula	$EEI = \frac{\text{Energy savings}}{\text{Baseline energy consumption}} \times 100 \text{ [%]}$
Details	This KPI measures the percentage improvement in energy efficiency by comparing the actual energy savings to the baseline

	consumption, indicating the project's impact on reducing energy use.
KPI: 04	Actual Demand flexibility (ADF)
Definition	Actual Demand Flexibility as Percentage of Peak Load
Formula	$ADF = \frac{\text{Actual Flexible load}}{\text{Peak load}} \times 100 [\%]$
Details	Assesses the flexibility of demand as a percentage of peak load, indicating how much of the peak load can be adjusted or shifted in response to market signals. It is crucial for optimizing energy distribution and enhancing grid stability.
KPI: 05	Flexibility Activation Rate (FAR)
Definition	Proportion of requested flexibility that was activated during demand response or flexibility events.
Formula	$\begin{aligned} \text{Flexibility Activation Rate} \\ &= (\text{Activated Flexibility}) / (\text{Target Flexibility}) \\ &\times 100 [\%] \end{aligned}$
Details	Indicates the efficiency and responsiveness of flexibility providers (e.g., DERs, households, or aggregators) in delivering energy flexibility when requested. A high value reflects effective activation mechanisms and asset readiness, essential for market participation and grid balancing.
KPI: 06	Peak Load Reduction (PLR)
Definition	Reduction in peak electricity demand achieved through demand-side management or flexibility actions.
Formula	$\begin{aligned} \text{Peak Load Reduction} \\ &= (\text{Baseline Peak Load} - \text{Actual Peak Load}) \\ &/ (\text{Baseline Peak Load}) \times 100 [\%] \end{aligned}$
Details	Measures the effectiveness of interventions in lowering the maximum energy demand during peak periods. This is critical for reducing grid stress, avoiding infrastructure overuse, and minimizing peak-related energy costs.
KPI: 07	Self-Consumption Rate (SCR)
Definition	The share of locally generated renewable energy (e.g., PV) that is consumed on-site instead of being exported.
Formula	$\begin{aligned} \text{Self - Consumption Rate} \\ &= (\text{Local PV Consumption}) / (\text{Total PV Generation}) \\ &\times 100 [\%] \end{aligned}$
Details	Indicates how efficiently a household (facility) utilizes its own renewable energy production. Higher values suggest better alignment of generation with consumption, which contributes to grid independence and cost reduction.
KPI: 08	Self-Sufficiency Rate (SSR)

Definition	Proportion of the total electricity demand that is met through local renewable energy generation.
Formula	$\text{Self – Sufficiency Rate} = \frac{(\text{Local PV Consumption})}{(\text{Total Energy Consumption})} \times 100 [\%]$
Details	Reflects the degree to which a site can fulfill its energy needs using its own generation, enhancing resilience and reducing reliance on the grid. It is a key indicator in evaluating decentralized energy systems.
KPI: 09	Energy Exported to Grid
Definition	The total amount of excess locally generated energy (e.g., PV) sent back to the public electricity grid.
Formula	$\text{Energy Exported to Grid} = \text{Total PV Generation} - \text{Local PV Consumption [kWh]}$ $\text{Energy Exported to Grid} = \text{Total PV Generation} - \text{Local PV Consumption [kWh]}$
Details	Measures how much surplus energy is not used on-site. While it may generate feed-in revenue, excessive exports can indicate underutilization of self-consumption potential or lack of storage capacity.
KPI: 10	Renewable Energy Usage (REU)
Definition	Percentage of energy from renewable sources.
Formula	$\text{REU} = \frac{\text{Renewable energy used}}{\text{Total energy consumed}} \times 100 [\%]$
Details	This KPI measures the proportion of energy consumption derived from renewable sources, reflecting the project's commitment to sustainability and reducing reliance on non-renewable energy.

TABLE 4. ENERGY KPIS

The list presented above outlines a selection of key performance indicators (KPIs) that are relevant to the energy-related use cases and functionalities to be implemented within the scope of the project. While these KPIs provide valuable insight into self-consumption system performance, energy efficiency, and flexibility engagement, the list is not exhaustive and may be further refined or expanded as the project evolves and additional requirements or technologies are identified. Towards the evaluation of these KPIs, the actual measurements from the metering systems on site will be considered.

2.2.2 Business / Economic KPIs

In this section the economic/business KPIs considered in the project are presented. Economic KPIs are tacitly linked with the energy impact as presented above and focus on financial efficiency, such as cost savings, flexibility rewards etc. to demonstrate the economic value generated by the project. Business KPIs evaluate market deployment,

investment deferral, and return on investment etc. The non-exhaustive list of KPIs is presented below.

KPI: 11	Energy cost savings
Definition	Energy Cost Savings for Consumers/Prosumers
Formula	$\text{Cost Savings} = \text{Baseline Cost} - \text{Post Implementation Cost}$
Details	This KPI assesses the energy cost savings for consumers or prosumers (those who both produce and consume energy). It calculates the difference between baseline costs and post-implementation costs, highlighting the economic benefits of adopting energy-saving measures or renewable energy within a community or cluster.
KPI: 12	Flexibility Activation Reward
Definition	Total monetary rewards achieved by activating demand-side flexibility
Formula	$\text{Flex Reward} = (\text{Energy Reward With Flexibility} - \text{Energy Reward no Flexibility})$
Details	Captures the economic value of participating in demand response or shifting load from high- to low-cost periods. Especially relevant for aggregators and end-users using automation.
KPI: 13	Revenue from Energy Export
Definition	Earnings generated by feeding excess locally generated renewable energy (e.g., from PV) into the grid.
Formula	$\text{Revenue} = \text{Energy Exported to Grid} \times \text{Feed-in Tariff [€/kWh]}$
Details	Shows the financial benefit of grid-connected prosumers. Can be used to assess tariff design effectiveness and business model sustainability.

TABLE 5. ECONOMIC KPIs

As a key aspect of the project is focusing on investments planning and evaluation, the focus is also on the evaluation KPIs for the business activities of the project. The relevant KPIs associated with investments planning are presented below.

KPI: 14	Investment Deferral (ID)
Definition	Contribution to Annual Deferral of Electricity Grid Investments
Formula	$\text{Investment Deferral} = \text{Total Deferred Investment (m.u)}$
Details	This KPI quantifies the annual deferral of investments in electricity grid infrastructure. By deferring investments, either through improved efficiency or alternative energy solutions, this KPI reflects the contribution to reducing immediate capital expenditures while still meeting energy demands.
KPI: 15	Net Present Value (NPV)
Formula	$\text{NPV} = \sum_{t=0}^{t=n} \frac{R_t}{(r+1)^t} - C_0$

Details	<p>This KPI measures the value a project adds, considering the time value of money. Where:</p> <ul style="list-style-type: none"> • R_t: Net cash inflow during the period t • r: Discount rate • t: Time period of investment • CO: Initial investment <p>A positive NPV indicates that the projected earnings exceed the anticipated costs, making the project financially viable.</p>
KPI: 16	Return on Investment (ROI)
Definition	Financial return relative to cost.
Formula	$ROI = \frac{Net\ profit}{Total\ investment} \times 100 \text{ [\%/year]}$
Details	This KPI measures the financial efficiency of the investment by comparing the net profit generated to the total investment cost. It indicates the profitability and effectiveness of the project in generating returns relative to the expenses incurred
KPI: 17	Payback Period (PP)
Definition	Time to recoup investment
Formula	$PP = \frac{Total\ investment}{Annual\ savings} \text{ [years]}$
Details	This KPI calculates the time required to recover the initial investment through the annual savings generated by the project. It provides insight into the risk and time horizon associated with the investment recovery

TABLE 6. BUSINESS KPIS

In addition to the measurements stated above, additional metrics are defined in order to evaluate the project activities as defined in the DoA. These are presented in the table below though not considered as part of the core KPI framework of the project.

	Marketplaces deployment (MD)
Definition	Number of Marketplaces (Flexibility/Data) Deployed in DIGITISE
Formula	$MD = \frac{Number\ of\ Marketplaces\ deployed}{target\ value} \times 100$
Details	This KPI measures the number of flexibility and data marketplaces deployed in the DIGITISE project. It tracks progress toward the target value, reflecting the success in establishing platforms that facilitate energy market operations and data exchange.

	Flexibility Market business stakeholder engagement (<i>FMBsE</i>)
Definition	Number of Business Stakeholders Engaged in Flexibility Markets
Formula	$FMBsE = \frac{\text{Business Stakeholders Engaged in Flexibility Markets}}{\text{target value}} \times 100$
Details	This KPI assesses the engagement level of business stakeholders in flexibility markets within the DIGITISE project. It quantifies the involvement relative to the target, indicating how effectively the project attracts and engages key market participants.

TABLE 7. BUSINESS METRICS

2.2.3 Environmental KPIs

These KPIs evaluate DIGITISE’s contribution to climate goals by measuring CO₂ reduction, renewable energy integration, and avoidance of RES curtailment. They reflect the project’s impact on environment as a direct impact of energy related actions (impact) mentioned above. The non-exhaustive list of KPIs is presented below.

KPI: 18	CO₂ Reduction
Definition	Reduction in CO ₂ emissions
Formula	$\text{CO}_2 \text{ Reduction} = \text{Baseline Emissions} - \text{Post-Implementation Emissions}$ [kg CO ₂ /period]
Details	This KPI quantifies the environmental benefit of the project by measuring the decrease in CO ₂ emissions. The baseline emissions represent the emissions level before the implementation of the project’s activities, while the post-implementation emissions reflect the impact of energy efficiency measures
KPI: 19	Emission Factor Improvement (EFI)
Definition	Improvement in emission factors of energy sources used
Formula	$\text{EFI} = \left(\frac{\text{Baseline Emission Factor} - \text{Post-Implementation Emission Factor}}{\text{Baseline Emission Factor}} \right) \times 100 [\%]$
Details	This KPI quantifies the environmental benefit of the project by measuring the decrease in other emissions. Reflects cleaner energy sourcing or fuel switching.
KPI: 20	Curtailment Avoidance (CA)
Definition	Contribution to the Avoidance of RES Curtailment
Formula	$\text{CA} = \left(1 - \frac{\text{Curtailment of RES Energy}}{\text{Total Potential RES Energy Generation}} \right) \times 100$
Details	This KPI assesses the extent to which curtailment of renewable energy is avoided, ensuring that energy generated from renewables is fully utilized. It is crucial for maximizing the efficiency of renewable energy systems and improving grid management

TABLE 8. ENVIRONMENTAL KPIs

2.2.4 Social KPIs

Social KPIs assess consumer engagement, perceived comfort, and user acceptance, highlighting the DIGITISE project influence on end-user satisfaction, behavioural change, and overall quality of experience. These indicators help evaluate how well the energy solutions and non-energy services align with user needs and preferences, the level of trust and confidence users place in the system, and the extent to which individuals are willing to adopt and interact with new technologies and services. By capturing qualitative and quantitative feedback from users, social KPIs provide valuable insights into the human dimension of DIGITISE innovation, which is essential for ensuring long-term impact and widespread adoption. The non-exhaustive list of social related KPIs covering the different aspects of the project (evaluation of the energy business objectives – non energy services, evaluation of trust/engagement in ICT, evaluation of project specific aspects) is provide below.

KPI: 21	Consumer Perceived Comfort (CPC)
Definition	Consumer Perceived Comfort
Formula	$CPC = \frac{\text{Sum of Comfort Ratings}}{\text{Total Response}} \times 100$
Details	This KPI measures the perceived comfort of consumers participating in the DIGITISE project. It reflects how satisfied consumers are with the project's outcomes, based on their comfort ratings, which is crucial for user satisfaction and engagement.
KPI: 22	Consumer Perceived Health Conditions (CPC)
Definition	Consumer Perceived Health Conditions
Formula	$CPC-H = (\text{Sum of Health Condition Ratings}) / (\text{Total Responses}) \times 100$
Details	This KPI measures how consumers perceive the impact of the DIGITISE project on their personal health and indoor well-being. It captures subjective assessments of physical comfort, air quality, and general health-related conditions attributed to the energy solutions. High values reflect a positive perception of health-related benefits, contributing to acceptance and long-term use.
KPI: 23	Consumer Perceived Convenience (CPC)
Definition	Consumer Perceived Convenience
Formula	$CPC-C = (\text{Sum of Convenience Ratings}) / (\text{Total Responses}) \times 100$
Details	This KPI evaluates how convenient consumers find the use of energy applications and services introduced by the DIGITISE project. It reflects the ease of interaction, time savings, and simplicity of managing energy use, which are key factors

	influencing continued user engagement and technology adoption.
KPI: 24	Consumer Perceived Security Enhancement (CPC)
Definition	Consumer Perceived Security Enhancement
Formula	$CPC-S = (\text{Sum of Security Perception Ratings}) / (\text{Total Responses}) \times 10$
Details	This KPI assesses the degree to which consumers feel that their home security has improved through the DIGITISE project's solutions. It includes perceptions of security of energy systems. High values indicate increased user confidence and system trustworthiness.
KPI: 25	Adaptive Thermal Comfort Compliance (ATCC)
Definition	Adaptive Thermal Comfort Compliance
Formula	$ATCC = (\text{Number of hours conditions are within adaptive comfort band} / \text{Total hours}) \times 100$
Details	This KPI assesses the percentage of time indoor conditions comply with adaptive comfort standards (e.g., EN 16798-1 or ASHRAE 55).
KPI: 26	Relative Humidity Compliance (RHC)
Definition	Compliance with Recommended Indoor Relative Humidity
Formula	$RHC = (\text{Hours within RH range [30-70\%]} / \text{Total monitored hours}) \times 100$
Details	This KPI measures how often indoor relative humidity (RH) stays within the recommended comfort range (30%–70%) specified in EN 16798-1. Proper RH levels are essential for thermal comfort and health.
KPI: 27	Volatile Organic Compounds Index (VOCI)
Definition	VOC Concentration Compliance
Formula	$VOCI = (\text{Hours with TVOCs} < 300 \mu\text{g}/\text{m}^3 / \text{Total monitored hours}) \times 100$
Details	This KPI monitors compliance with recommended levels of Total Volatile Organic Compounds (TVOCs) as a proxy for chemical pollutants indoors. A value of $< 300 \mu\text{g}/\text{m}^3$ is often used as a reference based on EU health guidelines and best practices for Category I/II comfort levels. (in case of CO ₂ eq measurements then the limits are Category I: < 800 ppm Category II: < 1000 ppm Category III: < 1200 ppm)

TABLE 9. SOCIAL KPIS –NON ENERGY SERVICES

Note: There are additional KPIs defined in the literature for thermal comfort evaluation (PMV, PPD, operative temperature etc...). The final selection though depends on the installations to take place at the demo sites and data selection.

Note 2: There are additional IAQ parameters to be considered for the evaluation of indoor health related parameters (CO₂, PM_{2.5}). The final selection though depends on the installations to take place at the demo sites and data selection. The approach to be followed remains the same with the identification of boundaries for the different metrics to be considered.

Apart from the KPIs dedicated to the evaluation of the non-energy services of the DIGITISE project, additional social KPIs are considered to evaluate the overall impact of the technical implementations of the project. To proceed with the evaluation of these KPIs, dedicated forms/online/onsite surveys will take place to gather the feedback required. More details about this process will be defined as part of the demonstration plan in WP6. The details of the KPIs are available below.

KPI: 28	User acceptance rate among pilot participants (UAR_{pilots})
Definition	User Acceptance Rate of DIGITISE Results among Pilot Participants
Formula	$UAR_{pilots} = \frac{\text{Number of Accepting Users}}{\text{Total Users}} 100$
Details	This KPI assesses the acceptance rate of DIGITISE results among participants in pilot projects. It indicates the proportion of users who find the solutions acceptable, highlighting the project's success in meeting user expectations and gaining their approval.
KPI: 29	Perceived Usefulness (PU)
Definition	Average user perception of the value or benefit derived from using the system.
Formula	$PU = (\text{Sum of Usefulness Ratings}) / (\text{Total Responses}) \times 100$
Details	Reflects the extent to which users believe the system improves their performance or quality of life, a critical driver of adoption according to the Technology Acceptance Model (TAM).
KPI: 30	Consumer data sharing interest (CDS)
Definition	Interest of Consumers to Channel Data through DIGITISE
Formula	$CDS = \frac{\text{Sum of Interest Ratings}}{\text{Total Response}} 100$
Details	This KPI evaluates the interest of consumers in sharing their data through the DIGITISE platform. It measures how willing consumers are to channel their data, which is crucial for the success of data-driven energy services and the overall project.
KPI: 31	Consumer sovereignty features/AI Trust ($Trust_{cons}$)
Definition	Trust of Consumers in Sovereignty Features/AI Trust of DIGITISE
Formula	$Trust_{cons} = \frac{\text{Sum of Trust Ratings}}{\text{Total Responses}} 100$

Details	This KPI evaluates consumer trust in sovereignty features and AI-driven aspects of the DIGITISE project. It reflects how confident consumers are in the digital tools and AI technologies used, which is critical for ensuring widespread adoption and user comfort with the system.
KPI: 32	Level of user understanding of digital energy services ($Understanding_{user}$)
Definition	User Simplification of Digital Energy Services/Increased Understanding
Formula	$Understanding_{user} = \frac{\text{Sum of Understanding Ratings}}{\text{Total Responses}} \cdot 100$
Details	This KPI measures the level of user understanding of digital energy services, focusing on how well users comprehend and find these services simplified. It is key to ensuring that users can effectively interact with and benefit from digital energy solutions.

TABLE 10. SOCIAL KPIS- OVERALL FEEDBACK

The set of Social KPIs presented aims to capture the human-centric impact of ICT and energy solutions, focusing on dimensions such as user satisfaction, engagement, comfort, convenience, perceived health benefits, and trust. These indicators go beyond technical performance to assess how end-users experience and interact with the systems implemented in the project. Data for these KPIs is typically collected through user surveys, self-assessment questionnaires, or structured interviews, using standardized Likert scale ratings (e.g., 1 = strongly disagree to 5 = strongly agree). This approach enables the quantification of subjective perceptions in a consistent and comparable manner. The detailed questionnaires and surveys to be conducted for the evaluation of these social aspects will be conducted as part of the work in WP6.

Note: Similar to the energy KPIs, there are specific metrics to be considered in order to evaluate the overall objectives of the project as listed in the DoA and presented below.

	Energy Literacy Consumer engagement (ELCE)
Definition	Number of Consumers Engaged in Activities to Enhance Energy Literacy
Formula	$ELCE = \frac{\text{Consumers Engaged in Activities to Enhance Energy Literacy}}{\text{Target value}} \cdot 100$
Details	This KPI tracks the number of consumers engaged in activities aimed at enhancing their energy literacy. It reflects the project's effectiveness in educating consumers about energy usage, which is vital for informed decision-making and active participation in energy markets.
	Consumers/prosumers co-creation involvement (CoCI)

Definition	Number of Consumers/Prosumers Involved in DIGITISE Co-Creation Activities
Formula	$CoCI = \frac{\text{Consumers or Prosumers Involved in Co – Creation Activities}}{\text{Target value}} \times 100$
Details	This KPI measures the involvement of consumers and prosumers in co-creation activities within the DIGITISE project. It indicates the level of consumer/prosumer participation in the development and improvement of project solutions, essential for creating user-centered innovations.
Community Engagement Level (CEL)	
Definition	The extent of community involvement.
Formula	$CEL = \frac{\text{Targeted Community}}{\text{Number of Participants}} \times 100 [\%]$
Details	This KPI measures the level of engagement and involvement of the targeted community within the project. It reflects how effectively the project is reaching and involving its intended audience, highlighting the success of outreach efforts and community participation in various activities.

TABLE 11. SOCIAL METRICS

2.2.5 Technology Related KPIs

The technical KPIs measure aspects related to the system overall performance converting uptime, digital solutions deployment, and data accuracy, focusing on technological advancements and their direct impact on ICT solutions management and system performance. The non-exhaustive list of technical KPIs is listed below, considering the deployment of the different energy applications but also focusing on the deployment of the Data space and analytics framework introduced in the project.

KPI: 33	System uptime (SU)
Definition	The percentage of time systems are operational.
Formula	$\text{System Uptime} = \frac{\text{Total operational time}}{\text{Total time}} \times 100 [\%]$
Details	This KPI tracks the availability and operational status of systems, reflecting the reliability and continuous operation capabilities crucial for performance and service delivery.
KPI: 34	System Reliability (SR)
Definition	System operational reliability
Formula	$SR = \frac{\text{Total operational time} - \text{downtime}}{\text{Total time}} \times 100 [\%]$

Details	This KPI measures the reliability of the system by evaluating the percentage of time it operates without failure, indicating robustness and resilience
KPI: 35	Data Availability (DA)
Definition	Proportion of time data assets are accessible
Formula	$DA = (\text{Time data was available}) / (\text{Total monitoring time}) \times 100 [\%]$
Details	This KPI evaluates how often datasets are accessible for querying or download. High availability ensures data-driven services and processes are not disrupted.
KPI: 36	Error Rate
Definition	Percentage of errors in the system.
Formula	$\text{Error rate} = \frac{\text{Number of errors}}{\text{Total transactions}} \times 100 [\%]$
Details	This KPI quantifies the rate of errors during system operations, reflecting the system's accuracy and reliability in performing tasks or transactions
KPI: 37	Data Accuracy
Definition	Accuracy of data collected.
Formula	$\text{Data accuracy} = \frac{\text{Accurate data points}}{\text{Total data points}} \times 100 [\%]$
Details	This KPI measures the proportion of correct data points collected, indicating the quality and reliability of the data being used for analysis and decision-making
KPI: 38	Data breach Success (DBS)
Definition	Successful Data Breaches – Number of Datasets Acquired by Unauthorized Users
Formula	$DBS = (\text{Verified unaltered data entries}) / (\text{Total entries}) \times 100 [\%]$
Details	This KPI tracks unauthorized data access incidents. A value of zero reflects strong data security and user trust.
KPI: 39	Model Accuracy (MA)
Definition	Correct predictions over total predictions
Formula	$MA = (\text{Number of correct predictions}) / (\text{Total predictions}) \times 100 [\%]$
Details	This KPI measures the overall correctness of an AI or DT model's output. It reflects how well the model performs on real or test data.

TABLE 12. TECHNICAL KPIS

Apart from the list of KPIs that reflect the overall performance of the different ICT solutions, there is a series of metrics to be considered for the technical evaluation of the project (as extracted from the DoA)

	Analytics services deployment (ASD)
Definition	Number of Analytics Services Deployed in DIGITISE

Formula	$ASD = \frac{\text{Number of analytics services deployed}}{\text{target value}} \cdot 100 \text{ [\%]}$
Details	Tracks the number of analytics services deployed within the DIGITISE project. It measures progress towards the target value, indicating the project's success in implementing data-driven tools to enhance energy management and decision-making.
	Digital solutions, End-user Apps deployment (DS)
Definition	Number of Digital Solutions and End-user Apps Deployed in DIGITISE
Formula	$DS = \frac{\text{Number of Digital solutions, End user Apps deployed}}{\text{target value}} \cdot 100 \text{ [\%]}$
Details	Evaluates the deployment of digital solutions and end-user applications in the DIGITISE project. It indicates the extent to which these tools have been implemented, reflecting the project's focus on enhancing user engagement and digital interaction.
	DT models availability
Definition	Number of DT Models Configured and Made Available as Open Source
Formula	$MA_{DT} = \frac{\text{Number of DT Models Configured and Made Available}}{\text{Target value}} \cdot 100 \text{ [\%]}$
Details	Measures the availability of Digital Twin (DT) models configured and made accessible as open-source tools. It reflects the project's contribution to innovation and the sharing of digital resources within the energy sector.
	Standards-based Connectors to IoT and DERs ($CO_{IOT,DEERS}$)
Definition	Open Standards-based Connectors to IoT and DERs
Formula	$CO_{IOT,DEERS} = \frac{\text{Connectors to IoT and DERs}}{\text{target value}} \cdot 100 \text{ [\%]}$
Details	This KPI tracks the deployment of open standards-based connectors to Internet of Things (IoT) devices and Distributed Energy Resources (DERs). It indicates the project's progress in creating interoperable solutions that facilitate integration and communication within the energy ecosystem.
	Multi-sector Open standards coverage (OSC)
Definition	Coverage of Widely Adopted Open Standards in the Energy, Health, Mobility, Finance
Formula	$OSC = \frac{\text{Coverage of Widely Adopted Open Standards}}{\text{target value}} \cdot 100$
Details	This KPI assesses the coverage of widely adopted open standards across multiple sectors, including energy, health, mobility, and finance. It indicates the project's success in

	aligning with industry standards, promoting interoperability, and ensuring compatibility across different sectors.
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TABLE 13. TECHNICAL MEASUREMENTS AS DERIVED FROM THE DOA

We have presented above the list of KPIs defined to support the demonstration and validation activities of DIGITISE. As the project evolves and based on its needs, additional KPIs may be defined to complement the demonstration and evaluation framework.

2.3 KPIs link to use cases

As stated in the DoA “this task will early link the project use cases with the different sub-groups of Key Performance Indicators (KPIs) to effectively address the unique characteristics of each demo case, while ensuring a consistent evaluation of project outcomes.

As mentioned above, at the heart of the DIGITISE project are a series of interconnected Use Cases (UCs –in Annex I for reference reasons), each designed to address specific challenges and opportunities in the evolving energy landscape. These use cases, detailed in the previous deliverable D2.1, span a wide spectrum of multidisciplinary fields, reflecting the project’s holistic approach to decarbonization, digitalization, and democratization of energy systems. These activities are directly linked to the project’s KPIs, ensuring that each UC contributes measurable outcomes aligned with DIGITISE’s energy, technical, social, business, economic, and environmental objectives.

The table below presents a structured overview of these KPIs, including their relevance to specific Use Cases (UCs). The KPIs serve as a shared reference point for all project partners, ensuring that activities carried out within the use cases are aligned with the overall project objectives and can be quantitatively and qualitatively assessed. We must point out that we have merged UC1–UC4 that refer to the data space implementation and also UC5–UC6 that refer to the analytics layer implementation and thus the evaluation reflects each framework/implementation.

#	KPI	UC1-UC4	UC5-UC6	UC7	UC8	UC9	UC10	UC11	UC12	UC13	UC14
1	Energy savings					x	x		x		
2	Target Demand flexibility			x	x				x		
3	Energy Efficiency Improvement					x	x		x		
4	Actual Demand flexibility			x	x						
5	Flexibility Activation Rate			x	x						
6	Peak Load Reduction					x	x		x		
7	Self-Consumption Rate						x		x		
8	Self-Sufficiency Rate						x		x		
9	Energy Exported to Grid					x	x				
10	Renewable Energy Usage						x		x		
11	Energy cost savings					x	x				
12	Flexibility Activation Reward			x	x						
13	Revenue from Energy Export					x	x				
14	Investment Deferral								x		
15	Net Present Value								x		
16	Return on Investment								x		
17	Payback Period								x		
18	CO2 Reduction					x	x		x		
19	Emission Factor Improvement					x	x		x		
20	Curtailment Avoidance								x		
21	Consumer Perceived Comfort									x	
22	Consumer Perceived Health Conditions									x	
23	Consumer Perceived Convenience									x	
24	Consumer Perceived Security Enhancement									x	
25	Adaptive Thermal Comfort Compliance									x	

26	Relative Humidity Compliance									x	
27	Volatile Organic Compounds Index									x	
28	User acceptance rate among pilot participants	x	x	x	x	x	x	x	x	x	x
29	Perceived Usefulness	x	x	x	x	x	x	x	x	x	x
30	Consumer data sharing interest	x									
31	Consumer sovereignty features/AI Trust	x									
32	Level of user understanding of digital energy services	x	x	x	x	x	x	x	x	x	x
33	System uptime	x	x	x	x	x	x	x	x	x	x
34	System Reliability	x	x	x	x	x	x	x	x	x	x
35	Data Availability	x	x	x	x	x	x	x	x	x	x
36	Error Rate	x	x	x	x	x	x	x	x	x	x
37	Data Accuracy	x	x	x	x	x	x	x	x	x	x
38	Data breach Success	x	x	x	x	x	x	x	x	x	x
39	Model Accuracy		x					x			

TABLE 14. KPI LINK TO USE CASES

Building on the KPIs detailed above and the project's list of use cases, the four demonstration sites serve as real-world environments for testing, validating, and refining the DIGITISE project's innovative energy and digital solutions. Each site is strategically linked to specific use cases (UCs) as reported in D2.1, which are, in turn, mapped to a variety of technical, social, business, economic, and environmental KPIs. To ensure robust and meaningful evaluation, use case leaders must coordinate closely with the respective pilot site partners to access relevant data sources—whether from smart meters, IoT devices, energy management platforms, or consumer engagement activities. This coordination is essential to ensure that both quantitative and qualitative KPIs are comprehensively assessed during the project's demonstration phase. The tools required for standardized data collection during pilot implementations—including online surveys and data recording forms—will be specified in the initial tasks of WP6.

2.4 Standards-based baseline and verification methodologies

As part of the comprehensive evaluation framework for validating project activities—and moving beyond the mere elicitation of KPIs—it is also necessary to consider standards-based baseline and verification methods to assess both energy and non-energy-related aspects of the project. A key requirement is the establishment of a clear and quantified baseline at the reference point, which will serve as the foundation for measuring impact, improvement, and overall performance against the defined KPIs. Accurate Measurement and Verification (M&V) methodologies are critical for ensuring fair compensation, controlling programme costs, maintaining participant engagement, and accurately assessing the benefits of energy-related interventions. Inaccurate M&V can lead to distorted results, such as over- or under-payment of participants and misleading estimations of programme impacts.

To support this, a state-of-the-art analysis of various baseline methodologies (e.g., IPMVP, FEMP) is conducted, followed by an early elicitation process to define the most suitable approaches. This ensures that the necessary inputs for KPI calculation are well-grounded, consistent, and aligned with the specific use cases and demonstration environments of the project.

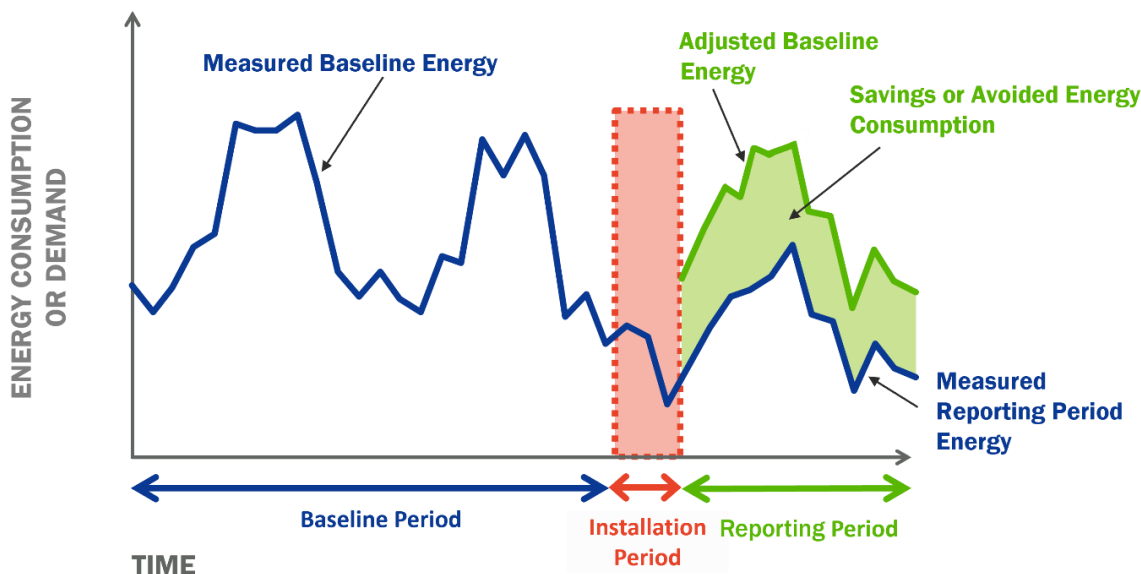
Starting with the energy related baseline calculations, there are numerous Measurement and Verification (M&V) methodologies especially when it comes to the national level regulation. In the context of the DIGITISE project, IPMVP, FEMP and ISO 50015 [3] are considered as part of the review analysis.

2.4.1 International Performance Measurement and Verification Protocol

The International Performance Measurement and Verification Protocol (IPMVP[1]) is a critical framework for determining energy savings achieved through energy efficiency measures (EEMs). It is divided into three volumes:

1. Volume I: Concepts and options for determining energy and water savings, outlining the essential concepts and methodologies to apply the protocol.
2. Volume II: Addresses environmental aspects of indoor air quality as related to EEMs.
3. Volume III: Focuses on M&V methods in new buildings and renewable energy systems, divided into two parts—one for new construction and one for renewable energy technology applications.

The IPMVP methodology emphasizes key principles such as accuracy, relevance, and transparency in M&V reports, which focus on comparing energy consumption before and after the implementation of EEMs. The reporting period is compared with a reference period, adjusting for variables like temperature, occupancy, and operational hours to estimate the savings accurately. Savings are determined using the equation:



$$\text{Savings} = (\text{Baseline Period Energy} - \text{Reporting Period Energy}) \pm \text{Adjustments.}$$

The IPMVP offers four options for measuring savings:

- Option A: Retrofit isolation through key parameter measurement.
- Option B: Retrofit isolation by measuring all relevant parameters.
- Option C: Measuring the whole facility's energy consumption.
- Option D: Calibrated simulation, often for cases where real measurements during the reference period are unavailable.

The latest iteration of the International Performance Measurement and Verification Protocol (IPMVP), titled Core Concepts 2022, was released in March 2022. This updated version provides enhanced clarity regarding the requirements for continuous measurement under Option B, ensuring more precise and consistent data collection for the verification of energy savings. Furthermore, the revision introduces advanced

methodologies for measurement and verification (M&V), effectively addressing the evolving landscape of energy efficiency technologies and practices. The revised document also offers comprehensive guidance on adherence to the IPMVP framework and the selection of appropriate M&V options, thereby facilitating improved decision-making in project planning. These updates are designed to reinforce the IPMVP's relevance and efficacy as a tool for the accurate measurement and verification of energy and water savings across a wide range of projects and applications.

In the DIGITISE project, the main focus is on Option B, Option C, and Option D, particularly for handling shorter data periods for calibration and baseline construction, while also evaluating long-term investments. A crucial aspect of any M&V plan is selecting reference and reporting periods that accurately reflect normal operation cycles. The DIGITISE project, which focuses on energy systems in a building context, can leverage the IPMVP approach to calculate and forecast energy savings over time and thus facilitate the accurate KPI calculation.

2.4.2 ASHRAE Guideline 14

Originally published in 2002, *ASHRAE Guideline 14: Measurement of Energy, Demand, and Water Savings*[2] was developed to address the industry's need for a standardized methodology to quantify energy and power savings in buildings. Given the inherent complexity of accurately measuring energy and demand reductions—due to variations in building usage, occupancy, behavior, and external factors such as weather, this guideline provides a structured approach for evaluating performance improvements.

The latest revision, published in Spring 2023, marks the second major update to the guideline. The 2023 edition incorporates extensive new content, reflecting advancements in industry knowledge and practice. The revisions aim to enhance the guideline's applicability, especially within the context of energy performance contracts and utility-driven programs.

Key updates in the 2023 revision include:

- **Expanded Instrumentation and Testing Methods:** Comprehensive guidance on standard testing procedures and recommended instrumentation practices.
- **Enhanced Sensor Guidance:** Detailed recommendations regarding sensor selection, installation, maintenance, and calibration intervals.
- **Measurement Duration Recommendations:** Application-specific guidance on appropriate measurement timeframes for accurate data collection.
- **Improved Demand Savings Analysis:** Expanded focus on time-of-use considerations and system resiliency in demand savings calculations.
- **Renewable Energy Integration:** New content addressing energy generation and storage from renewable sources.
- **Uncertainty Quantification:** Significantly enhanced guidance on assessing uncertainty, including measurement and sampling errors, model-based uncertainty, and end-to-end uncertainty estimation.

- Data Handling Protocols: Additions related to data acquisition, recording integrity, and validation procedures.
- Advanced Analytical Techniques: New instructions for implementing regression analysis to support M&V efforts.

We need to point out that IPMVP (International Performance Measurement and Verification Protocol) and ASHRAE Guideline 14 are two of the most widely used frameworks for Measurement and Verification (M&V) of energy savings. ASHRAE Guideline 14 is more technically prescriptive, focusing on engineering and statistical validation. It sets detailed criteria such as limits for statistical uncertainty and model accuracy and is often used in North American contexts where high precision is required, such as utility incentive programs or complex retrofit projects. Towards this direction, IPMVP offers a flexible, high-level framework that is widely used, allowing DIGITISE partners to choose the most appropriate method based on data availability, project complexity, and cost-benefit considerations.

2.4.3 DR Related Aspects Measurement and Verification Protocol

Apart from the energy efficiency-related methodologies, M&V methodologies for DR events are also considered as part of the analysis. These methodologies are crucial for assessing the performance of DR programs, which involve adjusting building energy usage in response to signals from the grid operator to either reduce demand during peak periods or shift it to off-peak times. Below are the various baseline M&V methods for Demand Response (DR) events, which help establish a reliable reference for comparing energy consumption during DR events:

1. Baseline Estimation Techniques: Methods such as Maximum Base Load, Meter Before/Meter After, Baseline Type I/II, and Experimental Design provide different ways to establish a reference point for energy consumption before and after a DR event. Additional Baseline Methods include more advanced techniques like Moving Average, Pseudo-Baseline, Dynamic Baseline, and Energy Model Calibration, offering more dynamic or flexible approaches to handle complex buildings and variable conditions.
2. Data Analysis Methods: These include Day Matching and Regression Analysis, which are used to identify patterns and relationships in energy consumption, refining baseline estimates.

Together, these methodologies provide a comprehensive toolkit for establishing accurate baselines, adjusting for external factors, and quantifying the impact of DR actions on energy consumption. It should be noted that this is not a complete list of the standards-based M&V methods for DR events, and special conditions apply per demo case.

2.4.4 Non-Energy Related Aspects Measurement and Verification Protocol

Finally M&V methodologies for non-energy services are considered. As a starting point is the review of comfort related methodologies and standards that are briefly presented:

- ASHRAE 55 (and EN 16798-1 [4] for Europe as commented below) is the well-known standard focusing on comfort conditions within the building environment. There are different KPIs (PMV, PPD, operative temperature etc.) specified as part of the standardization while also considering baseline comfort levels and track deviations or improvements.
- IPMVP framework for comfort. As stated above IPMVP and more specifically Option D – Calibrated Simulation leverages a calibrated building simulation model to evaluate pre- and post-retrofit thermal comfort performance and validate key thermal comfort indicators, providing a robust method for assessing occupant well-being in the conditioned spaces. The calibrated simulation approach enables validation of comfort conditions using a series of metrics as defined in ASHRAE 55 (PMV/PPD, Operative Temperature, CO₂ Concentration etc.)
- Also, EN 16798-1 (similar to the ASHRAE 62.1 for US) specifies the boundaries and the KPIs to be considered for the evaluation of IAQ contaminants in buildings by setting design and operational ventilation rates, defining indoor environmental quality (IEQ) parameters and supporting building energy performance assessments (e.g., under the EPBD).
- The different building certifications bodies (Well Building Standard / LEED/ BREEAM) also specify methodologies and boundaries for comfort/health conditions in premises. These certifications bodies also consider the above standardization or refer to additional configurations based on particular conditions.

In relation to the previous analysis, special reference is made to the Smart Readiness Indicator (SRI)[5], a European Union initiative designed to assess the smartness of buildings and their ability to efficiently manage energy consumption, enhance occupant comfort, and interact with external systems. This indicator is part of the Energy Performance of Buildings Directive (EPBD) and is aimed at encouraging the integration of smart technologies in the built environment. The SRI evaluates a building's performance across four key areas: Energy Management, Building Flexibility, Occupant Interaction, and Automation and Control. This approach aligns closely with the activities in the DIGITISE project. The Energy Management component focuses on how effectively a building optimizes its energy consumption through smart systems. Building Flexibility evaluates the building's ability to adapt and integrate with external systems, such as smart grids or renewable energy sources, including the ability to engage in demand-response programs, where energy use is adjusted based on grid needs, especially during peak demand periods. The Occupant Interaction area of the SRI assesses the level of control and automation

available to building occupants, focusing on aspects of their indoor environment such as lighting, temperature, and air quality, with the aim of enhancing convenience and comfort.

It is evident that a range of evaluation approaches are adopted for the assessment of the diverse activities implemented within the DIGITISE project. The International Performance Measurement and Verification Protocol (IPMVP) is employed as the principal framework for evaluating energy efficiency-related aspects. Furthermore, tailored adaptations of this framework will be applied for the evaluation of Demand Response (DR) events addressed in the project. Lastly, for the assessment of non-energy services, the project draws upon measurement processes as specified in relevant European Standards (e.g. EN 16798 for comfort performance measurement), ensuring alignment with established best practices and standardization requirements.

3 Markets design and operation assessment

As stated in the DoA, task T2.4 focuses on analyzing current market practices and proposes modifications to flexibility products and related processes to better align with the capabilities and constraints of flexible assets. Specifically, this task examines the characteristics of flexible markets (both at local DSO level and balancing markets) with their characteristics —such as ramp-up and ramp-down times, service duration etc.—to translate these into clearly defined flexibility and demand response products tailored for overlay flexibility and balancing markets. Through this analysis, T2.4 aims to refine the technical requirements and operational frameworks underpinning these markets. The outputs of this deliverable will feed directly into WP5, which is responsible for implementing consumer enrolment mechanisms and managing transactions within flexibility marketplaces. The analysis starts with the review of the current market framework and then on the basis of the analysis, the early specifications of the different flexibility products/services to be examined in the DIGITISE project are provided.

3.1 Balancing Markets

3.1.1 General

Balancing Markets (BM) are mechanisms used in electricity systems to maintain the balance between supply and demand in real time. Their main function is to ensure the electrical grid's frequency stays within a certain range, which is essential for the network's dependable operation. To maintain the balance of the electrical grid, flexibility capacity is auctioned in the balancing markets. Through these auctions, BSPs (Balancing Service Providers) offers their reserve capacity to the TSO/SOs (Transmission System Operators/System Operators), committing to adjust their consumption or electricity production when the TSO requires it to correct frequency imbalances in the grid.

The main role of TSOs, who are the Balancing Off-takers, is to monitor the grid and identify any frequency deviations. When needed, they call on BSPs to deliver the necessary adjustments, which could involve activating reserve capacity or modifying consumption patterns. These functions are implemented by means of the balancing products, which operate in a hierarchical structure, addressing different levels of frequency imbalance. The first mechanism to prevent frequency imbalances is the Frequency Containment Reserve (FCR). FCR is activated automatically and immediately in response to sudden frequency deviations (short-term imbalances in frequency), ensuring the system stabilizes. This is a physical process carried out by synchronous generators, which, when connected to the grid, automatically adjust their generation to help stabilize the system during frequency deviations. The generator does not receive compensation for this service, as it is a natural response to being connected to the grid.

In countries like Spain, and Greece, this process does not receive compensation, as it is a natural characteristic of synchronous machines. In contrast, countries like Estonia, and Croatia have an internal market based on daily auctions for FCR, where providers can offer their services with a minimum of 1 MW.

France participates in the FCR Cooperation [6] platform, which allows for the cross-border exchange of FCR reserve capacity. Through this platform, countries take part in daily auctions to meet their FCR obligations, with each country required to purchase at least 30% of its FCR capacity through regional cooperation. The products acquired in these auctions have a 4-hour duration. This mechanism is governed by European regulations, including limits on the amount of FCR each country can export (1–25 MW). By mandating participation in these regional auctions, the platform promotes market liquidity, increases efficiency, and enhances overall system stability across Europe.

If the imbalance persists, the next level, the automatic Frequency Restoration Reserve (aFRR), is activated. This product is also automatic, managed by SO, and corrects larger sustained frequency deviations that cannot be addressed by FCR. Furthermore, aFRR is remunerated, and the generator decides to bid in a market to offer its services. If the price does not match or if the generator does not submit a bid, it is not obligated to adjust its power. For this service, the PICASSO [7] platform is used, which facilitates cross-border exchanges of aFRR energy among European countries. Through daily auctions, each country buys a portion of its aFRR obligation, with products lasting 4 hours, ensuring efficiency and flexibility in balancing energy across Europe. When all the necessary energy for the day is secured, deviations between forecasted and actual values occur. Manual Frequency Restoration Reserve (mFRR) provides a very fast response (which commands a high price) to almost perfectly balance demand and generation. This service requires manual activation, which is managed by the System Operator through market mechanisms. It has a reaction time of just a few minutes (up to 15 minutes), and its duration per activation is typically around 2 hours, though it can vary depending on the situation. MARI [8],[9] platform allows participating TSOs to procure mFRR services via cross-border exchanges, with countries participating through daily tenders to secure balancing energy. The platform also operates an automatic clearing mechanism for bids.

Replacement Reserves (RR) are similar but are used to replace depleted reserves, with a focus on future needs. RR is more anticipatory, ensuring long-term system stability. The TERRE [10] platform operates similarly to MARI but focuses on RR. It allows for cross-border cooperation to address system imbalances through bidding.

Apart from the above, Active Demand Response Service (SRAD) consist of reserve mechanisms designed to handle exceptional system conditions that fall outside the scope of standard balancing products. They are primarily activated during emergency events to

provide additional support and maintain system stability, ensuring the continuity and resilience of grid operations under extraordinary circumstances.

All the European platforms discussed are managed by ENTSO-E (European Network of Transmission System Operators for Electricity). ENTSO-E coordinates these platforms to facilitate cross-border balancing, enhance grid stability, and improve market efficiency across Europe. The platforms align with European regulations, enabling smooth cooperation between countries to maintain a reliable and efficient electricity grid. It is important to note that the MARI platform is based on the LIBRA platform that has been implemented for RR in the TERRE project. The MARI platform consists in (i) a data management platform (Libra Data Management), handling communications and data exchanges with TSOs and ENTSO-E, pre-processing, postprocessing and archiving, and (ii) an optimization module (AOF) optimizing the activations and computing Cross Border Marginal Prices (CBMP).

Except for Cyprus, all other participating countries have either fully operational balancing markets or are actively developing them at national and European levels, with a strong emphasis on the deployment of flexibility products. Most nations—again excluding Cyprus—are also actively engaged in regulatory initiatives aimed at supporting market balancing mechanisms. These initiatives include regulatory testing environments and "sandboxes" designed to evaluate and promote new flexibility solutions.

Given that Cyprus is a small island system with no interconnections from the moment, it faces more challenges in establishing operational BMs. This is not the case for Ireland though, which does not participate in the transnational balancing markets surveyed. The Cyprus system typically rely on state-operated gas plants to manage demand and consumption. Therefore, there is insufficient data available regarding their participation in the surveyed balancing market frameworks. As such, when referring to "all countries" in the following sections, the analysis will exclude Cyprus.

In addition, all participating countries are either operationally involved in or are working towards joining the European cooperation platforms such as PICASSO, MARI, TERRE, and FCR Cooperation, as discussed previously. Table 15 presents a general overview of the BMs across the participating countries, summarizing the current operational status, platform involvement, and the key balancing products available in each country.

Country	Platform	Situation	FCR	aFRR	mFRR	RR	SRAD	Is there any specific requirement to participate in balancing services?	Is the regulatory or technical framework blocking?
Portugal	FCR	Not connected	Yes**	Yes	Yes	Yes	No	Yes (national and EU regulations and technical requirements)	Yes (complex regulations and real-time capabilities)
	PICASSO	Accession ongoing							
	MARI	Operational							
	TERRE	Operational							
Spain	FCR	Not connected	Yes*	Yes	Yes	Yes	Yes	Yes (regulatory register and technical requirements)	Yes (high power requirements)
	PICASSO	Accession ongoing							
	MARI	Operational							
	TERRE	Operational							
France	FCR	Operational	Yes***	Yes	Yes(sharing)	Yes	No	Yes (national and EU regulations and technical requirements)	Yes (complex regulations and real-time capabilities)
	PICASSO	Accession ongoing							
	MARI	ATC sharing							
	TERRE	Operational							
Ireland	FCR	Not connected	Yes*	No	No	No	No	No	Ireland's Geographic resulting in Interconnection Constraints
	PICASSO	Not connected							
	MARI	Not connected							
	TERRE	Not connected							
Estonia	FCR	Not connected	Yes**	Yes	Yes	No	No		

	PICASSO	Accession ongoing						Yes (national and EU regulations and technical requirements)	Yes (complex regulations and high technical standards)
	MARI	Operational							
	TERRE	Not connected							
Croatia	FCR	Not connected	Yes*	Yes	Yes	No	No	N/A	N/A
	PICASSO	Accession ongoing							
	MARI	Accession ongoing							
	TERRE	Not connected							
Greece	FCR	Not connected	Yes*	Yes	Yes	No	No	Yes (national and EU regulations and technical requirements)	Yes (regulatory framework and energy storage licensing and operation)
	PICASSO	Operational							
	MARI	Accession ongoing							
	TERRE	Not connected							
Cyprus	FCR	Not connected	Yes*	No	No	No	No	No	No need for relatively small island systems, where CCGT SO-TSO owned plants are activated if needed.
	PICASSO	Not connected							
	MARI	Not connected							
	TERRE	Not connected							

* It does not have a FCR Market because it is a connection requirement.

** It has an internal TSO FCR market.

*** It belongs to the FCR Cooperation Platform

TABLE 15 BALANCING MARKETS COMPARISON ACROSS COUNTRIES

3.1.2 Portugal

Portugal actively participates in the BM, with products such as FCR, aFRR, mFRR, and RR. Regarding European platforms, Portugal is integrated as an operational member in MARI and TERRE, while in PICASSO it is a non-operational member with the intention of actively participating in the near future. In FCR Cooperation, it is not connected.

Portugal's TSO, REN (Redes Energéticas Nacionais), is responsible for managing balancing products in the country. The BSPs (Balancing Service Providers) in Portugal include power producers, demand-side aggregators, and storage operators, but there is currently no Independent Market Operator (IMO). The main Regulatory Bodies are ERSE (the Portuguese Energy Services Regulatory Authority) and ENTSO-E (the European Network of Transmission System Operators for Electricity). New participants can access the market by meeting the regulatory and technical requirements established by REN and the corresponding European platforms.

In Portugal, the balancing market is governed by the Electricity Balancing Guideline (EB GL) and national regulations from ERSE as well as the European BM platforms. Participants must comply with national energy laws and EU regulations. They must also be capable of providing real-time data and responding automatically to frequency deviations. ERSE is responsible for verifying compliance with these requirements.

Technologies used to facilitate balancing actions include hydropower, thermal plants, battery storage, and renewable energy sources with storage capabilities. Balancing capacity is procured through auctions organized at the European level via platforms like ENTSO-E. The activation of balancing actions happens within seconds, with auctions being held regularly according to system needs. Automatic activation is carried out almost instantaneously to respond to frequency imbalances.

Balancing energy prices are determined through auctions using either pay-as-bid or marginal pricing systems. Portugal also participates in the cross-border balancing mechanism with other European countries through ENTSO-E. Digital platforms play a key role in the market, facilitating real-time data exchange and auction management.

The FCR market in Portugal is divided into zones, which are defined by REN and ENTSO-E, both responsible for verifying proper service delivery. If BSPs fail to provide the required flexibility at the necessary time, penalties will be applied according to the established terms. This verification is carried out by ERSE and REN in compliance with European regulations.

The main barriers include the complexity of complying with national and European regulations and the need to guarantee sufficient real-time capabilities for new market operators.

The potential for BM products in Portugal is high, especially with the growing demand for frequency regulation services due to the variability of renewable energy sources. The integration of new technologies and participation in European platforms will enhance the flexibility of the grid and operational efficiency.

3.1.3 Spain

Spain actively participates in the BM, with products such as FCR, aFRR, mFRR, RR, and SRAD. Regarding European platforms, Spain is integrated as an operational member in MARI and TERRE, while it is not connected to FCR Cooperation, operating instead at the national TSO level. Consequently, there is no cross-border balancing for FCR. For aFRR, marginal pricing is applied for availability (capacity payments) assigned on a day-ahead (D-1) basis, though cross-border activation is not yet fully in place. For mFRR, the connection to the MARI platform will enable Spanish BSPs to participate in EU balancing services and vice versa. For RR, Spain already participates through the TERRE platform. It is also expected that by May 2025, Spain will integrate into PICASSO, alongside the definition of the independent aggregator figure, which will mark a turning point in the Spanish BM landscape.

The Spanish TSO, REE (Red Eléctrica de España), is responsible for managing balancing products in the country. The profile of BSPs varies depending on the product. For FCR, which operates internally at the TSO level, BSPs are typically synchronous generators or storage facilities capable of automatically responding to frequency deviations. In the case of aFRR, BSPs are mainly large industrial customers or generators, with a minimum contracted power requirement of 200 MW which is intended to be reduced to 100 MW with the integration of PICASSO. For mFRR, the participant profile is similar, although the minimum required power is reduced to 1 MW. Regarding RR, both BSPs and BRPs, including generators and consumers, can participate. For SRAD, consumers with a minimum flexible power of 1 MW are eligible, but it is expected to be reduced or allowed by means of aggregation of supply points. The main regulatory body overseeing the balancing market in Spain is CNMC (National Commission on Markets and Competition).

The new participant must be prequalified by the TSO to provide the service by successfully passing a series of control tests defined in the procedure *"P.O. 3.8 Pruebas para la participación de las instalaciones en los procesos y servicios gestionados por el operador del sistema"* The operation of the Spanish balancing market, including participant rights and obligations, is governed by the European Balancing Guideline,

PICASSO project rules, and national regulations. The main regulatory bodies are the CNMC and the TSO, REE which oversee compliance with market access requirements, technical standards, and operational procedures, ensuring participants are properly registered, meet minimum capacity thresholds, and provide real-time data and performance capabilities.

The technologies used to facilitate balancing actions in Spain include large generation plants, big industrial customers, batteries, and consumers with more than 1 MW of flexible capacity. Demand response solutions, with or without storage, also contribute to system flexibility.

Balancing capacity in Spain is procured through auctions, typically based on a pay-as-bid system for capacity, where providers are paid their offered price if selected. For energy activation, marginal pricing (pay-as-cleared) may apply. Capacity auctions are usually held day-ahead (D-1), while activations occur closer to real time depending on system needs.

In Spain, the balancing market is not divided into zones; it operates under a national procedure managed by the TSO according to national requirements. REE is responsible for verifying that balancing services are actually delivered through real-time monitoring, data collection, performance evaluation, compliance analysis, and financial settlement processes. If a BSP fails to provide the committed balancing service, it is subject to penalties and must pay deviation costs. The CNMC (National Commission on Markets and Competition) oversees that the qualification, activation, and settlement of balancing services are conducted correctly and transparently.

The main barriers in Spain are the high minimum power requirements for new participants and the absence of a defined independent aggregator figure in the current regulatory framework.

Spain has significant potential to integrate more renewable energy sources into balancing markets, particularly in products such as aFRR and mFRR. However, the variability and limited controllability of certain renewable sources, such as photovoltaic (PV) and wind energy, currently restrict their participation. In contrast, other flexible and controllable resources, such as hydropower and batteries, can participate under similar conditions to non-renewable generators. Regarding mFRR, the progressive integration of batteries and flexible demand resources is expected to strengthen the provision of necessary reserves.

3.1.4 France

France has a mature balancing market managed by RTE (Réseau de Transport d'Électricité), the country's Transmission System Operator. RTE operates a decentralized model to ensure grid stability, using dynamic capacity calculations throughout the day. France is connected to European platforms such as TERRE for Replacement Reserves (RR) and FCR Cooperation and is preparing to join PICASSO and MARI by the end of 2024–2025. On the MARI platform, France shares its Available Transmission Capacity (ATC) with neighbouring countries. This means that France can exchange balancing energy more efficiently by utilizing the cross-border transmission capacity, allowing for a better optimization of energy flows and reducing potential congestion across borders.

To join the balancing market, new participants must register with RTE and complete a prequalification process involving technical tests to verify their dynamic response capabilities. FCR capacity is contracted through cross-border D-1 auctions. Participants must comply with the Ancillary Services Chapter 4 approved by the CRE (Energy Regulation Commission) and sign a participation agreement. For aFRR and mFRR, prequalification and participation in daily or annual auctions are also required, depending on the product.

Participants must comply with the European Electricity Balancing Guideline and national regulations under the supervision of the CRE. To qualify as a Balancing Service Provider, they must meet national energy laws and EU regulations, with FCR requirements defined by the dimensioning rules developed by continental European TSOs under Article 153(2) of the System Operation Guideline (SOGL).

Technically, BSPs must be capable of providing real-time data and automatically responding to frequency deviations. FCR auctions are based on four-hour delivery periods, with a minimum bid size of 1 MW and prices expressed in €/MW. Participants must also be able to submit indivisible bids up to 25 MW. RTE and CRE oversee compliance through the prequalification processes.

In the FCR, aFRR, and mFRR markets, balancing energy prices are determined using either pay-as-bid or marginal pricing systems. As of November 2023, the aFRR market adopted a pay-as-clear model with separate prices for upward and downward energy. For mFRR, capacity is remunerated under pay-as-bid, while energy payments are settled at marginal pricing.

Cross-border balancing mechanisms are fully integrated via European platforms such as ENTSO-E, PICASSO, and MARI, facilitating energy exchange between countries. France and Spain are actively working towards full MARI operability by 2025.

Digital platforms play a critical role in enabling real-time data exchange, auction management, and performance monitoring, thereby enhancing transparency and efficiency. Managed by RTE, these platforms also facilitate the smoother integration of renewable energy sources into the balancing markets.

Balancing products like FCR, aFRR, and mFRR support the integration of renewables by providing fast responses to the variability of wind and solar generation, thus stabilizing frequency and ensuring grid security.

In France, the FCR, aFRR, and mFRR markets are not divided into zones; RTE operates the system as a unified network for all three products. Service delivery is verified through real-time monitoring using digital platforms, supervised by RTE and CRE to ensure regulatory compliance. If a BSP fails to meet its obligations, penalties apply, including loss of availability payments and financial penalties based on undelivered energy or failure to activate. Penalty structures are similar for FCR and aFRR, while mFRR penalties are based on the higher value between capacity payment and spot market price. Verification processes, power reductions, and settlements are managed by RTE, with transparency guaranteed through RTE's digital systems and CRE oversight.

In addition to regulatory and technical challenges, aggregators face significant barriers. High minimum capacity requirements and restrictions on aggregating smaller assets limit their market participation. Although some pilot frameworks and dedicated auctions have aimed to encourage aggregators, strict bid size requirements and real-time response obligations remain major obstacles. Regulatory uncertainty, such as the temporary suspension of the aFRR market in 2021, further undermines aggregator confidence, exposing them to higher financial risks from market non-compliance penalties. Despite these challenges, the integration of flexible resources through aggregators remains essential for increasing renewable energy participation in the balancing markets.

3.1.5 Ireland

Ireland, likely due to the constraints of its small island-based power system, does not participate in ENTSOE European Balance initiatives where countries can share the Balancing resources used by their transmission system operators such as PICASSO (aFRR), MARI (mFRR) and TERRE (RR).

Ireland's Electricity Market is nonetheless coupled with the Internal Energy Market for Electricity and Gas since 2018, and the electricity market comprises two ex-ante markets and a Balancing Market. The TSO (Eirgrid) calls on balancing services to keep the transmission system balanced. Energy balancing services are offered into the Balancing

Market by generators and consumers. For example, if demand is higher than expected, the TSO might instruct a generator with available capacity to increase its output. After the trading period, IMO calculates the actual vs. scheduled positions and settles payments for energy delivered or consumed during balancing.

In addition, the TSO operates a program for Delivering a Secure, Sustainable Electricity System which includes mechanisms for procuring and recompensing providers for grid services including Synchronous Inertial Response, Fast Frequency Response, Primary Operating Reserve and Dynamic Reactive Response (DRR).

3.1.6 Estonia

Estonia has a mature balancing market, regulated by its TSO, Elering, which has been operational for more than two years. The country offers balancing products such as FCR and aFRR. At the European level, Estonia is fully operational in the MARI platform for mFRR, while it remains a non-operational member in PICASSO for aFRR, with plans to integrate more actively in the future.

Elering coordinates balancing activities across both supply- and demand-side participants, fostering a broad market ecosystem that includes Energy Service Companies (ESCOs), Aggregators, Local Energy Communities (LECs), and consumers/prosumers as the main Balancing Service Providers. The market is supervised by the Estonian Competition Authority and the Ministry of Economic Affairs and Communications.

To promote innovation, Estonia is actively exploring advancements in balancing market mechanisms through regulatory sandboxes. These initiatives support the testing of new flexibility solutions, including demand response projects that Elering is developing. Interested participants can apply to join the balancing market by registering through Elering and must comply with both technical and regulatory requirements to participate.

The Estonian balancing market is governed by the European Electricity Balancing Guideline (EB GL) and the national Estonian Electricity Market Act, under the supervision of the Estonian Competition Authority. To qualify as a Balancing Service Provider (BSP), entities must be registered in the EU or Estonia and comply with national energy and data protection regulations. Technically, BSPs must meet Elering's metering, control, and response requirements to enable real-time monitoring and frequency deviation management. Compliance is verified by Elering and the Estonian Competition Authority through prequalification and monitoring processes.

Balancing actions in Estonia are supported by demand response systems, battery storage, and smart grid technologies. Balancing capacity is procured through auctions managed by Elering, alongside some bilateral contracts for specific services. The frequency and duration of balancing actions are typically short-term, ranging from a few seconds to several minutes depending on real-time system needs. Balancing energy prices are determined through marginal pricing at the auction level, with a minimum bid size of 1 MW. Estonia also collaborates closely with other Baltic states and Nordic countries to enhance cross-border balancing capabilities.

The Estonian market currently operates as a single national market. The main barriers to the balancing market in Estonia are regulatory complexity and high technical requirements. Compliance with both national and EU standards can discourage new entrants. Technically, the need for advanced real-time metering and automation systems is a significant hurdle, especially for small-scale storage and renewable assets. While aggregation can help, symmetrical bid requirements and associated costs still limit broader participation.

Estonia has strong potential to expand renewable energy integration by enhancing demand response integration, increasing cross-border balancing cooperation, and developing storage solutions to improve system flexibility.

3.1.7 Croatia

Croatia has a well-developed balancing market, operated by the Croatian Transmission System Operator (HOPS), which manages the entire Load-Frequency Control (LFC) area, scheduling, and monitoring. The market operates on a self-dispatch model, and the main balancing products are aFRR and mFRR. Croatia is a non-operational member of the PICASSO and MARI platforms, while FCR is managed at the national level.

BSPs can be individual network users or aggregators who sign a Balancing Service Agreement with HOPS for each service. These BSPs must pass a pre-qualification process to demonstrate their technical ability. The Croatian Distribution System Operator (HEP ODS) and HROTE (IMO) also play key roles. New market participants must sign the Entering Balancing Service Agreement and provide a Certificate of Technical Ability. For more information on the pre-qualification process, visit HOPS Prequalification Process [11].

Balancing actions are facilitated by demand response and energy production assets. The activation process is semi-automated, with reserves and imbalances managed every 15 minutes by different BSPs. Pricing follows the Methodology for Pricing of Ancillary Services,

with compensation based on power reserve (EUR/MW) and voltage/reactive power control (EUR/h).

Croatia is integrated into the Continental Europe synchronous area and the Slovenia–Croatia–BiH Load–Frequency Control Block (LFC block SHB). The minimum bid size is 1 MW. The main barrier to further development is the need for greater automation in the balancing market.

3.1.8 Greece

Greece has a well-established balancing market, managed by the Independent Power Transmission Operator (IPTO). The main balancing products in the market are FCR, aFRR, and mFRR. Greece is a non-operational member of the PICASSO and MARI platforms but is actively working on fully integrating into these platforms for better coordination and exchange of balancing services.

The role of the TSO, IPTO, is crucial in organizing the balancing market and ensuring grid stability. IPTO is responsible for managing the country's Load–Frequency Control area, scheduling, and monitoring, and oversees the activation of balancing services when necessary. The market operates under both automatic and manual activation for balancing services, depending on the type of imbalance.

BSPs in Greece include power suppliers, aggregators, and generators who sign a Balancing Service Agreement with IPTO. New participants must go through a prequalification process to prove their technical ability to provide balancing services. The Greek market is regulated by ENTSO–E, and the Regulatory Authority for Energy, Waste and Water (RAAEY), which is the independent body in charge of regulating and supervising the energy, water and waste management sectors in Greece.

Balancing actions are supported by demand response, energy production assets, and storage systems. Greece participates in cross-border balancing mechanisms with other European countries via ENTSO–E. The minimum bid size for balancing services is 1 MW.

In Greece, balancing energy prices are determined through auctions where BSPs offer their reserve capacity. The prices are calculated based on the activated balancing energy offers, and the process is explained in more detail on the IPTO website [12]:

- For **aFRR**: The upstream balancing energy price for aFRR is determined by taking the maximum between the mFRR upstream balancing energy price and the aFRR upstream energy bid price of the BSP. This is done during an Imbalance Settlement

Period. If the mFRR price cannot be calculated, the relative price of the BSP's aFRR offer is used.

- For **mFRR**: The upstream balancing energy price for mFRR is calculated as the maximum between the upstream mFRR bid price and the upstream aFRR bid price.

These prices are influenced by the integration with European platforms like MARI and PICASSO. Greece currently consists of one bidding zone. In the future, there may be a split into multiple bidding zones to better manage grid congestion and renewable energy integration. The main challenge for the Greek balancing market is the need for greater automation and the integration of more flexible resources to accommodate the growing share of renewable energy.

3.1.9 Cyprus

The Balancing Market in Cyprus plays a crucial role in the operation of its electricity grid, especially as the country transitions to a more competitive and renewable-friendly energy market. The Cyprus Transmission System Operator is responsible for managing this market, ensuring that supply and demand are balanced in real time to maintain the stability of the electricity system.

The design of the balancing market in Cyprus is aligned with the European Union's Electricity Balancing Guideline, part of the broader EU regulations aimed at harmonizing electricity markets across member states. More specifically, for the purposes of harmonization with Directive (EU) 2019/944 on common rules for the internal market in electricity, public law on the Regulation of the Electricity Market known as the "Cyprus Transmission System Operator- 2021" by the Cyprus Electricity Authority, was established setting the details for the operation of the Balancing Market.

While the market was initially expected to open fully by 2021, various delays have pushed back the timeline. Ongoing challenges include electricity grid with EU standards and ensuring there is sufficient competition to break the dominance. Efforts are intensifying to launch a competitive electricity market by July 2025, marking a significant milestone in Cyprus's energy sector evolution.

3.2 Local Flexibility Markets

Apart from the review of the balancing markets that are already mature at the European level, the concept of Local Flexibility Markets is further analyzed as a current trend at Local Energy Communities level.

3.2.1 General

Local Flexibility Markets (LFMs) are emerging as a key solution to modern challenges in electricity networks, especially with the increasing integration of renewable energy and the decentralization of power generation. LFMs enable the dynamic exchange of flexibility services—such as adjusting consumption or generation in response to grid needs—at the local level. By allowing distributed energy resources like batteries, electric vehicles, smart appliances, and proactive consumers to participate, these markets help Distribution System Operators (DSOs) manage congestion, defer costly infrastructure upgrades, and maintain grid stability. LFMs represent a shift from traditional top-down electricity management to a more participatory, decentralized model, where local actors contribute to the overall efficiency and resilience of the energy system.

Among the countries analysed, only France has an established and operational LFM. Portugal, Ireland and Estonia are running localized flexibility programs led by key electricity sector stakeholders, while Spain and Croatia are exploring LFM implementation through various pilot projects and experimental schemes to better understand operational needs and challenges. On the other hand, Cyprus lacks any form of flexibility market, including day-ahead, intraday, or balancing markets.

The most common Flexibility Service Providers (FSPs) include battery energy storage system (BESS) operators, electric vehicle fleet managers, aggregators, ESCOs, and Local Energy Communities (LECs). These actors typically operate at low (LV) or medium voltage (MV) levels. On the demand side, Distribution System Operators and Transmission System Operators are generally the main Flexibility Off-takers (FOs). In some instances, DSOs also behave as Independent Market Operators. To participate in LFMs, FSPs must meet a series of technical, legal, and insurance requirements, often documented and submitted through structured templates, which are subsequently reviewed by the DSO or IMO.

Regulatory frameworks are largely grounded in EU Directives 2019/943 and 2019/944, transposed into national legislation and supplemented by National Energy and Climate Plans (NECPs). However, the implementation level and legal clarity vary across countries. Due to the early-stage nature of most LFMs, technical specifications such as response times, data granularity, and communication protocols are often undefined or inconsistent. This lack of standardization makes it difficult to establish common benchmarks or facilitate cross-border comparison.

In the operational models currently observed, the most common flexibility product is Demand Response (DR) aimed at peak load reduction. Typically, the FO sends a flexibility activation request (via API, email, or phone), and the FSP adjusts consumption accordingly during a predefined time window. In some cases, the power increase/reduction and timeframes are pre-agreed, but DSOs are never allowed to curtail consumption unilaterally.

FSPs are compensated not only for the actual energy shifted (measured in kW), but also for maintaining readiness to provide flexibility, even when not activated. Payment schemes vary and may include pay-as-bid mechanisms or fixed price offers set by the DSO. The minimum bid size generally ranges from 100 kW to 1 MW, although Ireland does not impose a minimum threshold.

In addition to short-term services, France offers one and Portugal offers four extra long-term flexibility services designed to support network investment deferral and congestion management. In more mature markets, LFMs are often structured into geographic zones aligned with grid constraints or the jurisdiction of different DSOs. For pilot projects, however, a single market zone is typically applied.

A crucial technical aspect is the baseline consumption definition, which allows for measuring actual flexibility delivered. This baseline is usually calculated based on historical consumption profiles and it is a prerequisite for accurate remuneration of services rendered.

The main barriers hindering LFM deployment across countries include:

- Low digitalization levels among DSOs, especially in terms of real-time data acquisition and communication.
- Lack of harmonized procedures among market actors, creating inefficiencies and entry barriers.
- Regulatory uncertainty, including the absence of a clearly defined role for aggregators.
- Limited awareness and low financial incentives, which reduce FSP engagement.
- Insufficient smart meter rollout, hindering data collection and verification.

LFM are still at the early stages of development, facing challenges like regulatory complexities and coordination issues between DSOs and TSOs. However, these barriers will be overcome soon. As smart grid technologies advance and aggregators and demand-

side response solutions grow, LFMs are expected to play a crucial role in enhancing grid stability and integrating renewable energy, optimizing local supply and demand balance.

Key takeaways per country are shown in Table 16.

	PT	ES	FR	IE	EE	HR	GR	CY
Is there any flexibility initiative currently active?	Yes (LFM programs)	Yes (flexibility products)	Yes (established market)	Yes (LFM programs)	Yes (LFM programs)	Yes (flexibility products)	Yes (flexibility products)	No
Are the main flexibility actors involved in your country's initiative?	Yes (FSPs, FO, IMO)	Yes (FSPs, FO)	Yes (FSPs, FO)	Yes (FSPs, FO)	Yes (FSPs, FO)	Yes (FSPs, FOs, IMO)	Yes (FO)	Yes (FO)
Are there any Regulatory Bodies (RB) or Local Entities (LE) involve?	Yes (RB, LEs)	Yes (RB, LEs)	Yes (RB)	Yes (LEs)	Yes (RBs, LEs)	Yes (RBs, LE)	Yes (LE)	Yes (LEs)
How many services does it offer?	5	1 (Regulatory Sandbox)	2	1	1	1	1	No
How is flexibility activated? (Implicit or Explicit)	Implicit	Explicit	Explicit	Both	Explicit	Explicit	Explicit	No

Is there a minimum bid size to participate in LFM?	Not specified	Not specified	500 kW	No minimum	100 kW	1000 kW	~100 kW	No
Are the LFM zones geographically defined?	Yes	Yes	Yes	No	No	No	Not specified	No
Which are the main technical barriers	Regulatory framework evolving; challenges with DERs integration and communications	PV overloading, low DSO digitalization, no aggregator definition, grid connection barriers	Low attractiveness for FSPs, low awareness, evolving regulation, few assets	Unclear tests, short program history, low inertia challenges	Limited regulation, tech integration issues, low demand urgency	Grid tariffs, slow smart meters, slow DSO operations	Not specified	No
Is the regulatory framework blocking the operational functioning of LFMs?	Yes (framework evolving, needs more clarity)	Yes, framework not adapted and market design not supportive	Yes, evolving rules and lack of standard EU framework	-	Yes, limited regulation and lack of clarity	Yes, energy communities' integration needed	Not specified	No

TABLE 16 LOCAL FLEXIBILITY MARKETS COMPARISON ACROSS COUNTRIES

3.2.2 Portugal

Portugal does not have a fully mature local flexibility market yet but is moving forward through pilot initiatives. The main reference is the collaboration between E-REDES, the distribution system operator, and the Piclo Flex platform, which acts as an Independent Market Operator. Piclo [13], already established in countries such as the United Kingdom, enables the coordination of flexibility offers from different providers in response to specific grid needs.

The Piclo Flex Portugal project, active since 2022, allows the participation of various FSPs including BESS operators, electric vehicle aggregators, and demand response actors. These providers operate at low or medium voltage levels and participate through calls for flexibility published on the platform.

The main Flexibility Off-taker is E-REDES, while ERSE oversees the regulatory framework. FSPs must register to the Piclo platform, meet technical and legal requirements, and go through a prequalification process.

The regulatory framework includes EU Directives 2019/943 and 2019/944, along with national legislation such as Decree-Law 15/2022 and Regulation 560/2014, which define market participation conditions and obligations for all actors involved.

From a technical perspective, FSPs must provide real-time data, respond within 15 minutes, and interface with the system using standardized communication protocols (such as APIs). The main product is peak demand reduction, activated explicitly upon request from the DSO, typically via email or phone.

Under Piclo Flex Portugal, five flexibility services are offered, each built around two key elements: operational activation—the FSP’s ability to respond in real time to DSO requests—and scheduled availability, which involves a prior commitment to be available during specific time windows. Each service combines these in different ways:

- **Peak Reduction** targets structural, sustained reductions during peak hours. The FSP adjusts its consumption permanently without needing specific requests. Only the energy reduced is compensated.
- **Scheduled Utilization** defines pre-agreed time slots in which the FSP commits to provide flexibility if requested. It enables better grid planning and compensates both availability and actual delivery.
- **Operational Utilization** responds to unexpected or ad hoc needs. There is no prior commitment from the FSP, who decides in real time whether to provide the service. Only delivered activations are paid.

- **Operational Utilization + Scheduled Availability** combines planned availability with the possibility of being activated during the agreed periods, giving the DSO more reliable resources without guaranteeing usage.
- **Operational Utilization + Variable Availability** builds on the previous model but allows the FSP to adjust the amount of flexibility on short notice—useful in situations where available capacity fluctuates.

Except for Peak Reduction, all services require explicit activation by the DSO, typically via email, phone call, or, in some cases, through API.

Compensation is generally based on a pay-as-bid model, in which FSPs submit price offers that the DSO evaluates based on location and cost. However, for some services—particularly those involving scheduled availability—prices may be contractually predefined. While there is no formal minimum threshold, offers of 100 kW or more are typically considered operationally viable and competitive.

The current flexibility framework in Portugal originated from the FIRMe [14] pilot project, launched by E-REDES to test demand-side flexibility in real network conditions. This initiative enabled the activation of multiple flexibility opportunities, laying the groundwork for the current market structure and services [15].

The Portuguese flexibility market is organized into geographic zones, defined by E-REDES based on local grid conditions. FSPs may only participate if their assets are located within one of these zones. Service delivery is verified by comparing actual consumption against a baseline calculated from historical data. In cases of non-compliance, contractual penalties may apply, and future participation may be restricted. The process is supervised by ERSE, in coordination with Piclo and the DSO.

Despite the progress made, challenges remain, including the limited digitalization of DSO procedures, low perceived value of flexibility, complex entry processes for new participants, lack of public visibility, and the incomplete rollout of smart meters, which hinders accurate and automated verification.

3.2.3 Spain

Spain does not yet have a fully developed local flexibility market. At present, there is no formal structure or defined products, although various pilot initiatives and regulatory sandboxes [16] are being implemented by entities such as OMIE [17] and IDEA [18] to explore the technical and economic feasibility of flexibility services.

These initiatives include voltage control tests within the transmission network and targeted calls such as the one launched by IDAE in 2023, aimed at supporting innovative projects linked to energy flexibility. While no results have been published, these efforts lay the groundwork for future developments.

Currently, there are no Independent Market Operators (IMO) for flexibility in Spain, and any interaction between actors—such as aggregators and DSOs or TSOs—is managed directly within pilot frameworks. The role of the aggregator, which is essential for enabling small-scale participation, is still not formally recognized in national regulation.

Participation in the electricity market requires registration with the CNMC [19] and compliance with general technical and legal requirements. FSPs must be capable of real-time response, provide granular data (typically every 15 minutes or less), integrate with market platforms, and meet applicable regulatory standards. However, these conditions are not specific to flexibility, since a formal market structure for such services has yet to be established.

The current legal framework consists of EU directives such as 2019/944 and 2019/943, alongside national instruments like the Electricity Act (Law 24/2013), the NECP, the Climate Change and Energy Transition Law, and several royal decrees governing self-consumption, grid access, and energy transition incentives. Still, none of these instruments explicitly regulate local flexibility markets.

As there is no mature market nor standardized products, no formal flexibility services have been deployed in Spain, and there are no clear definitions regarding activation procedures, payment schemes, or service verification.

In terms of operational procedures, while each DSO is assigned to a specific geographic area, this division is based on regulatory and historical criteria rather than local grid constraints or flexibility potential. There is no standardized method for verifying service delivery, though in pilot setups the DSO may assume this responsibility. Similarly, there is no unified method to establish baseline consumption; in some test environments, baseline values have been based on day-ahead offers submitted by market participants.

No formal penalty mechanisms are in place either, aside from contractual terms applied in pilot agreements. Any future supervision of the flexibility market would likely be led by the CNMC in coordination with DSOs and the system operator, although these institutional roles are not yet clearly defined.

Key barriers to implementation include the absence of a dedicated regulatory framework, the lack of a defined aggregator role, and limited digitalisation—especially among smaller DSOs. Technical challenges include insufficient real-time data infrastructure, lack of harmonised procedures, and the incomplete deployment of smart meters, all of which hinder reliable and automated verification. Additionally, the low perceived value of flexibility and its limited public visibility reduce engagement from potential FSPs. According to CEMOSA [20] (Spanish engineering and consultancy company), while flexibility can help defer unnecessary infrastructure investments, its rollout will require lowering transaction costs, improving market transparency, and ensuring equitable access to information for all actors involved.

3.2.4 France

France has an operational LFM since 2020, launched by Enedis [21], the country's main DSO, which covers around 95% of national consumption at the distribution level. This market integrates periodic tenders and sandbox projects to enhance its functionality, allowing flexibility requests to be made up to 44 months in advance.

The market has seen notable growth: by 2024, Enedis awarded 51 flexibility services to 3 FSPs across 30 departments, reaching 46 MW of capacity, compared to just 4.5 MW awarded in 2023. The flexibility products offered by Enedis are designed to address local grid congestion and reduce the need for costly infrastructure upgrades.

FSPs in France include aggregators, large consumers, energy communities, and renewable producers, with no IMO involved. Instead, Enedis directly manages the relationship with FSPs through its platform. To participate, FSPs must register their assets, meet technical criteria, and pass a prequalification process.

The regulatory framework for the market is based on EU Directives 2019/943 and 2019/944, as well as the French Energy Code. The Commission de Régulation de l'Énergie supervises the market to ensure it operates transparently and competitively.

Enedis offers two main flexibility services:

- **Short-term Congestion Management:** This service allows FSPs to reduce or shift their consumption to alleviate grid congestion in specific areas, particularly when congestion does not justify grid investments. Flexibility is activated in response to real-time congestion events detected by Enedis. FSPs commit to provide flexibility upon accepting an activation request. The service is activated explicitly, based on the immediate grid needs and communicated via email or phone call. Payment is made on a pay-as-bid basis during congestion events, with a fixed price for availability and variable payments depending on the amount of load reduced. The minimum offer size is 500 kW / kVA.

- Investment Deferral Flexibility – Long term. Pay per use + Availability: This service helps Enedis defer infrastructure investments by using flexibility from FSPs in areas approaching grid capacity limits. FSPs guarantee availability and are remunerated with a fixed payment for being on standby, along with variable payments based on the amount of load shifted. The activation is explicit, and Enedis contacts FSPs via email or phone. Payments are made monthly via bank transfer. The minimum bid size is 500 kW / kVA.

Both products require explicit activation, typically via email or phone, and in some cases, through API. Compensation can be based on a pay-as-bid system or fixed prices, depending on the contract. The minimum usual participation threshold is 500 kW. The market is divided into zones based on local grid conditions, and service delivery is verified by comparing actual consumption with a historical baseline. Penalties may apply for non-compliance. The CRE and Enedis ensure that all activities follow the appropriate regulatory standards.

Despite its operational status, the French LFM still faces several challenges: there is a lack of competition in certain zones, complex processes for new participants, and a need to further automate operations. Enedis is working to improve aggregator participation and enhance system efficiency.

3.2.5 Ireland

Ireland offers the Beat the Peak Business [22] service through ESB Networks, a demand response scheme where eligible commercial electricity users are paid to reduce their electricity demand between 4:30pm and 7:00pm during business days (Monday to Friday, excluding public holidays). This service allows businesses to manage their energy usage more efficiently by reducing consumption during peak hours, which helps to improve grid stability and avoid stress on the network.

There is no minimum power requirement to participate, meaning that even small consumers, such as households with suitable metering, can get involved. This flexibility is enabled through the successful roll-out of smart meters, which allow precise measurement of electricity usage and the activation of demand response services.

The payment structure for the Beat the Peak program is based on a rate per kWh reduced, with payments ranging between 34 c/kWh and 82 c/kWh. For example, if a company reduces its load by 50 kW during the mentioned period (3h), it could receive approximately 102€ per day, based on a payment of 68 c/kWh. The duration of the

flexibility period is rounded up to 3 hours, even though the actual time is 2:30 hours, to simplify administrative calculations and ensure appropriate compensation.

The service is not divided into geographical zones, as flexibility is managed at the national level, within the Republic of Ireland (Northern Ireland is excluded from this program). ESB Networks (DSO) collects data from utility meters, and baseline demand is calculated from the average of historic quarter-hourly demand data for each participating site. The flexibility provided is verified using this historic data, and there is no penalty currently applied to FPSs for failing to meet the demand reduction. However, this may change in the future market design, where penalties could be introduced.

In terms of regulatory and participation requirements, eligible participants must meet the MCC10/Quarter Hour Meter criteria, pass a series of prequalification assessments, and comply with legal and technical standards outlined in the program's contract. The contract also requires that participating sites have appropriate metering and pass annual Generation Interaction Checks if applicable, ensuring safe integration with distributed generation sources.

Despite the advantages of this demand response program, there are several barriers. These include the need for clearer definitions of proving tests, prequalification assessments, and the challenge of getting businesses to invest in the required assets, especially since the program has been running for less than two years. There is also an ongoing consultation regarding the future design of the market, with ESB Networks proposing longer-term contracts to encourage greater participation.

Additionally, Ireland's low inertia energy system and its transition to electric vehicles and heat systems create a greater need for flexibility services to stabilize the grid and manage increased demand.

3.2.6 Estonia

Estonia does not yet have a fully developed LFM, but notable progress has been made through initiatives such as the Elering Smart Grid Pilot Project [23], launched in 2019 by the national TSO, Elering. This project aims to increase grid flexibility by integrating DERs and enabling demand response (DR) through digital platforms and real-time communication.

Within this framework, Elering offers the Demand Response Service, allowing FSPs—such as ESCOs, aggregators, prosumers, and local energy communities—to reduce or shift electricity consumption when the grid is under stress. Activation is explicit and can occur

at any time, delivered via API or other digital interfaces. FSPs do not commit to fixed volumes in advance but must be ready to respond when called.

FSPs are compensated based on the energy curtailed, with pricing determined by contract or dynamic market conditions. Payments are made by bank transfer following verification through real-time metering and historical baselines. The minimum bid size is 100 kW.

The service is governed by the Estonian Electricity Market Act and EU directives, including the Clean Energy Package and GDPR (General Data Protection Regulation). Participation requires legal and technical compliance, including compatible metering and communication infrastructure. Oversight is provided by the Estonian Competition Authority and the Ministry of Economic Affairs and Communications.

Although promising, challenges persist—such as regulatory gaps, system integration issues, and limited involvement of smaller actors. However, the Smart Grid Pilot and Demand Response Service lay the groundwork for a more flexible and resilient electricity system in Estonia.

3.2.7 Croatia

Croatia does not yet have a mature local flexibility market. Although the Electricity Market Act (OG 111/21 and 83/23) and the Law on Renewable Energy Sources and High-Efficiency Cogeneration (OG 138/21 and 83/23) formally recognize new market actors—including aggregators, citizen and renewable energy communities, and energy storage operators—the necessary bylaws and implementation mechanisms are still under development.

A key reference for regulatory vision is the NECP which includes a Renewable Energy Source Measure (RES-4) aimed at establishing a regulatory framework for active customer aggregators and local energy actors, aligned with EU directives. However, in practice, participation remains limited due to institutional and operational barriers.

Currently, seven aggregators are registered with HERA, the Croatian Energy Regulatory Agency. One of them, KOER, operates the country's first virtual power plant, and is the only actor currently offering a structured flexibility service in Croatia. Since 2022, KOER has participated in mFRR tenders coordinated by HOPS (Croatia's TSO). This service includes both upward and downward flexibility, through:

- Modulation of electricity consumption across its aggregated portfolio
- Curtailment of electricity production when needed

Activation of the service is explicit, performed via email or phone call from HOPS based on real-time grid conditions. Compensation is provided in two components: capacity

reservation payments and per-activation remuneration. Participation occurs through weekly tenders, with monthly settlements issued via bank transfer. The minimum bid size is 1000 kW, making the service primarily suited for large-scale aggregators. To participate, end users must complete a prequalification process defined by HOPS, resulting in a Certificate of Technical Ability, which is a prerequisite for contracting balancing services. The process and technical criteria are publicly available on the HOPS platform.

At present, no Independent Market Operator exists. The main actors are HOPS (TSO), HEP ODS (DSO), and HROTE (Energy Market Operator). The market is not divided into geographic zones; services are managed at the national level. Baseline consumption is calculated using 15-minute intervals, either based on the average of the previous four periods or using near-term forecasts. Penalties apply in case of non-compliance.

Structural and technical barriers persist, particularly the lack of dynamic pricing and tailored tariffs for peer-to-peer or microgrid trading within energy communities. Tariff structures currently favour self-consumption and feed-in mechanisms. Moreover, the slow rollout of smart meters hampers real-time verification and automation, although the DSO plans to replace 95% of legacy meters by 2030.

From the perspective of stakeholders like KOER, operational delays from the DSO and the absence of API connections hinder scalability. Enabling broader participation—especially from smaller consumers and energy communities—will require regulatory simplification and modernization of technical infrastructure.

3.2.8 Greece

Greece does not yet have a mature LFM. Although the legal and regulatory framework acknowledges the potential of flexibility services, there is currently no established market structure where such services can be traded regularly. Instead, efforts have focused on exploring flexibility—particularly Demand Response—through pilot programmes and sandbox initiatives, aiming to assess its feasibility and prepare for future integration into the energy market.

Among flexibility products, DR stands as the only standardised and technically implementable service within the current framework. Legally supported by Law 4001/2011 and aligned with EU energy directives, DR allows large electricity consumers, mainly from the industrial sector, to reduce or shift their consumption during peak demand periods or when the grid is under stress.

The main actors involved include HEDNO (the Hellenic Electricity Distribution Network Operator) as the FO, and RAAEY (Regulatory Authority for Energy, Waste and Water), which oversees compliance and regulation. In practice, FSPs receive explicit activation requests during high-demand scenarios, and are expected to reduce consumption temporarily to support grid stability. Activation may occur through API, SMS, or email, depending on the technical capabilities of the participant.

Payment structures typically consist of a fixed participation fee and variable remuneration based on kW curtailed. Contracts are agreed bilaterally between HEDNO and participants, with payments issued via bank transfer, usually within 30 days after service verification. The minimum bid size is often set at 100 kW or more, reflecting the industrial-scale focus of current programmes.

Despite its structured design, DR in Greece remains confined to experimental settings, and has yet to be integrated into a full-fledged flexibility market. Key barriers include:

- The lack of a formal trading platform
- Limited participation beyond large consumers
- Low automation levels and fragmented ICT infrastructure
- The absence of standardised operational procedures for wider scalability

Nevertheless, DR has been progressively gaining traction since 2017, and ongoing sandbox programmes involving stakeholders like METLEN/PROTERGIA aim to refine its implementation. The ultimate objective is to transition from isolated pilots to a regulated, market-based flexibility environment, enabling DR and other services to support Greece's decarbonisation and grid resilience goals in the coming years.

3.2.9 Cyprus

Cyprus does not yet have a LFM or balancing market in operation. The TSO has recently introduced a market model including Day-Ahead, Intraday, and Balancing Markets, with the goal of launching a fully competitive electricity market by July 2025.

The sector has long been dominated by the Electricity Authority of Cyprus (EAC), a state-owned utility responsible for most generation, distribution, and supply—mainly from fossil fuels. While efforts to liberalise the market are ongoing, flexibility-specific initiatives or regulatory sandboxes have not yet been implemented. The Cyprus Energy Regulatory Authority (CERA) oversees this transition and ensures alignment with EU directives.

As a small and electrically isolated island, Cyprus faces additional barriers to flexibility market development, including limited interconnection options and dependency on a

single dominant provider. These factors make it more difficult to implement advanced flexibility models, despite growing interest in modernising the grid.

The aforementioned analysis is conducted to support the review of the market framework in Europe, with a particular focus on the demonstration countries of the DIGITISE project. It provides an overview of current practices adopted by established markets and assesses the implications of the existing market design, with an emphasis on flexibility markets at the European Commission (EC) level. This analysis paves the way for the definition of innovative flexibility services and related processes to be examined in the project.

3.3 DIGITISE Flexibility Services and products

As outlined in the Description of Action (DoA), the primary objective of this task is to propose innovative flexibility services and related processes, and to elaborate on the definition of discrete flexibility and demand response products to be offered in overlay flexibility markets. These products are designed considering the characteristics of the flexible assets involved in the project as well as the corresponding technical requirements defined by the overlay markets. While a more detailed analysis of the different flexibility products and service offerings will be reported in D2.3, an early identification is provided in brief in the following section.

In this context, and in alignment with the Living Lab (LL) methodology adopted in the project, feedback from the demonstration partners—serving as domain experts—was incorporated to ensure a well-informed design of innovative flexibility and DR products. This approach aims to facilitate their future adoption both within the demonstration countries and across the broader EC market. Then, and taking into account the review of the literature as well as the feedback from experts, a non-exhaustive list of flexibility related services and products specifications to be examined in DIGITISE is provided.

Following the analysis of the various markets and flexibility products, key considerations and limitations have been identified and are presented in this section. The market analysis is provided in summary form to establish the foundational principles for the definition of DIGITISE flexibility products. It should be noted that this analysis focuses on functional and technical aspects, while non-technical dimensions (e.g., regulatory, structural, or policy-related issues) are considered out of scope.

Starting with the current conditions of local flexibility markets at the European Commission (EC) level and drawing from the analysis of mature implementations already presented, several key aspects emerge. A central consideration is the coordination between Transmission System Operators and Distribution System Operators, which is

essential for the coherent deployment of flexibility services. Equally important is the locational granularity of flexibility activation. Flexibility must be dispatched at the right location to effectively relieve local grid constraints. In parallel, flexibility markets must be inclusive of all relevant asset types—such as Heating, ventilation, and air conditioning (HVAC) systems, batteries, and electric vehicles—provided they comply with technical eligibility criteria.

Another critical point is the lack of harmonization in product definitions. Flexibility services differ widely in terms of their ramp-up times, durations, and reliability thresholds. This variability poses a challenge for scaling solutions across different regions or enabling cross-border interoperability. The availability and interoperability of digital platforms further compound this issue. While various digital infrastructures are emerging to support local market operation, their development remains uneven, often proprietary, and not fully interoperable.

As a result of these conditions, several limitations hinder the effectiveness of existing local flexibility markets. One major issue is the fragmentation in the design of flexibility products, which includes inconsistent baseline methodologies and varying activation rules. These inconsistencies create entry barriers for participants and reduce investor confidence. In many markets, asset aggregation is underutilized, and the absence of long-term signals or commitments discourages asset owners from participating. Moreover, value stacking—i.e., the ability of an asset to provide multiple services across DSO, TSO, and ancillary markets—is often restricted or entirely unavailable. This significantly weakens the economic rationale for investing in flexible infrastructure.

In response to these market limitations, the development of innovative flexibility products becomes important. The key parameters of these products are provided:

- These products must be clearly defined, with standardized technical parameters such as minimum service duration, response time, and ramp rate. The design of products must reflect specific grid needs, for instance, congestion management, voltage support, peak shaving, demand turn-up, or fast frequency reserve. However, care must be taken to avoid over-fragmentation of services, as offering too many distinct products can affect market impact. These definitions are aligned with the capabilities of the flexible assets in the project (e.g., batteries, HVAC, PV-coupled systems) and are designed to be transferable across use cases.
- It is equally important that the flexibility product definitions align with the technical characteristics of the participating assets. Flexibility products in DIGITISE are developed to support a wide range of asset types, from individual residential devices to community-scale storage, thereby enabling broader participation, including small-scale prosumers.

- For example, the ramp rate of a battery differs significantly from that of a building HVAC system, and product design must accommodate such variations. Products must also be stackable, allowing an asset to participate in multiple services where technically feasible and regulatory compliant.
- Control schemes for dispatch and fallback mechanisms must be well defined to maintain system reliability.
- Additionally, accurate baseline definitions and trusted measurement and verification processes are critical for fair settlement. Currently, many flexibility offerings rely on short-term contracts or spot auctions, which are insufficient to justify long-term investments in enabling technologies such as smart HVAC systems or distributed storage. The project leverages open, interoperable digital platforms to support flexibility activation, monitoring, and settlement integrating simplified but robust measurement and verification methodologies. Addressing these issues is fundamental to developing a robust and scalable local flexibility market architecture that can support both the needs of the grid and the business models of participants.

On the basis of the aforementioned limitations, the DIGITISE project directly promotes the co-design and demonstration of innovative flexibility products tailored to community-scale energy systems. These products are developed with a clear emphasis on technical feasibility, interoperability, and market replicability, drawing from both stakeholder input and real-world constraints observed in demo sites. Rather than adopting a one-size-fits-all model, the DIGITISE approach is focusing in the real-world operational constraints of demo partners and local grid needs. Therefore, direct feedback and interest from the demo partners is considered following the user centric approach adopted in the project. The list of flexibility products to be considered is defined below.

TABLE 17 FLEXIBILITY PRODUCT 1: DIRECT LOAD CURTAILMENT – HVAC SYSTEMS

Attribute	Details
Use Case & Description	Curtailment of HVAC systems in buildings to support grid congestion management, voltage control, and short-term reserves. Triggered through pre-agreed conditions by aggregator or DSO.
Market Type	DSO-operated local flexibility markets, TSO balancing markets
Target Asset	Building HVAC systems integrated with BEMS
Activation Method	Automated curtailment signal based on predefined activation triggers

Attribute	Details
Contract Types	Availability-based contracts, performance-based settlement, short-term tenders

TABLE 18 FLEXIBILITY PRODUCT 2: FAST RESERVE RESPONSE – BATTERY STORAGE SYSTEMS

Attribute	Details
Use Case & Description	Behind-the-meter storage systems provide immediate response to frequency deviations, supporting frequency stabilization and emergency support.
Market Type	TSO Fast Frequency Response (FFR), local ancillary services
Target Asset	Stationary battery systems with inverter-based control
Activation Method	Fully automated dispatch based on real-time grid frequency monitoring
Contract Types	Pay-as-bid contracts, availability-based contracts with performance obligations

TABLE 19 FLEXIBILITY PRODUCT 3: DEMAND TURN-UP (ABSORPTION SERVICE) – HVAC / BATTERIES

Attribute	Details
Use Case & Description	Assets are activated to absorb excess energy or increase demand (e.g., pre-heating or charging) during periods of low demand or high renewable generation.
Market Type	DSO flexibility markets
Target Asset	HVAC systems with inertia; stationary battery systems
Activation Method	Contract-based activation with automated scheduling
Contract Types	Time-bound contracts with capacity payments and energy absorption incentives

TABLE 20 FLEXIBILITY PRODUCT 4: SCHEDULED LOAD MODULATION – EV CHARGING

Attribute	Details
Use Case & Description	Aggregators manage EV charging schedules to defer or modulate load based on system needs, supporting peak shaving and local congestion management.
Market Type	Aggregator-coordinated local flexibility schemes
Target Asset	Smart EV charging infrastructure (e.g., fleet, workplace)
Activation Method	Remote control by aggregator; no user intervention required
Contract Types	Contracted service windows, volume-based activation settlement

TABLE 21 FLEXIBILITY PRODUCT 5: MULTI-SERVICE FLEXIBILITY PRODUCT BUNDLES

Attribute	Details
Use Case & Description	Aggregated flexible assets (e.g., HVAC, batteries, EVs) offer bundled services to both DSOs and TSOs, improving efficiency and supporting cross-market needs.
Market Type	DSO/TSO-coordinated hybrid flexibility markets
Target Asset	Mixed portfolios of flexible assets managed by aggregators
Activation Method	Platform-based coordination under multi-party contractual arrangements
Contract Types	Layered service contracts, stackable service agreements, dynamic procurement frameworks

The definition of the various flexibility products is based on the characteristics of the flexible assets available on-site, the market conditions at the demonstration sites, and the priorities of the involved stakeholders. Several types of flexibility products are considered, with a common emphasis on direct control—aligned with the project’s focus—thereby excluding any implicit or manual user interaction. Finally, particular attention is given to the contractual processes, with an emphasis on defining and examining different contractual templates to address diverse business needs. Along with the definition of the flexibility products, the initial prioritization at the demo sites is reported, based on input from the demo partners, listed below

TABLE 22 MAPPING OF FLEX PRODUCTS TO DEMO SITES

Flexibility Product	Spain	Greece	Croatia	Ireland
1. Direct Load Curtailment – HVAC Systems	+	++	+	x
2. Fast Reserve Response – Battery Storage	x	+	+	++
3. Demand Turn-Up – HVAC / Batteries	++	++	++	++
4. Scheduled Load Modulation – EV Charging	x	+	x	+
5. Multi-Service Flexibility Product Bundles	+	++	+	++

Overall, the outcome of this task is the definition and preliminary assessment of innovative flexibility and demand response products, along with the specification of associated processes covering contract parameters to support assets activation, measurement, and settlement. These outputs serve as critical input to WP5, enabling the development and implementation of tools that support consumer enrolment in flexibility marketplaces and facilitate the execution of related market transactions. While a revision of the different flexibility products to be performed as the project evolves, this work contributes to the design of a robust, user-centric framework for flexibility service provision within the DIGITISE project, aligned with future European flexibility markets.

4 DIGITISE Architecture details

4.1 Methodological Framework

In this section, details for DIGITISE architecture are provided. The DIGITISE architecture employs a robust methodological framework built upon the well-established 4+1 architectural views [24][25] model as stated below.

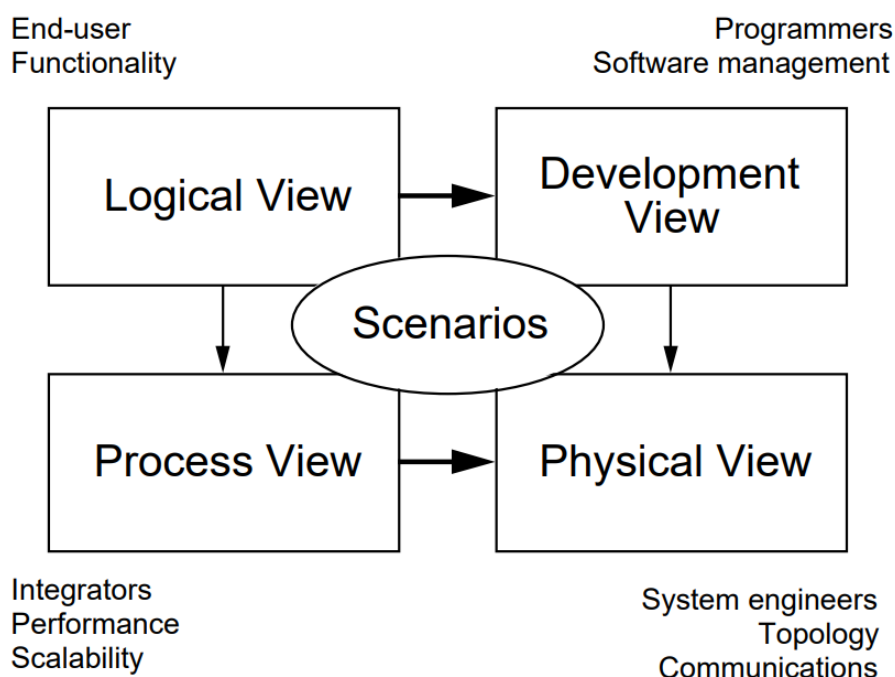


FIGURE 6 4+1 ARCHITECTURAL VIEWS MODEL

This approach ensures that all aspects of the system—ranging from high-level functionalities to specific deployment concerns—are comprehensively addressed and communicated to both technical and non-technical stakeholders.

At its core, the logical view abstracts the functional requirements into a coherent system design, delineating how each component contributes to overall functionality. By clearly mapping out business processes and system interactions, it provides a blueprint that guides the design and evolution of system components while ensuring that the architecture can be easily extended or modified in response to changing requirements. The overall definition of the Logical View considers the progress of the standardization in the energy sector with special emphasis on DERA3.1 [26] as promoted by BRIDGE. More details about this alignment in Annex II.

The process view captures the dynamic aspects of the system. It details how processes and threads interact, communicate, and synchronize to deliver the desired functionality under varying load conditions. By highlighting potential bottlenecks and addressing issues of performance, scalability, and reliability, this view is essential for evaluating the system's behavior in production environments.

Complementing the logical perspective, the development view (or implementation view) outlines the organization of software modules and their interdependencies. This perspective focuses on the static structure of the system, emphasizing best practices in modularity, maintainability, and reusability. It serves as a guide for developers, detailing how the software is partitioned into modules, packages, or services, and ensuring that coding standards and version control practices are consistently applied. The physical view maps the logical and development constructs onto the actual hardware and network infrastructure. It details how software components are distributed across servers, cloud environments, or on-premises infrastructure, ensuring that the architecture meets operational requirements.

The scenarios' view integrates all other perspectives by illustrating real-world use cases and interactions between users and the system. This view validates the architecture against practical scenarios, ensuring that all stakeholder requirements are met. Through sequence diagrams and narrative descriptions, it demonstrates how the system behaves in various operational contexts, bridging the gap between abstract design and practical implementation.

In the following, the logical and process view are covered in sections 4.2 and 4.3, the development and physical views in section 4.4 while section 4.5 covers the Scenarios (Use Case) View of DIGITISE project.

4.2 DIGITISE Conceptual View

In this section, an overview of the DIGITISE conceptual view as reported in the DoA is provided, highlighting the main deviations at this stage of the project. As stated in the DoA, the DIGITISE Architecture is conceptually split into three tiers:

1. The **DIGITISE Data Space** that effectively integrates real-time, batch, and streaming cross-sectorial data from various assets at household level as well as data available from external sources. It serves as the foundation for delivering intelligent insights and innovative digital services, all while maintaining enhanced security and sovereignty over the data.
2. The **DIGITISE Baseline AI Analytics and Digital Twins Solutions** to facilitate the extraction of valuable insights from the data collected and the execution of highly effective algorithms and routines for optimized management at consumer level, along with the beneficial automated participation of consumers in the energy flexibility markets.
3. The **DIGITISE end-user digital solutions, applications and products**, to collectively facilitate consumer engagement and automated involvement in energy related activities. Its aim is to generate value and direct benefit for the

consumers while also promoting citizens digital empowerment and energy literacy.

The **DIGITISE Data Space Environment** comprises 4+1 key layers:

- (i) the **Data Collection & Governance Layer** which facilitates the efficient handling and collection of data as well as the careful curation and storage,
- (ii) the **Semantic Interoperability Management Layer** to enable the semantic alignment of data with the DIGITISE Data Model by providing mechanisms and tools to ensure that data can be exchanged seamlessly and with consistent meaning across the various data assets, systems, and actors involved in the DIGITISE data value chain,
- (iii) the **Data Sovereignty Layer** that incorporates mechanisms dedicated to preserving data security within the DIGITISE data space including also measures to enhance sovereignty and control over consumer data,
- (iv) the **Data Retrieval and Marketplace Layer** which introduces advanced features for data querying of available data while further facilitating data sharing, promoting the enrolment of consumers in data economy scenarios.

In addition, the **DIGITISE Data Space Management Layer** serves as the component responsible for orchestrating the execution of various features and services offered by the DIGITISE Data Space. By integrating these core layers, along with their respective sub-components and associated features, the DIGITISE Data Space can deliver a comprehensive suite of value-added data services, covering all stages of the data management lifecycle, including Data Ingestion Data Interoperability and Storage, and Data Exploration and Sharing.

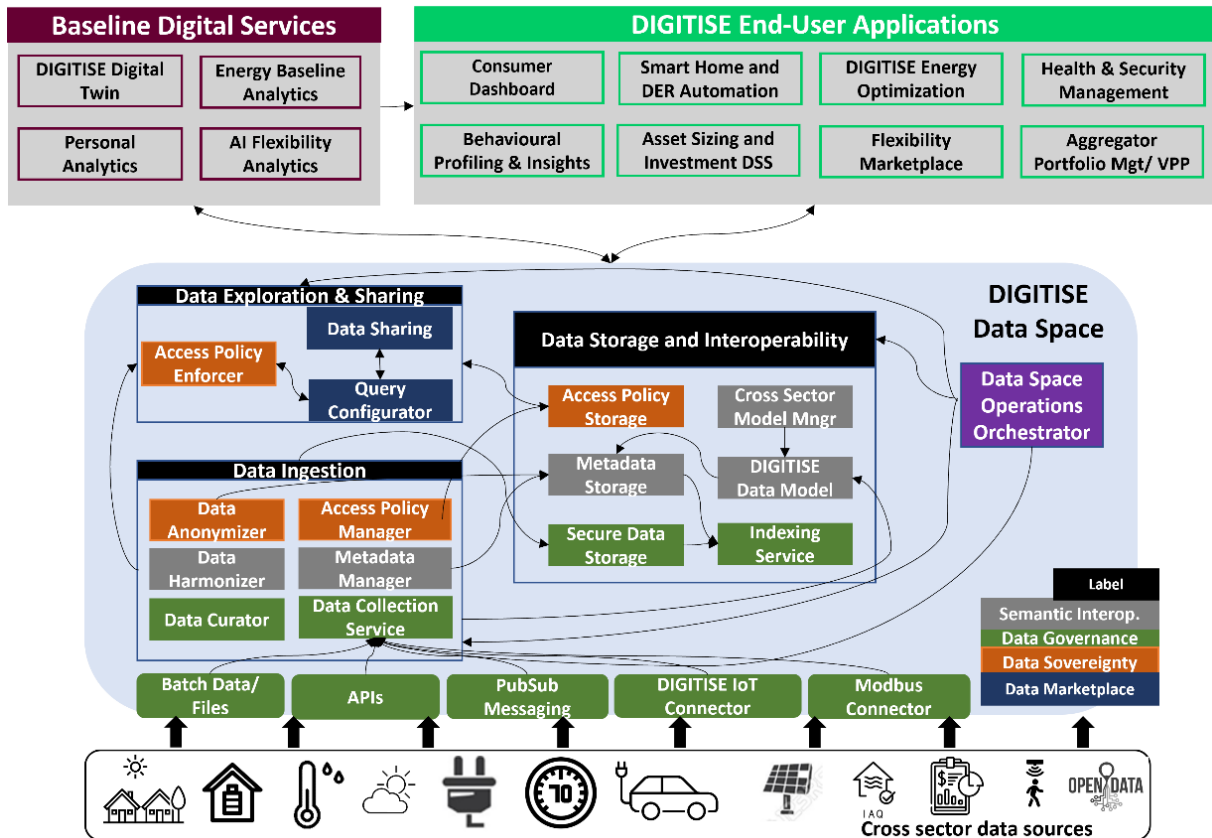


FIGURE 7 DIGITISE CONCEPTUAL VIEW

The **DIGITISE Baseline AI Analytics and Digital Twins** including the baseline components and intelligence artefacts that will facilitate the extraction of valuable insights from the cross sectorial data collected from the assets available at the consumers’ side and external open data sources and the execution of highly-effective algorithms and routines for optimized management at consumer/household level, along with the beneficial automated participation of portfolio members in the energy flexibility markets.

The **DIGITISE Baseline AI Analytics** consist in highly accurate:

- baseline personal analytics (consumer energy behaviour, occupancy profiles and comfort preferences) by combining energy and non-energy (i.e. occupancy parameters, ambient conditions, control actions performed over heating and cooling loads) data in order to extract valuable insights from the household environment and further enable the provision of personalized energy and non-energy (i.e. security/health) services,
- short-term forecasts of demand and generation (hour to day-ahead) addressing the dynamic nature of consumers’ energy behaviour to ensure a realistic and objective baseline establishment based on the actual status quo of consumers and their assets at each specific time period, thus avoiding over-generalized assumptions that can lead to significant errors and failures when verification of flexibility activation needs to be performed.

- DER Flexibility Analytics by profiling and forecasting the flexibility capacity of DERs available at consumer levels. Flexibility profiles and analytics will firstly employ the results of the personal analytics to be further correlated with the respective energy performance metrics and consumption data of DERs, to deliver highly accurate and personalized instances of Context-Aware Flexibility Profiling Models reflecting real-time flexibility as a function of multiple parameters, such as time, device operational characteristics, environmental context/conditions, occupant daily schedules, comfort and health conditions. Such flexibility profiles will constitute dynamic constructs that will be continuously updated based on real-time energy data, thus providing a robust framework for monitoring and analyzing energy related behaviour and corresponding flexibility features to accurately define and forecast the flexibility capacity (and its temporal dimension) that can be provided at each given time and market interval, thus facilitating the activation of consumers flexibility. The extraction of accurate baseline energy and flexibility profiles will facilitate the establishment of a sound ground-base for monitoring and verification of energy transactions and flexibility settlement and remuneration on activation events towards safeguarding the reliability of market mechanisms and increasing consumers' trust in energy flexibility transactions.

The **DIGITISE Household Level Digital Twin** implementation that will effectively address and optimize the management of the assets residing on the consumers' side towards maximizing the energy performance of the premises while also considering the provision of non-energy services. The Digital Twin implementation will step on the DIGITISE Baseline Analytics/ Forecasts, as well as the real-time data streams from the consumer side (metering, sub-metering, IoT, generation, storage, EVs), to facilitate

- (i) the monitoring and assessment in real-time of the total performance of consumer premises,
- (ii) the definition optimal context-aware and human-centric control strategies over the available assets and devices for maximizing the benefit of consumers, taking also into account the priorities and objectives set by the users,
- (iii) the assessment of long-term strategies for RES investment and penetration of smart flexible assets within the building environment.

The **DIGITISE End-User Applications** set the digital solutions, products and services for consumers/ prosumers to facilitate human interpretation, contextualization and capacity building around digital concepts, towards further enhancing digital empowerment and energy literacy. The pool of end user applications is delivered briefly:

- The Energy Savings and Self-consumption Optimization Application allowing the provision of detailed energy management optimization (in a human-centric manner) and self-consumption maximization (at the building level) with obvious

associated economic (cost savings) benefits for household citizens, by combining energy performance data fed from the Digital Twin and correlating them with real time data streams.

- The optimization application is accompanied by a Smart Home and DER Automated Control app to enable the realization of intelligent and automated control features over consumer loads, DERs and IoT devices available in consumers' premises as very effective means towards reducing intrusiveness and nuisance for consumers, while safeguarding the effectiveness and applicability of direct load control strategies under the objective of this application or within the frame of Explicit Demand Response through participation in flexibility schemas.
- As a means to advance the development and delivery of cross-sector applications (through utilization of the IoT data as well as the baselined profiles), the Health and Security Application aim to enhance and extend the smartness of the building (through SRI) as well as the literacy and acceptance of the citizens in innovative digital services, providing added value human-centric features and functionalities that promote the establishment of e health, secure and convenient building environment.
- The Asset Sizing and Investment Optimization Application which consist in a novel application that will enable informed and evident decision-making at household/consumer level to further increase RES integration, maximize self-consumption and further enhance the flexibility provision capabilities of consumers through cost-effective investment in RES, Storage and electromobility by incorporating data from the financial sector (i.e. investment costs, project financing etc..) in order to evaluate cost-effectiveness and other financial performance indices for the investments to be performed (i.e. payback period, IRR and ROI, WACC).
- The Behavioural Profiling and Insights Application, aims to enroll household citizens in data economy by providing added value on the data through the extraction of useful insights and user habits that may be utilized in purposes other than energy (i.e., marketing).
- The DIGITISE Consumer Application for Personalized Empowerment and Capacity Building focuses on the development and configuration of ambient and personalized application features (value-based behavioural segmentation, UIs and messages tailored to each segment) are aiming at consumer awareness, literacy, engagement and capacity building. Through an omni-channel environment, consumers will benefit from the DIGITISE cross-sectorial services in a seamless way, while further getting involved in market-based flexibility transactions.
- The DIGITISE Flexibility Marketplace Application will allow distributed flexibility sources to engage in flexibility market transactions with aggregators (or role undertaken by retailers/LECs in the energy sectors) and monetize their flexibility through the provision of added value (balancing and ancillary) services to the grid.

- The Aggregator Portfolio Management and Virtual Power Plant (VPP) Configuration Application will be tightly linked with the marketplace application and will consist in a novel module for aggregators that will facilitate the management of demand and flexibility profiles to forecast and decide upon the optimal management of flexibility sources (demand, generation, storage, EVs), while satisfying the goal of reduced complexity that comes from organizing flexibility profiles into clusters of homogeneous behaviour.

By presenting the conceptual view of the different systems as mentioned above, we proceed with the details of each component in the following section following the methodological framework as stated above.

4.3 DIGITISE Detailed Components Definition

In this section the details for the list of components that set the overall DIGITISE architecture are provided. Following the methodological approach, in this section we provide:

- a) An overview of the features to be supported per layers/application of the project considering also the identification of the key components.
- b) The list of core features specified in order to set the technical specifications for the implementation of each ICT solution
- c) The list of subcomponents and any dynamic interactions among these components and external systems

4.3.1 DIGITISE Data Space Environment

In this section the details of the DIGITISE Data Space are provided, considering the different pillars as specified in Section 4.3. First, the Data Ingestion Layer is the layer responsible for collecting data from a variety of data sources. The different components that consist of this layer are defined below.

4.3.1.1 Data Collection Component

Overview

Data Collection is the key component responsible for executing the ingestion process based on the configuration set up, ensuring that the defined ingestion process is faithfully followed. It carries out its tasks through the coordination of its sub-components, which consider different mechanisms suited to different data acquisition methods. These include facilitating batch data uploads for processing large volumes of data at scheduled intervals, directly subscribing to streaming data sources via PubSub real-time messaging methods to ensure continuous, low-latency ingestion, collecting data through standard and custom APIs that provide structured and unstructured data from a variety of external sources, and harvesting data exposed by the DIGITISE IoT and DER connectors, like Modbus, which enables seamless integration with industry-specific protocols. The Data

Collection thus functions as an adaptable, high-performance tool for acquiring diverse data sets, which are essential for comprehensive data processing and analysis workflows.

Technical specifications

In this section, the detailed technical specifications of the respective component are provided, taking into consideration the list of requirements as derived from D2.1 and further the detailed elaboration of the functionality to be delivered as part of the component. The list of core features is provided:

- Handling of Batch Data Collection (DC-01): This mode is engineered to handle large volumes of data that are accumulated over time. By leveraging the configurations, the system determines the data source, extraction schedule, and transformation requirements.
- Handling of On Demand Data Collection (DC-02): This mode dynamically triggers API calls to retrieve data either from third-party sources or from APIs supported by the DIGITISE data space. The on-demand mode is particularly valuable for real-time decision-making and analytics, offering a responsive mechanism to integrate up-to-date data into the system.
- Handling of Streaming Data Collection (DC-03): To support continuous data flows and low-latency requirements, DC-03 triggers the streaming data collection process. The system utilizes various PubSub protocols, such as Apache Kafka and MQTT, to subscribe to real-time data streams.
- Metadata Management (DC-04): At its core, this layer continuously collects and updates metadata from various stages of the data configuration process. While metadata are configured at the different steps, we report this functionality at the first step.

By adhering to the detailed specifications outlined in DC-01, DC-02, and DC-03, the system ensures that data ingestion is executed in a controlled, efficient, and scalable manner. These processes form the backbone of the overall data integration strategy, enabling robust and reliable data flow across the entire ecosystem.

Detailed interactions

By defining the core features per component, the detailed dynamic view of each application is provided, showcasing the interaction among the different components as well as the associated data exchanges.

- Within the Data Collection Component, key inputs include all data sources from the physical world, counting 3RD party APIs, streaming mechanisms, gateways etc....
- The data to be collected from this step are made available to the Data Harmonization Component for semantic alignment to the DIGITISE data model

The visual representation of the aforementioned dynamic view is presented below showcasing in a high level the data interfaces among the different components.

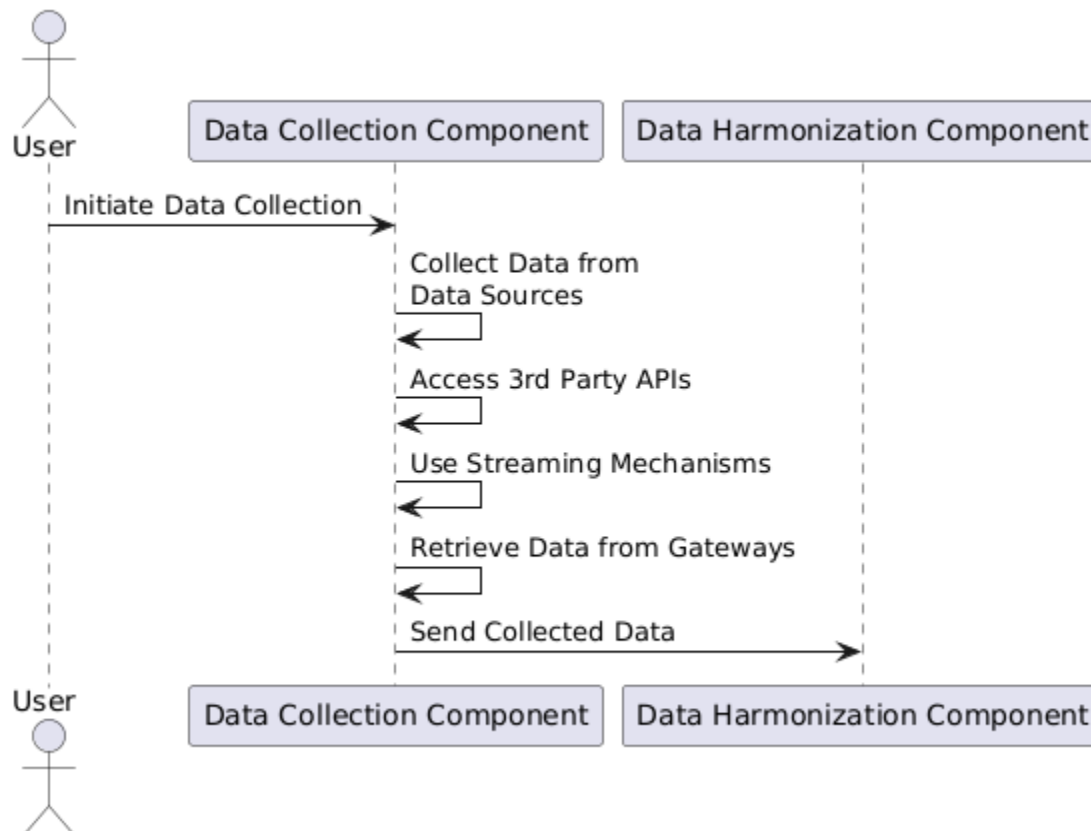


FIGURE 8 DATA COLLECTION COMPONENT

4.3.1.2 Data Harmonization Component

Overview

The Data Harmonization is a central component responsible for executing the mapping process according to the established configuration. Its primary function is to convert the uploaded data into the DIGITISE Data Model, ensuring that raw input is transformed into a structured format that can be easily interpreted and processed by downstream systems. This process begins by retrieving configuration settings, which detail the mapping rules, field correspondences, and transformation logic that must be applied to the incoming data.

Once the configuration is loaded, the Data Mapper receives data from upstream components. It systematically processes each record, translating fields from the original data into the standardized structure defined by the DIGITISE Data Model. This involves not only direct field-to-field mapping but also the conversion of data types and the enrichment of data with additional context or metadata as required. During this transformation, the component rigorously validates the data to ensure it conforms to the target schema, thereby maintaining a high level of data integrity and consistency.

Technical specifications

In this section, the detailed technical specifications of the respective component are provided, taking into consideration the list of requirements as derived from D2.1 and further the detailed elaboration of the functionality to be delivered as part of the component. The list of core features is provided:

- Handling of Semantic Mapping (SM-01): In summary, the Data Mapper plays a critical role in converting raw, heterogeneous data into a standardized, structured format defined by the DIGITISE Data Model. It ensures that data is reliably transformed and ready for subsequent processing. Its scalable, secure, and integrative design makes it an indispensable element of the data management ecosystem, capable of evolving alongside future data demands and technological advancements.

Detailed interactions

By defining the core features per component, the detailed dynamic view of each application is provided, showcasing the interaction among the different components as well as the associated data exchanges.

- Within the Data Harmonization Component, include all data collected from the previous step and the data collection.
- As a next step, the data are made available to the Data curation component for further process.

The visual representation of the aforementioned dynamic view is presented below showcasing in a high level the data interfaces among the different components.

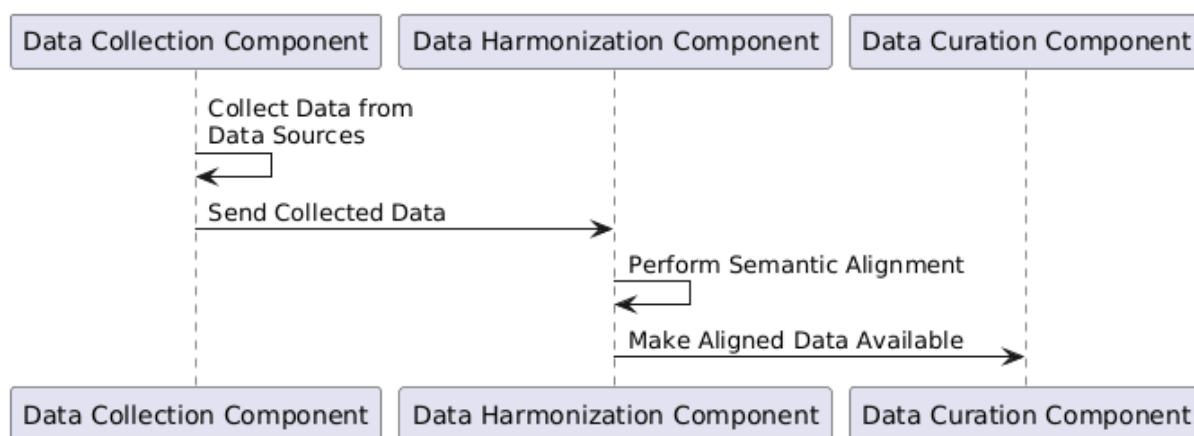


FIGURE 9 DATA HARMONIZATION COMPONENT

4.3.1.3 Data Curation Component

Overview

The Data Curation Service is a fundamental component responsible for executing the quality enhancement process, ensuring that data integrity, consistency, and reliability are

maintained throughout the data handling process. Its primary function is to apply the necessary data curation processes as configured, aligning with the predefined quality standards and transformation rules established during the design phase. It performs essential data validation, cleansing data from outliers, and enrichment tasks, identifying and rectifying inconsistencies, missing values, duplicates, and other anomalies that could compromise the usability and trustworthiness of the data. Through configurable rule sets, it enables dynamic adaptation to various data quality requirements, making it highly flexible and scalable.

Technical specifications

In this section, the detailed technical specifications of the respective component are provided, taking into consideration the list of requirements as derived from D2.1 and further the detailed elaboration of the functionality to be delivered as part of the component. The list of core features is provided:

- Handling of Data Curation (DCU-01): In summary, the Data Curation services get a crucial role in maintaining high-quality data. By enforcing structured curation processes and integrating seamlessly within the broader data handling, it ensures that data remains accurate, complete, and fit for purpose, supporting reliable decision-making and analytics-driven insights.

Detailed interactions

By defining the core features per component, the detailed dynamic view of each application is provided, showcasing the interaction among the different components as well as the associated data exchanges.

- Within the Data Curation Component, include all data to be collected from the previous step and the data harmonization process.
- As a next step, the data are made available to the Data Anonymizer component for further process.

The visual representation of the aforementioned dynamic view is presented below showcasing in a high level the data interfaces among the different components.

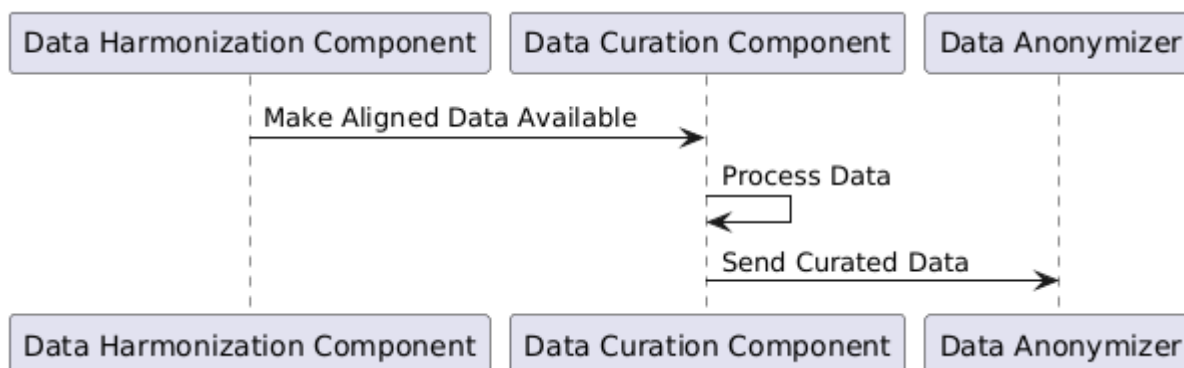


FIGURE 10 DATA CURATION COMPONENT

4.3.1.4 Data Anonymizer Component

Overview

The Data Anonymizer Service is essential in helping data providers safeguard sensitive information by preventing unintended disclosure, data breaches, and exposure. During the design phase, data providers define their anonymization strategies by identifying the fields that require anonymization, selecting appropriate techniques such as k-anonymity or l-diversity, and determining the acceptable level of information loss to maintain a balance between privacy and data usability. Once deployed, the service ensures that these anonymization mechanisms are effectively enforced, preserving data confidentiality while supporting secure and compliant data-sharing practices.

Technical specifications

In this section, the detailed technical specifications of the respective component are provided, taking into consideration the list of requirements as derived from D2.1 and further the detailed elaboration of the functionality to be delivered as part of the component. The list of core features is provided:

- Handling of Data Anonymization (DAC-01): The Data Anonymization Configuration defines the parameters and techniques applied to protect sensitive data within DIGITISE. It is configured during the design phase and enforced at runtime to ensure privacy and compliance.

Detailed interactions

By defining the core features per component, the detailed dynamic view of each application is provided, showcasing the interaction among the different components as well as the associated data exchanges.

- As a follow up of the Data Curation Component, include all data to be protected and handled from the respective service.
- As a next step, the data are made available fully anonymized for further consideration.

The visual representation of the aforementioned dynamic view is presented below showcasing at a high level the data interfaces among the different components.

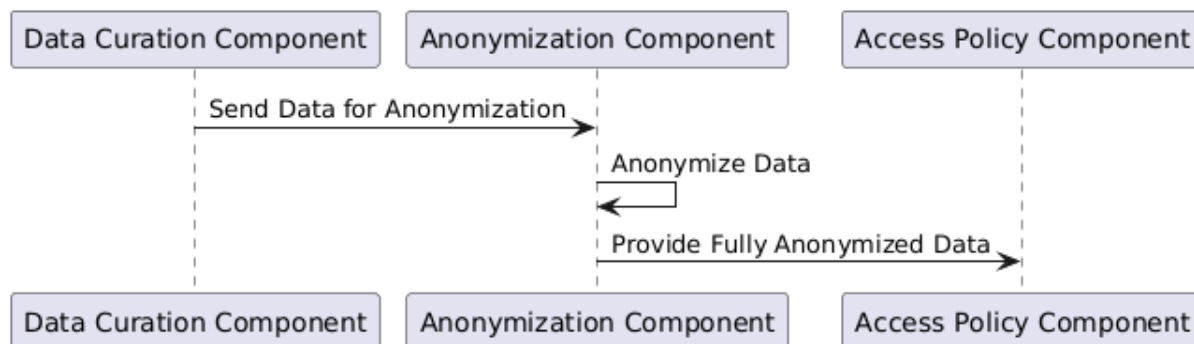


FIGURE 11 DATA ANONYMIZATION COMPONENT

4.3.1.5 Execution Master

Overview

The Data Execution Master in DIGITISE is responsible for orchestrating the execution of data processing workflows tailored to specific project requirements. It operates on-demand, facilitating seamless interactions with various components, such as data collectors, transformation modules, quality assurance services, and security protocols. This system is designed with robust error handling capabilities, allowing for quick recovery and rollback in case of any issues during execution.

Built for adaptability, the Data Executor can operate across different environments. Its primary purpose is to ensure the secure and efficient collection, processing, and storage of data according to predefined configurations set by data providers, all while maintaining high standards of data integrity and quality throughout the workflow.

Technical specifications

In this section, the detailed technical specifications of the respective component are provided, taking into consideration the list of requirements as derived from D2.1 and further the detailed elaboration of the functionality to be delivered as part of the component. The list of core features is linked with the execution of the different processes as specified above to support data gathering and governance namely:

- Execution of data collection (EM-01): Gathering raw data from various sources, including DERs/ IoT, external systems ensuring completeness and accuracy.
- Execution of data harmonization (EM-02): Standardizing and aligning data formats, structures, and units to enable seamless integration and comparison across datasets.
- Execution of data curation (EM-03): Cleaning, validating, and enriching data to enhance quality, consistency, and usability for analysis and decision-making.
- Execution of data anonymization (EM-04): Removing or obfuscating personally identifiable information (PII) to protect privacy while maintaining data utility for research or analysis.

Detailed interactions

By defining the core features per component, the detailed dynamic view of each application is provided, showcasing the interaction among the different components as well as the associated data exchanges.

- It is evident that the execution is linked with the configuration of the different processes as named above.
- The outcome of the execution is the storage of data to the storage entity of the project.
- In addition, the execution process is linked with the operations monitor in order to showcase the performance of the different steps

The visual representation of the aforementioned dynamic view is presented below showcasing in a high level the data interfaces among the different components.

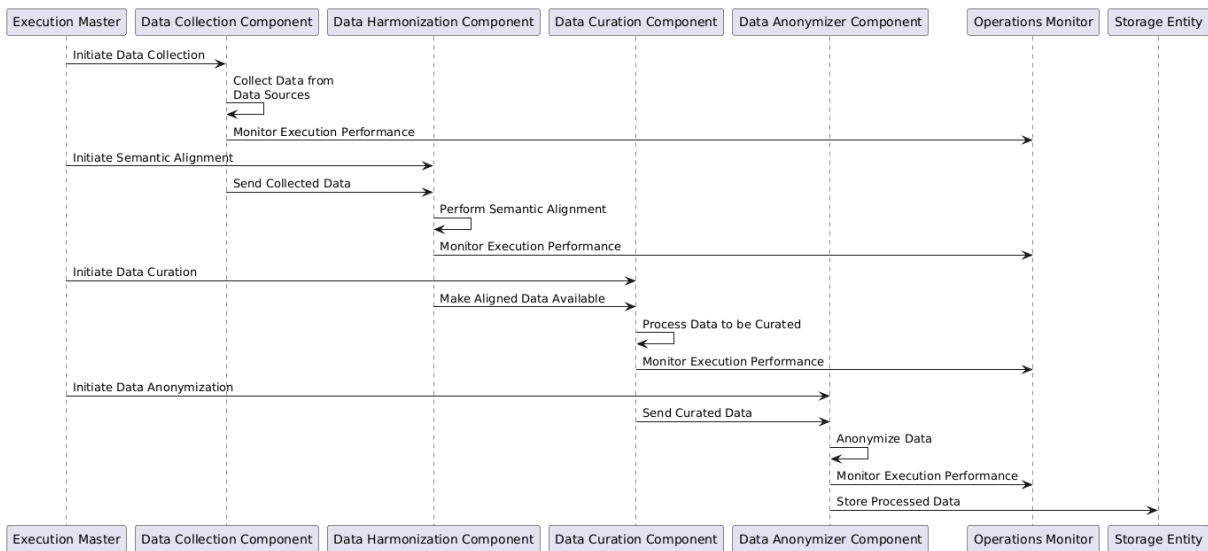


FIGURE 12 EXECUTION MASTER COMPONENT

4.3.1.6 Access Policies Management Component

Overview

The Access Policy Manager plays a critical role in regulating data access within the DIGITISE ecosystem. It is designed to enforce security, compliance, and governance standards by establishing clear and adaptable access policies. These policies define the criteria under which different entities—such as users, applications, and external systems—are permitted to interact with datasets.

Through its centralized governance framework, the Access Policy Controller ensures a scalable, transparent, and policy-driven approach to access management, fostering trust and accountability in data transactions. To achieve seamless and secure access management, the controller continuously monitors access requests, ensuring they align with organizational policies and regulatory requirements. By offering granular control over

data-sharing permissions, it enhances interoperability across federated environments while safeguarding sensitive information.

Technical specifications

In this section, the detailed technical specifications of the respective component are provided, taking into consideration the list of requirements as derived from D2.1 and further the detailed elaboration of the functionality to be delivered as part of the component. The list of core features is provided:

- Access Policy Configuration (APM-01): Access policy configuration is a fundamental aspect of the Access Policy Controller, enabling users to define and customize rules that govern data access. These policies dictate how users, applications, and third-party systems interact with datasets based on predefined conditions.
- Access Policy Store (APM-02): Configured policies are securely stored in the Access Policy Store, ensuring consistency.
- Access Policy Distribution (APM-03): Policy distribution mechanism allow enforcement component to retrieve and apply policies dynamically, adapting to changes in security and operational requirements. Through this layer, the defined series of attributes and rules, are considered to ensure that data are only accessed by authorized users.

Detailed interactions

By defining the core features per component, the detailed dynamic view of each application is provided, showcasing the interaction among the different components as well as the associated data exchanges. In more details the different interactions are reported:

- As a follow up of the configuration of data processes (collection, harmonization, curation), the definition of access policies and data license management is considered through the Access Policy Configuration
- Then the configuration details as stored to the dedicated storage entity.
- Then when the time comes for data interaction, the activation of the Access Policy Distribution during runtime, ensuring policies are consistently applied throughout data transactions.
- Data Retrieval Service: Regulates data exchange by verifying and enforcing access policies before permitting sharing or retrieval.

The visual representation of the aforementioned dynamic view is presented below showcasing at a high level the data interfaces among the different components

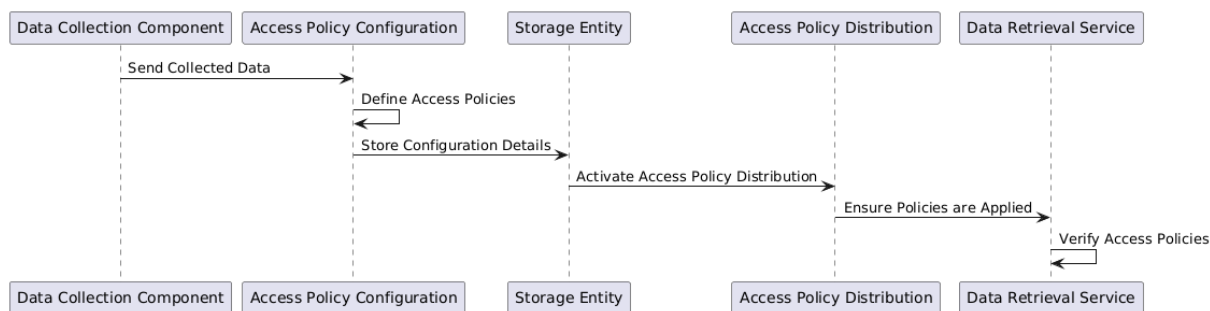


FIGURE 13 ACCESS POLICY MANAGEMENT COMPONENT

4.3.1.7 Data Storage Component

Overview

The Data Storage layer is a fundamental component within the DIGITISE architecture, responsible for the secure and efficient management of all data ingested into the data space. This layer serves as the backbone for data storage, ensuring seamless integration, accessibility, and compliance with interoperability standards across various domains. As a unified component within the DIGITISE ecosystem, the Data Storage layer integrates multiple database modules to support the diverse data attributes of the project. These modules ensure optimal performance, scalability, and adaptability, catering to different data formats and requirements.

A key aspect of the Data Storage and Interoperability architecture is its ability to support multiple database types, ensuring flexibility in handling diverse data formats. By integrating relational, NoSQL, and graph databases, the system can efficiently store and manage structured, semi-structured, and unstructured data, catering to a wide range of use cases. This multi-database approach enhances adaptability, allowing seamless interactions between different data models and ensuring optimal performance across various domains.

In addition to its versatility, the architecture is designed for scalability and performance optimization. By leveraging distributed storage solutions, the system can accommodate vast amounts of data while maintaining high availability and low latency. This ensures that data retrieval and processing remain efficient, even as the volume of stored information grows. The combination of scalability and optimized performance enables the platform to support real-time data access and advanced analytics, making it a robust foundation for interoperability within the DIGITISE ecosystem.

Technical specifications

In this section, the detailed technical specifications of the respective component are provided, taking into consideration the list of requirements as derived from D2.1 and further the detailed elaboration of the functionality to be delivered as part of the

component. The analysis is presented considering the different storage elements examined in the project covering:

- Ingested Data: (DS-01): All structured and unstructured data collected from various sources within the data space.
- Metadata Storage (DS-02): Contextual information describing the datasets, enabling efficient discovery and usage.
- Cross-Sector Vocabularies (DS-03): Standardized terminologies facilitating data harmonization across different industries.

Note: Access Policies rules governing data access, ensuring security, compliance, and controlled sharing are stored to a dedicated database presented above.

Detailed interactions

By defining the core features, the detailed view of the data storage layer is provided, showcasing the interaction among the different components as well as the associated data exchanges. It is evident that the data storage layer interacts with the different systems as stated above in order to handle the data and metadata defined in the project, as depicted below

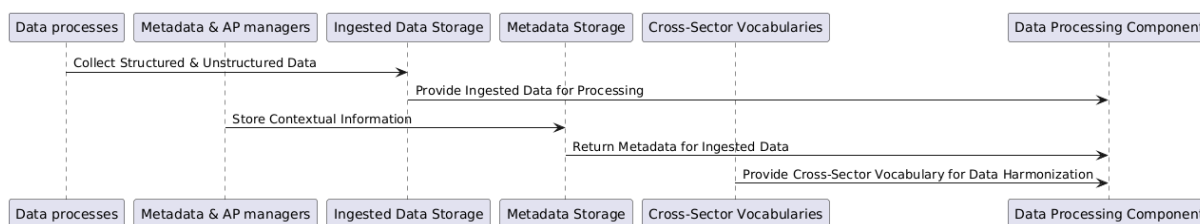


FIGURE 14 DATA STORAGE LAYER

4.3.1.8 Data Marketplace Component

Moving beyond data storage, the Data Exploration and Sharing layer aims at providing the DIGITISE Data Space with data exploration functionalities such that users (and applications) seek for specific datasets, to be able to view and request access on the data of interest. The first component is the data marketplace as presented in this section.

Overview

The Data Assets Marketplace serves as a comprehensive digital catalog where data assets are made readily available for acquisition. This platform empowers data providers to showcase their datasets by publishing detailed metadata descriptions, which include essential information such as data format, structure, provenance, and quality metrics. In addition to metadata, data providers can also define various pricing structures and access policies, allowing for greater flexibility in how their data is monetized and accessed.

The marketplace also facilitates interaction between data providers and consumers, creating opportunities for negotiations, feedback, and updates to dataset offerings. By

fostering a dynamic environment for data exchange, the Data Assets Marketplace enhances collaboration across sectors and promotes the responsible use of data, ultimately driving innovation and insights within the broader DIGITISE ecosystem.

Technical specifications

In this section, the detailed technical specifications of the respective component are provided, taking into consideration the list of requirements as derived from D2.1 and further the detailed elaboration of the functionality to be delivered as part of the component. More specifically

- Data Marketplace Overview (DM-01): This is the discovery interface for data consumers to efficiently search for and discover data assets that align with their interests and needs. Through this interface, consumers can enter specific queries, apply filters, and browse categorized data assets, making it easy to locate relevant datasets quickly.
- Contracts Management (DM-02): A core functionality is Smart Contract Management, which allows stakeholders to draft, negotiate, approve or reject, extend, and revise contract terms seamlessly
- Contracts Settlement (DM-03): This engine plays a significant role in ensuring that smart contracts, once signed by legal representatives, are effectively activated. It facilitates various types of transactions, managing the exchange of data assets based on predefined terms while also handling traditional financial transactions associated with these assets. Furthermore, the engine is responsible for remuneration management, ensuring that data providers receive appropriate payments for creating derivative data assets.

Detailed interactions

By defining the core features per component, the detailed dynamic view of each application is provided, showcasing the interaction among the different components as well as the associated data exchanges. In more detail the different interactions are reported:

- Interaction through the storage layer of the project with the metadata manager and the access policies definition towards searching over the metadata characteristics required for participation in the marketplace environment
- Through the Marketplace Overview, the data recipient search for data assets of interest for further exploitation
- As a follow up of the selection process, a contractual process is triggered which allows stakeholders to draft, negotiate, approve or reject, extend, and revise contract terms seamlessly

- Then, once the contractual process is over, the dataset is acquired and thus data can be retrieved. In addition, the Contracts Settlement process is activated in order to ensure the prompt settlement of the data assets acquired through the data marketplace

The visual representation of the aforementioned dynamic view is presented below showcasing at a high level the data interfaces among the different components

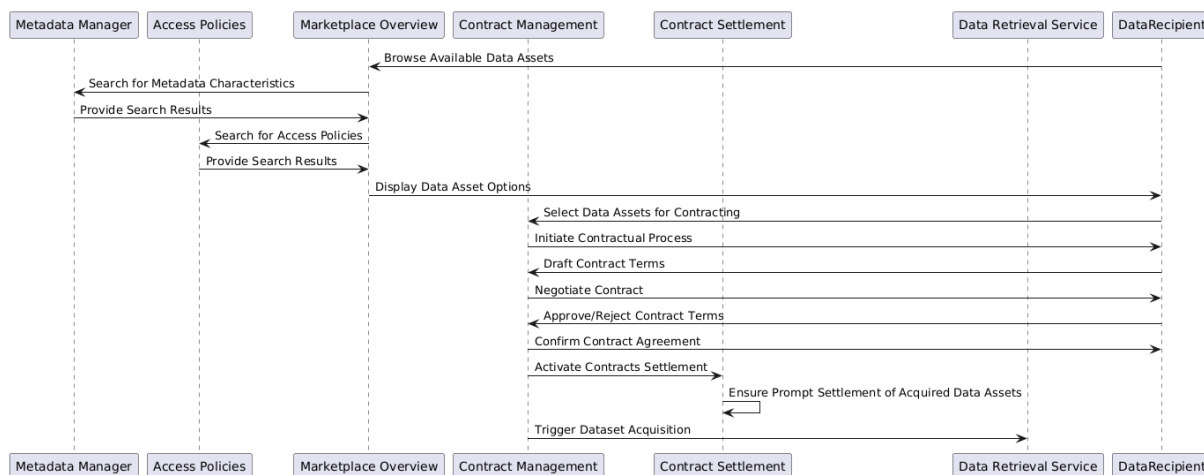


FIGURE 15 DATA MARKETPLACE LAYER

4.3.1.9 Data Exploration Component

Overview

The Data Exploration Component enables users to interact with and analyze acquired data assets, providing tools for efficient search, visualization, and preliminary analysis. This component facilitates a deeper understanding of data characteristics, structure, and potential insights before proceeding with further processing or retrieval.

Through this tool, users can engage with a variety of features designed to enhance their data exploration experience. The component includes advanced search functionality, allowing users to quickly locate specific datasets using keywords, tags, or metadata attributes. This feature streamlines the discovery process and helps users find relevant information amidst vast data collections.

In addition to search capabilities, the Data Exploration Component offers robust data visualization tools. Users can visually access data assets and therefore better understand their characteristics. These visualizations aid in identifying correlations and anomalies, enabling users to make informed decisions based on visual insights.

Overall, the Data Exploration Component serves as an essential part of the data lifecycle, empowering users to thoroughly investigate and understand their data assets, paving the way for more effective data processing, retrieval, and application in real-world scenarios.

Technical specifications

In this section, the detailed technical specifications of the respective component are provided, taking into consideration the list of requirements as derived from D2.1 and further the detailed elaboration of the functionality to be delivered as part of the component. More specifically:

- Data Search (DE-01): The process of searching for specific data assets based on keywords, metadata, filters to quickly find relevant information within the data pool, and following market acquisition
- Data Visual Exploration (DE-02): The use of graphical representations to analyze and interpret data assets enhancing understanding and decision-making for the available data assets

Detailed interactions

By defining the core features per component, the detailed dynamic view of each application is provided, showcasing the interaction among the different components as well as the associated data exchanges. In more details the different interactions are reported:

- Following market acquisition, the data assets are part of the pool for data visualization
- Then through advanced search features, the users are able to search for assets with specific characteristics

The visual representation of the aforementioned dynamic view is presented below showcasing at a high level the data interfaces among the different components

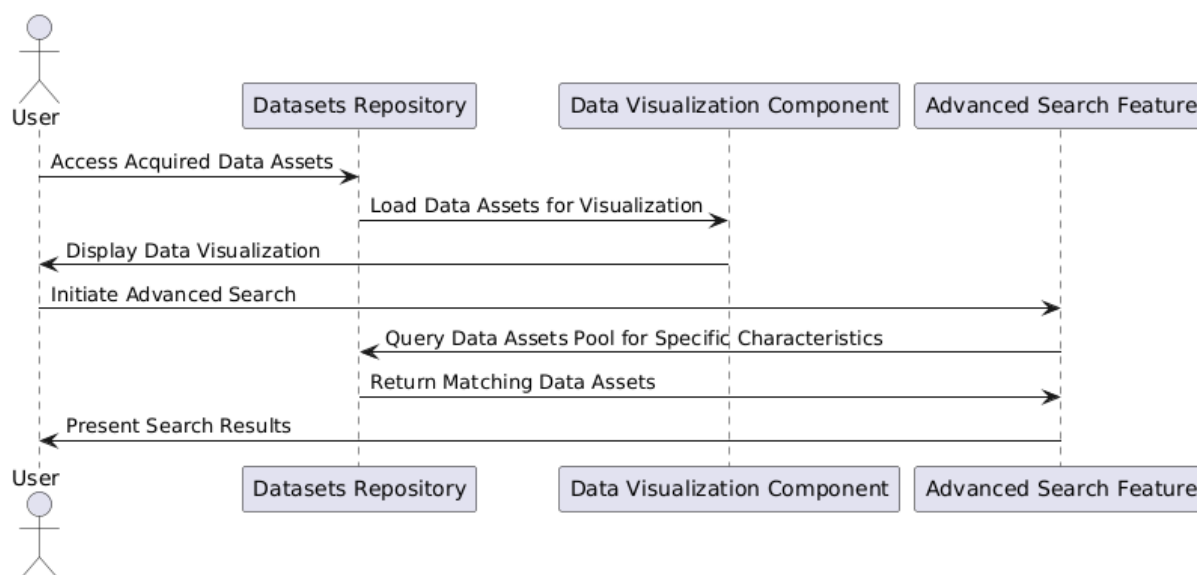


FIGURE 16 DATA EXPLORATION COMPONENT

4.3.1.10 Data Retrieval Component

Overview

Ultimately, the Data Retrieval Service provides real-time data access based on contractual agreements, enabling users to efficiently extract, filter, and organize only the data relevant to their specific applications.

For the DIGITISE data retrieval service, this functionality is exposed through a set of well-defined endpoints that allow seamless integration with external applications, data analytics platforms, and automated workflows. The API supports custom query configurations, enabling users to specify parameters such as data source selection, filtering criteria, sorting preferences, time ranges, and output formats.

Additionally, the service ensures secure access control, enforcing authentication and authorization mechanisms to protect data integrity and privacy. It is designed for scalability and efficiency, optimizing query execution through caching, pagination, and parallel processing where applicable.

Furthermore, the API provides real-time and batch retrieval options, allowing users to access live data streams or request historical datasets as needed. Through comprehensive logging and monitoring, the service ensures transparency, tracks query performance, and enables troubleshooting for improved reliability.

By offering a flexible and developer-friendly interface, the API-based Data Retrieval Service facilitates seamless interoperability across diverse systems, empowering users to integrate data-driven insights into their workflows effortlessly.

Technical specifications

In this section, the detailed technical specifications of the respective component are provided, taking into consideration the list of requirements as derived from D2.1 and further the detailed elaboration of the functionality to be delivered as part of the component. More specifically

- Query Configuration (DR-01): The process of defining and customizing data queries based on user requirements, including selecting data sources, applying filters, setting parameters, and specifying output formats to ensure efficient and relevant data retrieval.
- Data Sharing (DR-02): Its core function is to handle the retrieval and delivery of data slices; the service ensures that retrieved data is formatted appropriately and aligns with user-defined preferences established during the design phase.

Detailed interactions

By defining the core features per component, the detailed dynamic view of each application is provided, showcasing the interaction among the different components as well as the associated data exchanges. In more details the different interactions are reported:

- After exploring the acquired data assets, the user can proceed with configuring the query by defining the necessary parameters, such as filters, sorting criteria, and data selection preferences.
- Once the query configuration is complete, the user can initiate the data retrieval process, ensuring that only the relevant data is extracted according to the specified criteria.

The visual representation of the aforementioned dynamic view is presented below showcasing at a high level the data interfaces among the different components

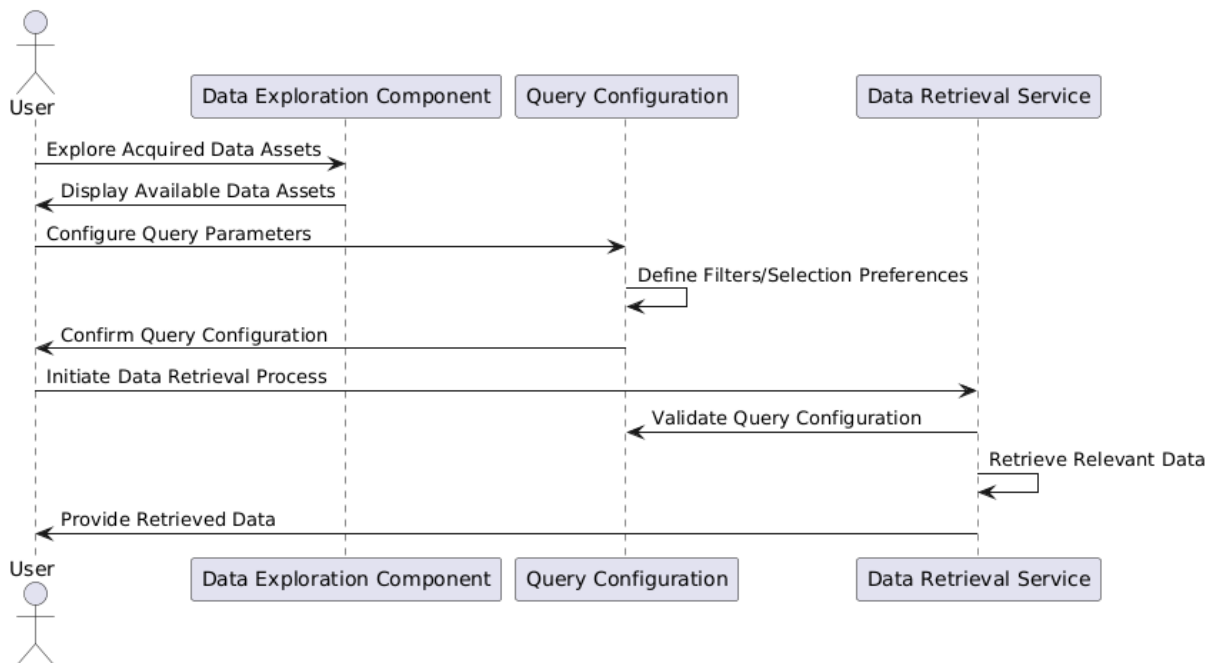


FIGURE 17 DATA RETRIEVAL COMPONENT

While the aforementioned services are defined as functional services to support the functionality derived from the analysis of use cases and requirements, the following services are defined to support the management and orchestration of the above (tightly linked with the deployment view to be presented in the following section and thus no detailed interactions are defined for these processes are the overall operation is transversal and linked to the overall deployment of the aforementioned services).

4.3.1.11 Resource Management

Overview

The Resource Management Layer serves as a vital overlay layer within the architecture, tasked with managing and coordinating the various sub-components and services that comprise the data space. Its primary function is to orchestrate the underlying resources, ensuring that they work together seamlessly to support the overall functionality of the system.

This layer facilitates effective resource allocation, optimizing the use of computational power, storage, and network capabilities to enhance performance and efficiency. It monitors the status and health of each resource, allowing for proactive management of workloads and ensuring that resources are utilized effectively to meet demand.

Furthermore, the Resource Management Layer enables dynamic scaling of resources based on real-time demand, allowing the system to adapt to varying workloads and optimize operational efficiency. Its ability to integrate with other layers and components of architecture ensures a cohesive and responsive environment, fostering innovation and collaboration among users and stakeholders within the data space. Through these comprehensive management and coordination functions, the Resource Management Layer plays a critical role in ensuring stability, security, and overall effectiveness of the data ecosystem.

Technical specifications

In this section, the detailed technical specifications of the respective component are provided, taking into consideration the list of requirements as derived from D2.1 and further the detailed elaboration of the functionality to be delivered as part of the component. More specifically:

- Orchestration of resources within the data ecosystem (RM-01): It effectively manages the interaction and integration of essential resources, such as computational power, storage, and network capabilities, ensuring seamless collaboration among all components.
- Resources allocation (RM-02): To optimize performance and efficiency, the layer facilitates the effective allocation of resources. It employs sophisticated algorithms that allow for the optimal distribution of computational and storage resources based on current workloads, ensuring that demands are met without compromising system performance.
- Real-time monitoring (RM-03): It continuously tracks the status and health of all resources, enabling proactive management through alert systems that notify administrators of any resource failures or performance issues. This capability allows for swift interventions, ensuring that the system remains stable and reliable.
- Dynamic scaling of resources (RM-04): it automatically adjusts resource levels based on workload metrics, providing the flexibility needed to handle varying levels of activity without manual intervention. This responsiveness enhances operational efficiency and ensures that users always have access to the resources they need.

4.3.1.12 Operations Monitor

Overview

The main objectives of the Data Operations Monitor service are to confirm the proper functioning of data collection and governance processes as defined above and to maintain the health and high quality of the resulting datasets. It logs relevant monitoring messages for each active process, as generated by the Execution Master. This service offers on-demand insights into overall data quality and reliability, providing "heartbeat" updates for all data collection and datasets linked to a user or their organization, including details on execution, completeness, and timeliness.

Results from the Data Operations Monitor are presented to data providers through a user interface and are accessible to authorized applications via monitoring APIs, facilitating quick issue resolution and ensuring a steady data flow. This support helps data providers address problems in their data processes, minimizing downtime and ensuring data quality and reliability. For data assets connected to active data sharing agreements, pertinent observations regarding refresh/update rates and quality metrics are communicated to the Data Marketplace to ensure compliance with contractual requirements.

Technical specifications

In this section, the detailed technical specifications of the respective component are provided, taking into consideration the list of requirements as derived from D2.1 and further the detailed elaboration of the functionality to be delivered as part of the component. More specifically:

- Monitoring and logging (OM-01): This logging mechanism captures essential metrics and events related to data processing, including execution status, completeness, and timeliness, allowing for a comprehensive overview of performance.
- Data quality insights (OM-02): It generates regular "heartbeat" updates for all data collection pipelines and datasets, ensuring that stakeholders remain informed about the current state of their data assets.
- User interface Viewer (OM-03): Data providers can easily view metrics related to data health, execution details, and quality assessments, empowering them to make informed decisions about their data management strategies.
- Compliance monitoring (OM-04): It effectively communicates observations regarding refresh and update rates, along with quality metrics for data assets connected to active data sharing agreements. By providing relevant data quality metrics to the Data Marketplace, the service ensures that organizations adhere to contractual requirements, promoting accountability and transparency in data sharing practices.

Overall, the Data Operations Monitor Service not only facilitates effective monitoring and logging of data processes but also enhances data quality insights, user experience, and compliance, ultimately contributing to a more reliable and efficient data ecosystem.

4.3.1.13 Identity Provider

Overview

Identity management is a vital aspect of the DIGITISE initiative, ensuring that interactions among users, applications, and data resources are secure, efficient, and trustworthy. This framework encompasses a range of processes designed to manage digital identities, authentication and access control.

At the heart of identity management in DIGITISE is robust user authentication. The initiative employs multiple mechanisms to verify the identities of individuals accessing the system. Traditional username and password combinations are considered to enhance security and significantly reduce the risk of unauthorized access.

DIGITISE also implements Single Sign-On (SSO) capabilities, allowing users to log in once and gain access to a variety of applications and services within the ecosystem. This not only simplifies the user experience but also minimizes the hassle of managing multiple credentials, making it easier for users to engage with the system. The initiative supports identity federation, enabling users to authenticate across different domains and platforms without needing separate credentials for each.

Technical specifications

In this section, the detailed technical specifications of the respective component are provided, taking into consideration the list of requirements as derived from D2.1 and further the detailed elaboration of the functionality to be delivered as part of the component. More specifically:

- User profile management (UM-01): The system maintains comprehensive user profiles that include relevant attributes, roles, and preferences. This information is leveraged to tailor the user experience, personalizing interactions and streamlining access to resources based on individual needs.
- User logs management (UM-02): By tracking authentication events and access patterns, the initiative supports compliance with data protection regulations and organizational policies, reinforcing trust among users and stakeholders.

In summary, identity management in DIGITISE serves as a foundational element that enables secure, efficient, and collaborative data sharing. By focusing on authentication, access control, and user experience, DIGITISE creates a trusted environment where stakeholders can effectively leverage data resources to drive innovation and informed decision-making.

4.3.2 DIGITISE Baseline AI Analytics and Digital Twins

As stated above, the DIGITISE Baseline AI Analytics and Digital Twins include the baseline components that will facilitate the extraction of valuable insights from the data collected

from the assets and the execution of highly-effective algorithms and routines for optimized management at consumer/household level.

Starting with the provision of baseline analytics services, there are 2 main steps considered in the overall process, the training and further execution reflected in the following component layers.

4.3.2.1 AI Configuration Component

Overview

The AI Configuration Component is a crucial layer dedicated to facilitating the creation and refinement of artificial intelligence models. This component offers a comprehensive environment that encompasses the entire lifecycle of machine learning (ML) and deep learning (DL) model development. It supports users from the initial stages of data exploration through to the final phases of model validation, ensuring a streamlined and efficient workflow throughout the process.

A significant advantage of the AI Configuration Component is its capability to simplify the construction of AI processes. Users can effortlessly integrate various elements, promoting a unified approach to model development. The component is compatible with a wide array of popular ML and DL libraries, allowing users to take full advantage of existing tools and frameworks.

The AI Configuration Component also emphasizes the importance of iterative testing and validation. Data scientists can continually assess their models, identifying areas that require enhancement to achieve greater accuracy and reliability in their AI solutions. This focus on refinement contributes to the overall quality of the models developed within this framework.

Technical specifications

In this section, the detailed technical specifications of the respective component are provided, taking into consideration the list of requirements as derived from D2.1 and further the detailed elaboration of the functionality to be delivered as part of the component. More specifically:

- AI Streamlining (AIC-01): Facilitates the construction and integration of AI tasks, allowing users to combine various components seamlessly.
- ML and DL libraries (AIC-02): Supports a wide range of popular ML and DL libraries, enabling users to utilize existing tools and frameworks effectively.
- AI task Integrated Environment (AIC-03): Supports the entire lifecycle of ML and DL model development, from data exploration to model validation.
- Iterative Testing and Validation (AIC-04): Allows for continuous assessment of models to identify areas for improvement, enhancing accuracy and reliability.

Detailed interactions

By defining the core features per component, the detailed dynamic view of each application is provided, showcasing the interaction among the different components as well as the associated data exchanges. In more detail the different interactions are reported:

- The process begins with Data Retrieval, where users explore data to gain insights into its characteristics and determine its suitability for modeling.
- Following data exploration, users engage in AI task Construction. This stage involves integrating various components to build cohesive AI tasks, ensuring a streamlined approach to model development.
- An essential feature of the AI Configuration Component is its Library Utilization capability. Users can leverage a wide array of machine learning (ML) and deep learning (DL) libraries, which enriches the modeling process by incorporating existing tools and frameworks.
- To ensure the models meet the desired standards, users engage in Testing and Validation. By analyzing performance metrics and results, users can make informed decisions about necessary adjustments.
- The workflow is considering also Model Refinement, where users refine their models based on testing feedback.

Through this dynamic view, the AI Configuration Component effectively supports users in developing high-quality artificial intelligence models that meet evolving demands in the field. The visual representation of the aforementioned dynamic view is presented below showcasing at a high level the data interfaces among the different components

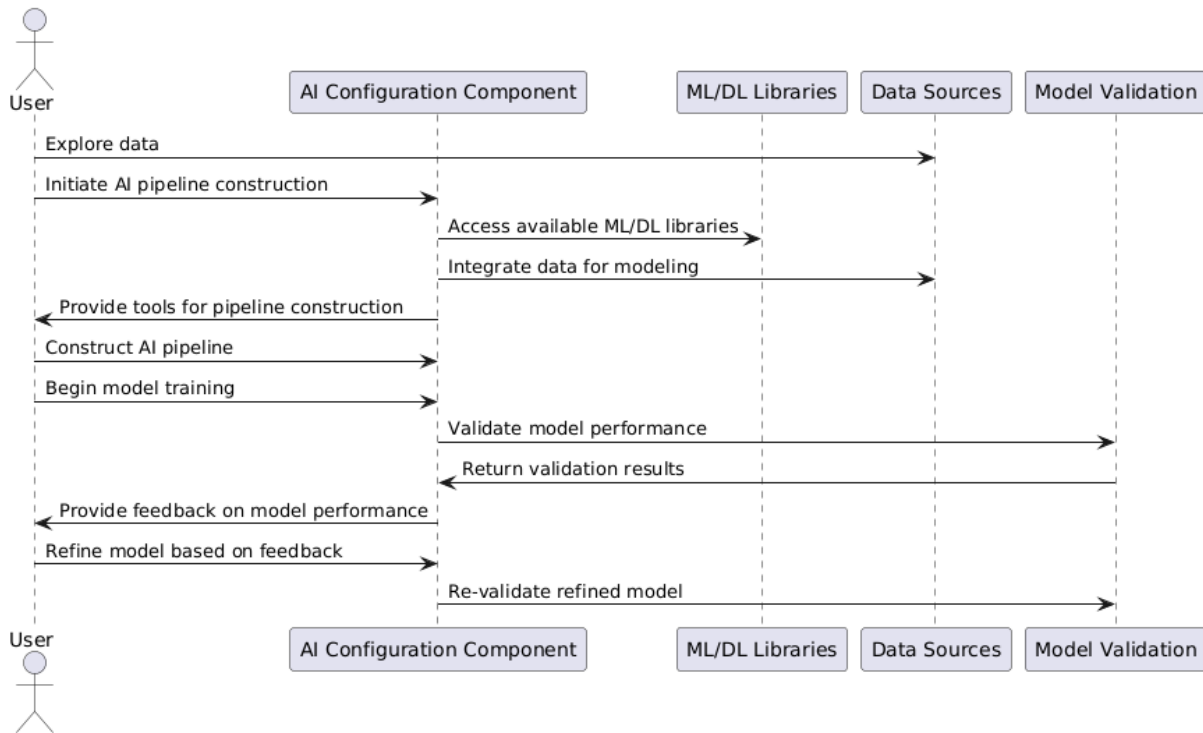


FIGURE 18 AI CONFIGURATION COMPONENT

4.3.2.2 AI Models Storage Component

As stated above, there are different types of models to be considered for training/execution in the project reflecting the needs of the different energy applications as listed below.

A non-exhaustive list of the different analytics models is provided in the following table, reflecting the requirements analysis as well as the specification needs from the technical partners of the project.

TABLE 23 DIGITISE ANALYTICS MODELS

Model Name	Description
Consumer Energy Behavior Analytics	Analyzes household energy consumption patterns to extract insights on how consumers use energy, helping to create personalized energy-saving strategies.
Occupancy Profile Analytics	Monitors occupancy data to understand when and how different spaces are used, improving energy efficiency and automation.
Comfort Preference Analytics	Assesses user preferences for heating, cooling, etc. optimize comfort while minimizing energy waste.
Ambient Condition Analytics	Tracks environmental parameters such as temperature, humidity, and air quality to enhance energy management and indoor comfort.
Short-Term Demand Forecasting	Provides hour-to-day-ahead predictions of household energy demand, ensuring accurate load planning.

Short-Term Generation Forecasting	Predicts renewable energy generation (e.g., solar, wind) in the short term to optimize self-consumption and grid interactions.
DER Flexibility Profiling	Analyzes Distributed Energy Resources (DERs) such as batteries, EVs, and solar panels to determine their flexibility potential.
Context-Aware Flexibility Profiling	Integrates real-time data, device characteristics, environmental conditions, and occupant behavior to dynamically assess available flexibility.

These model artefacts, following the configuration process are made available to the Models Storage Component for further exploitation in the project.

Technical specifications

The Models Storage Component serves as a crucial repository within the project, dedicated to housing various pretrained energy and non-energy models that reflect the diverse needs of different energy applications. This component is designed to facilitate easy access and exploitation of these models by technical partners involved in the project. Below are the technical specifications for the Models Storage Component:

- Model Repository (MS-01): Acts as a centralized storage location for various analytics models, including both energy-related and non-energy-related models.
- Integration Capability (MS-02): Seamlessly integrates with the AI Configuration Component and AI Execution Component, allowing for efficient retrieval and management of models.
- Model Metadata Management (MS-03): Maintains detailed metadata for each model, including description, parameters, and version history, to facilitate effective model management and selection.
- Versioning and Tracking (MS-04): Supports version control for models, enabling users to track changes, revert to previous versions, and manage model updates effectively.

Detailed interactions

By defining the core features per component, the detailed dynamic view of each application is provided, showcasing the interaction among the different components as well as the associated data exchanges. In more detail the different interactions are reported:

- The process begins with the AI Configuration Component initiating the upload of a model, such as the Consumer Energy Behavior Analytics model, to the Models Storage Component. This initial step is crucial for integrating new models into the system, making them accessible for future tasks.
- Once the Models Storage Component receives the model, it processes and stores both the model itself and its associated metadata. This metadata includes vital

information, such as the model's description, parameters, and performance metrics, which are essential for users to make informed decisions about which models to utilize.

- After successfully storing the model, the Models Storage Component provides it to the AI Execution Component for execution. This action ensures that the execution environment is fully informed about the model's specifications and requirements, which is critical for handling its performance during execution.

The visual representation of the aforementioned dynamic view is presented below showcasing at a high level the data interfaces among the different components

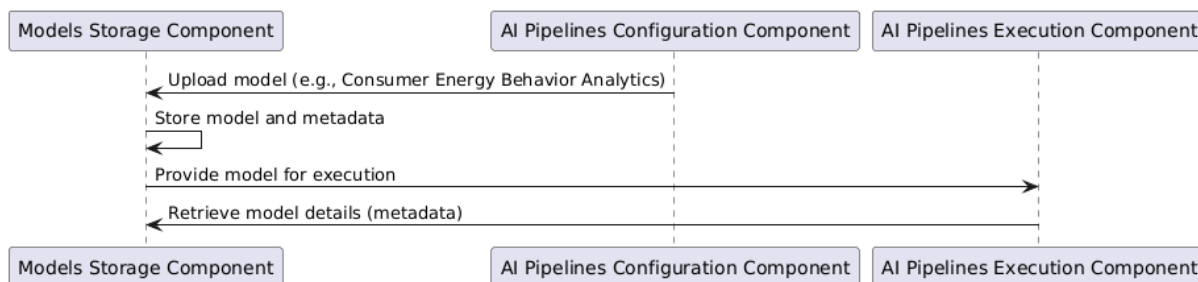


FIGURE 19 AI MODELS STORAGE COMPONENT

4.3.2.3 AI Execution Component

Overview

The AI Execution Component plays a vital role in the DIGITISE framework, focusing on the execution of AI models and workflows. It is designed to ensure that AI tasks are performed efficiently, regardless of their complexity.

By leveraging advanced computational capabilities, the AI Execution Component is equipped to process high volumes of data in real time. This allows for swift analytics and insights, which are crucial for applications that require immediate feedback or decisions. Furthermore, the component's scalability ensures that multiple AI tasks can be executed concurrently across various devices and environments, optimizing resource use and enhancing overall performance.

Ultimately, this component is essential for organizations looking to harness the power of AI effectively, facilitating a more agile and responsive approach to data-driven decision-making.

Technical specifications

In this section, the detailed technical specifications of the respective component are provided, taking into consideration the list of requirements as derived from D2.1 and further the detailed elaboration of the functionality to be delivered as part of the component. More specifically:

- Execution Efficiency (AIE-O1): Capable of executing a diverse range of AI tasks, from simple inference to complex model training operations.

- Data Handling (AIE-O2): Designed to process large volumes of data with high throughput. Supports real-time data analytics, enabling quick insights and responses.
- Scalability (AIE-O3): Facilitates the concurrent execution of multiple AI tasks
- Monitoring and Logging (AIE-O4): Implements robust monitoring features to track the status and performance of AI tasks. Logs execution details for analysis and troubleshooting.

Detailed interactions

By defining the core features per component, the detailed dynamic view of each application is provided, showcasing the interaction among the different components as well as the associated data exchanges. In more detail the different interactions are reported:

- The process of executing AI tasks begins with user initiation, where a user sets the schedule for the execution of an AI task
- This initiation triggers an integration of the AI Execution Component and with the AI Configuration Component (through the AI Models storage component). The latter ensures that the configured AI models and workflows are available for the execution process with the defined parameters.
- Once the model availability is established, the AI Execution Component moves on to data retrieval, where it efficiently gathers the data preparing it for subsequent processing. With the data ready, the component proceeds to execute the AI tasks as defined within the tasks. This execution can encompass a variety of actions, such as running models, performing detailed analyses, and generating valuable insights that inform decision-making.
- Throughout the execution process, the component maintains a robust monitoring and logging system. It continuously tracks the status and performance of the tasks, logging important details for troubleshooting and analysis.
- Finally, once the execution is complete, the component reports the results back to the DIGITISE platform for further exploitation.

The visual representation of the aforementioned dynamic view is presented below showcasing at a high level the data interfaces among the different components

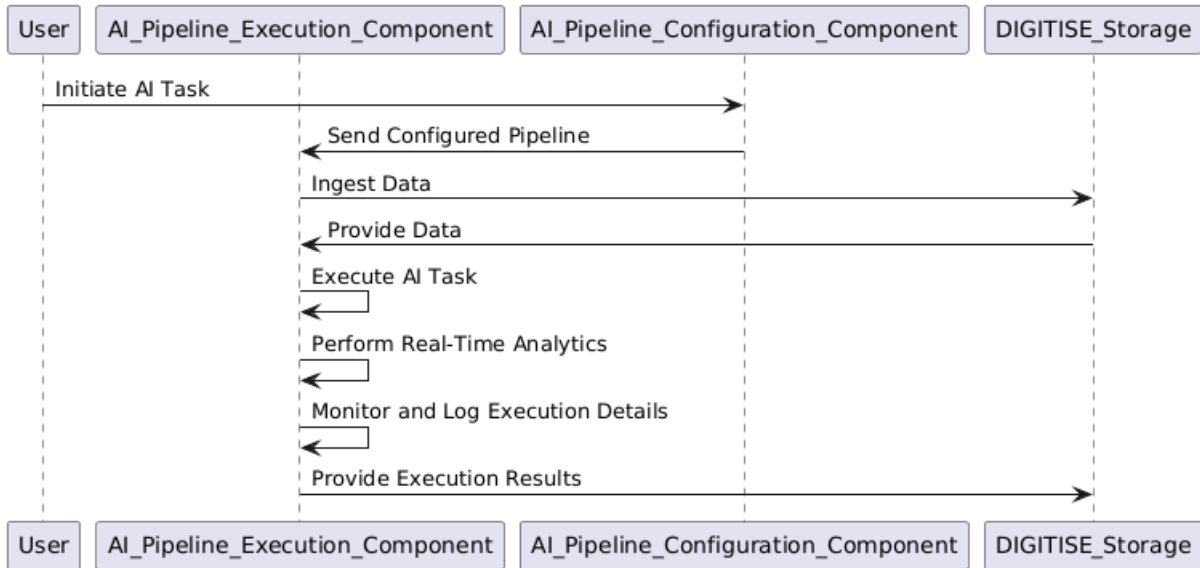


FIGURE 20 AI EXECUTION COMPONENT

4.3.2.4 DIGITISE Household Level Digital Twin

Overview

The Household Digital Twin is playing a pivotal role as one of the supporting tools for the operations of the DIGITISE applications. It offers its users the possibility to effectively experiment with diverse simulation scenarios that are based on digital twin models of the project's households. The three components of the Household Digital Twin are presented in the list below.

- **Household Simulation Engine:** The Simulation Engine allows the inner configuration of simulation models and their execution in a dedicated environment. Each household is considered to have its own customized model, and several additional parameters are considered at runtime of the simulation, where physical aspects of the households are taken into account and external factors or examined scenarios' data are ingested into the models.
- **Configuration Engine:** The Configuration Engine is part of the backbone of the digital twin, since it is responsible for the orchestration of the different activities needed to take place before and after a simulation is realized. When a request for a simulation execution is received, the configuration engine must gather and, if needed, formulate all the relevant data and parameter values in order to be supplied to the Household Simulation Engine. The triggering of a scenario execution also happens through the configuration engine by utilizing adapters dedicated to this task. With the completion of a simulation, the configuration engine collects the output, also, if needed, transforms it to an easily readable form and makes it available for retrieval.

- **API Connector:** The API Connector component of the Digital Twin provides the means to communicate with external platforms and applications of the DIGITISE solution. The users of the Household Digital Twin will be able to easily interact with it through a dedicated API for requesting the execution of a simulation scenario and retrieving the respective results. Moreover, through the API Connector, it is made possible to perform requests to DIGITISE Data Space for retrieving, if needed, relevant data that has been shared and made accessible through the data space.

Technical specifications

In this section, the detailed technical specifications of the DIGITISE Household Digital Twin are provided, taking into consideration the list of requirements as derived from D2.1 and further the detailed elaboration of the functionality to be delivered as part of the digital twin. The list of core features is provided below:

- **Configuration of household models (SE-01):** Provides the definition of the household models, which include relevant static household characteristics and model variables to be utilized during the simulation execution
- **Execution of simulation scenarios (SE-02):** Allows the ability to execute a simulation scenario for a household, by ingesting input data at runtime and producing an output of the results for the measured quantities
- **Formulation of the simulation's input and output (CE-01):** Transforms a provided input dataset into a form suitable to be ingested to the simulation engine. Also, if needed, formats the output result of a simulation in a way to be easily readable for the final users or to be stored
- **Setup of the simulation parameters (CE-02):** Based on the needs of a received request, a set of any parameters are defined and properly provided to the Simulation Engine
- **Triggering of the execution of a simulation (CE-03):** Allows the triggering of the execution of a simulation scenario to the Simulation Engine, along with any defined parameters, through a dedicated adapter
- **Storing of the simulation results (CE-04):** Stores the output results in a database for flexible (query and) retrieval
- **Simulation execution and results request interface (AC-01):** Offers an interface to the Digital Twin users to request the execution of a simulation scenario and the retrieval of simulation results
- **Data Space communication interface (AC-02):** Allows the Household Digital Twin to communicate when needed with the DIGITISE Data Space for requesting and retrieving data to be utilized in the simulations

Detailed interactions

By defining the core features per component, the detailed dynamic view of each application shows the interaction among the different components as well as the associated data exchanges. In more detail the different interactions are reported below: Main interactions of the DT components are taking place internally, involving the Household Simulation and the Configuration Engines. More specifically, the Household Simulation Engine receives a proper request (trigger) for the execution of a simulation from the Configuration Engine, through which any parameters as well as the needed inputs are defined. After a simulation run is complete, the Configuration Engine is responsible for the results collection.

Communication with external components is taking place through the API Connector. This includes, firstly, requests from other DIGITISE applications and tools for triggering a simulation execution but also for the retrieval of simulation results. The Configuration Engine is again involved in these interactions, since it receives the request information from the API Connector and processes it to prepare the input for the Simulation Engine, and similarly, it formulates the simulation results as a response to be sent back through the API Connector. Secondly, through the API Connector, a connection with the DIGITISE Data Space is accomplished, in order to retrieve any data needed for a simulation to be performed. The data received through the API Connector from the Data Space is passed to the Configuration Engine to be extracted and processed accordingly.

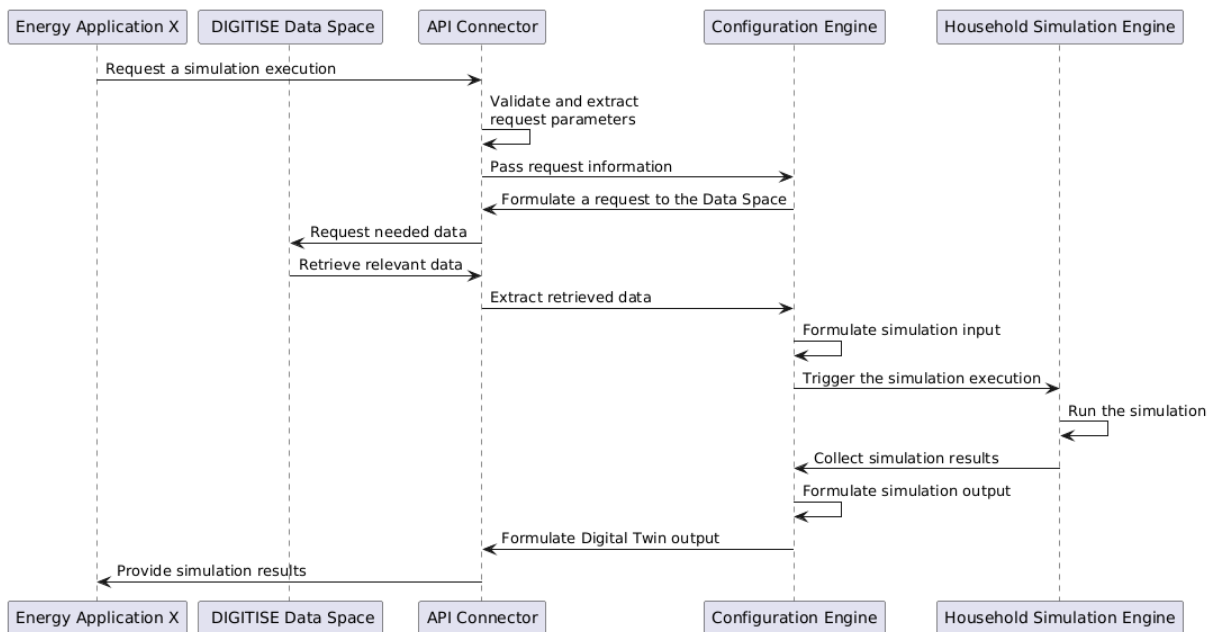


FIGURE 20 DIGITISE HOUSEHOLD LEVEL DIGITAL TWIN APPLICATION

4.3.3 DIGITISE Energy and Non-energy applications

4.3.3.1 Energy Savings and Self-consumption Optimization Application

Overview

The Energy Savings and Self-consumption Optimization Application is an advanced digital solution designed to enhance the efficient use of self-generated energy in prosumer households. As part of the DIGITISE suite, this application focuses on maximizing on-site energy utilization, minimizing grid dependency, and reducing overall energy costs through intelligent control strategies and real-time decision support.

At its core, the application (**Energy Optimizer Component**) integrates short-term forecasts of energy demand and photovoltaic (PV) generation with data from storage systems, electric vehicles (EVs), and other flexible devices. These data streams are sourced from smart meters, IoT sensors, and local energy management systems and are fed into the energy digital data space Market, where interacting by reading and writing the corresponding data. This application takes into account the energy forecasting on consumption, generation profiles, and grid electricity prices, to optimize the storage potential. By so doing it provides insights where recommending real-time control actions that prioritize self-consumption and shift flexible loads to maximize energy savings.

A critical functionality of the application is its ability to provide transparent feedback to users. It generates key performance indicators (KPIs) and detailed energy profiles, including consumption breakdowns from PV, grid, batteries, and EVs, as well as the state of charge (SoC) for local storage assets. These insights are visualized on the DIGITISE Dashboard, where users can explore various optimization scenarios and receive actionable recommendations to improve energy efficiency.

Through its integration with the Data Space (**Data Space Integration**), the application facilitates secure, standards-based data exchange between energy forecasting components, optimization algorithms, and the user interface. This enables seamless interoperability with other DIGITISE applications.

Moreover, the application provides case scenario recommendations for better decision-making in control strategies for intelligent energy flexibility potential utilization. This Energy Savings and Self-consumption Optimization Application empowers prosumers to become active participants in the energy ecosystem, reducing costs, supporting grid stability, and accelerating the clean energy transition. These recommendations are made visible through the dashboard (**Dashboard integration**) or executed through the Smart Home and DER Automated Control detailed in the next section

Technical specifications

This section outlines the technical foundation and key features of the Energy Savings and Self-consumption Optimization Application, based on the specifications from D2.1.

- **Real-Time Monitoring data integration:** Collects and processes live data from IoT sensors, EVs, and metering systems to support real-time decision-making.

- **AI-Based Forecast Integration:** Leverages short-term AI-driven forecasts for PV production, household energy demand, and grid pricing to guide optimization.
- **Dynamic Control and Flexibility Management:** Continuously optimizes the operation of flexible devices (e.g., smart appliances, EV chargers) and storage systems to prioritize self-consumption.
- **Comprehensive Energy Profiling:** Provides users with detailed energy consumption and generation profiles, including usage from PV, grid, batteries, and EVs.
- **Personalized Optimization Recommendations:** Delivers scenario-based energy-saving suggestions, including control strategies.
- **KPI Reporting:** Highlights key indicators such as self-consumption rates, grid import reduction, cost savings, and system efficiency.
- **Secure Data Exchange via Data Space:** Ensures safe and standardized interoperability between data sources, optimization logic, and user-facing applications.

Detailed interactions

Following the requirements defined in D2.1, the application's interactions with other DIGITISE modules are summarized below, based on the dynamic exchange flow depicted in the sequence diagram Figure 21.

- Input Data Retrieval: The Energy Optimizer component retrieves forecast and characteristic data from the Data Space, including Grid electricity prices, PV generation forecasts, Household energy demand forecasts, Energy storage characteristics
- Optimization and Scenario Analysis: Using the gathered data, the Energy Optimizer simulates and evaluates multiple control scenarios. It selects the most cost-effective and self-consumption-maximizing strategies. The two core sub-components are the optimization layer and the KPI and profiling calculator engines.
- Output to Dashboard:
 - User KPIs: Key metrics including energy profiles, battery/EV SoC, and consumption ratios are shared with the user through intuitive visualizations.
 - Recommendations: Control suggestions for optimizing energy usage and minimizing costs are sent to the Dashboard.

This application functions as a critical enabler of consumer empowerment and smart energy behaviour within the DIGITISE ecosystem. By combining analytics, real-time control, and user-centric insights, it paves the way for intelligent, sustainable, and cost-effective energy usage in modern prosumer households.

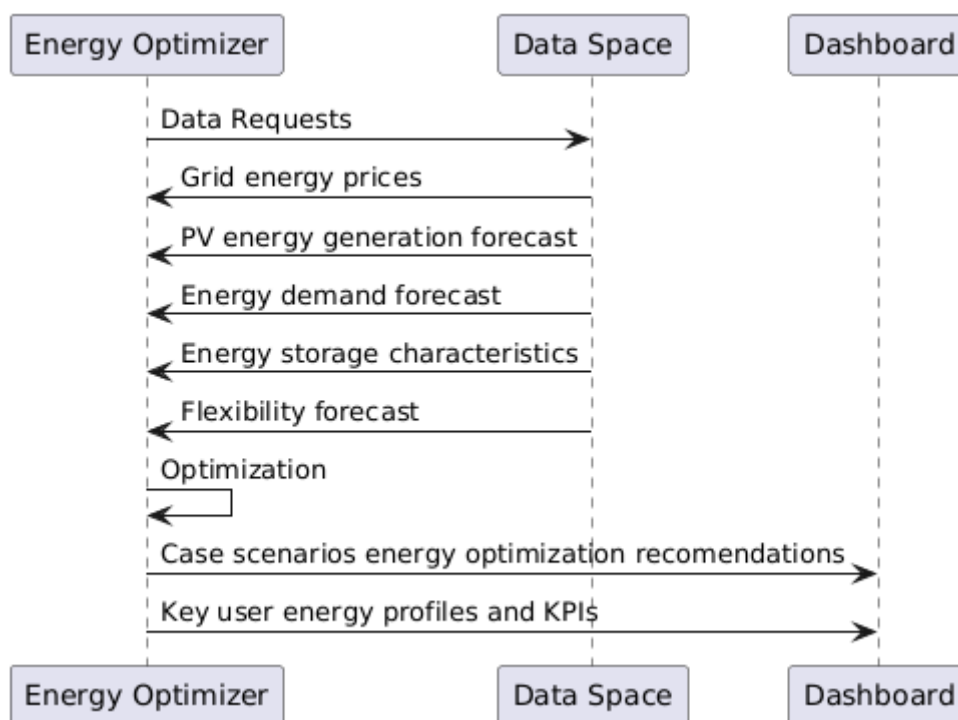


FIGURE 21: ENERGY SAVINGS AND SELF-CONSUMPTION OPTIMIZATION APPLICATION

In the following, we list the initial list of data to be consumed by the components made available either from the raw assets or the results of the analytics/DT as stated above.

TABLE 24 DATA/AI NEEDS ENERGY SAVINGS AND SELF-CONSUMPTION OPTIMIZATION APPLICATION

Data Artefact	Description
Energy prices	Retail electricity prices, used to support scenario modeling, and overall assessment of DER operations.
HVAC/DHW energy consumption data	Energy consumption data from demand side assets
EV CPs energy consumption data	Energy consumption data from EV CPs as flexible assets
Battery Profiling data	Energy charge/discharge data from batter assets
HVAC/DHW operation data	Operational data from the HVAC/DHW to support DER modeling task
Indoor/outdoor weather data	Environmental data (indoor temperature, humidity, outdoor temperature) to support DER modeling task
EV CPs operation consumption data	Operational data from the EV CPs to support DER modeling task
Battery operation data	Operational data from the Battery systems to support DER modeling task
Gen assets analytics	Forecasting data related to the operation of generation assets.

Demand assets analytics	Forecasting of consumption/ load profiles of demand-side assets that are to be considered in the overall analysis (total building, asset level)
Flexibility Analytics	Data-driven analysis of flexibility potential of the flexible assets in place.

4.3.3.2 Smart Home and DER Automated Control

Overview

The Smart Home and DER Automated Control is designed to seamlessly integrate consumers into energy activities by providing a fully automated, human-centric, and non-intrusive experience. At its core, it enables the transformation of high-level energy control strategies into precise, device-specific commands that are executed automatically, ensuring both energy efficiency and economic benefits.

A key aspect of this functionality is the **Automated Device-Level Control Execution (ADCE)**, which allows the different business applications to directly interact with individual devices without requiring manual intervention. By continuously receiving high-level directives from the DIGITISE business applications, the system ensures that each device operates in an optimized manner, reducing energy waste and lowering costs while maintaining user comfort. This automated execution removes the burden from consumers, offering smooth and effortless participation in energy-saving initiatives.

Complementing this, the **Smart DER Optimizer Component**, a crucial feature that bridges the gap between overarching energy strategies and the fine-tuned control of distributed energy resources (DERs). This capability enables the system to interpret broad energy management goals—such as load balancing, demand response, or self-optimization strategies integration—and convert them into precise operational commands for specific devices.

Overall, the Smart Home and DER Automated Control intelligent mechanism guarantees that energy efficiency measures are not only effective but also seamlessly integrated into the user’s daily routine, fostering greater acceptance and trust in automated energy management solutions.

Technical specifications

This section outlines the technical foundation and key features of the Smart Home and DER Automated Control, based on the requirements analysis and feedback gathered from D2.1.

- Modeling for Energy Efficiency Strategy Execution → Translates high-level energy strategies into precise, real-time control signals for individual devices,

incorporating insights from the Energy Savings and Self-Consumption Optimization Application.

- Modeling for Demand Response Strategy Implementation → Converts high-level demand response strategies into precise, real-time control signals for individual devices, leveraging results from the VPP application.
- Handling of Control Events Triggered by Business Applications → Serves as the interface layer that ensures seamless connectivity and management of direct control actions initiated by various applications within the DIGITISE framework.
- Execution of Control Events → Functions as the API Gateway, facilitating connectivity with hardware devices to trigger control actions, thereby enabling the automation framework deployment within DIGITISE.

Detailed interactions

Based on the aforementioned technical features, the different interactions with other system components within DIGITISE are defined.

The Smart DER Optimizer Component within the DIGITISE framework serves as a pivotal interface, to translate high-level energy strategies into actionable commands for household devices, ensuring efficient energy utilization and active consumer participation. To achieve this, the Smart DER Optimizer Component integrates with several key modules:

1. VPP Configuration Component: By processing flexibility contract information, actual flexibility data from the Portfolio Management Component, and flexibility requests from the simulated Grid Flexibility Layer, this component optimizes the allocation of flexible assets. The Smart DER Optimizer Component receives disaggregated flexibility requests from the VPP Configuration Component, enabling it to initiate specific demand response actions at the device level.
2. Energy Savings and Self-consumption Optimization Application: Insights from this application guide the Smart DER Optimizer Component in translating energy efficiency strategies into precise control signals for individual devices, promoting optimal energy usage and increased self-consumption.

On the other hand, the role of Automated Device-Level Control Execution component is to facilitate seamless communication and control between end-user devices and the broader energy management system. The Automated Device-Level Control Execution interacts with the Automation Deployment Component from the Health and Security Application (as well as the Smart DER Optimizer Component mentioned above) in order to receive direct control actions for execution. Vice versa, the Automated Device-Level Control Execution is acting as the gateway for routing the control actions to the physical assets integrated in the project.

The visual representation of the aforementioned dynamic view is presented below showcasing at a high level the data interfaces among the different components

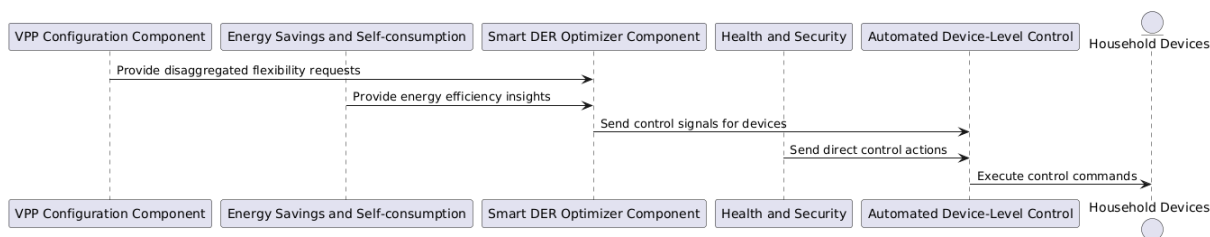


FIGURE 22: SMART HOME AND DER AUTOMATED CONTROL APPLICATION

Note: in the schema above and in order to support the DER modeling functionality access to the data from the Data Space environment is also considered. In the following, we list the initial list of data to be consumed by the components made available either from the raw assets or the results of the analytics/DT as stated above.

TABLE 25 DATA/AI NEEDS SMART HOME AND DER AUTOMATED CONTROL

Data Artefact	Description
HVAC/DHW energy consumption data	Energy consumption data from demand side assets
EV CPs energy consumption data	Energy consumption data from EV CPs as flexible assets
Battery Profiling data	Energy charge/discharge data from batter assets
HVAC/DHW operation data	Operational data from the HVAC/DHW to support DER modeling task
Indoor/outdoor weather data	Environmental data (indoor temperature, humidity, outdoor temperature) to support DER modeling task
EV CPs operation consumption data	Operational data from the EV CPs to support DER modeling task
Battery operation data	Operational data from the Battery systems to support DER modeling task
Disaggregate Flexibility Data	The asset level DR requests as triggered from the VPP application to be further transformed to control actions

4.3.3.3 Health and Security Application

Overview

The Health and Security Application is an intelligent, human-centric solution designed to monitor, assess, and enhance the indoor health and security conditions of household environments. By integrating real-time indoor data, sub-metering device streams, and AI-driven consumer profiling analytics, the application enables automated smart control strategies (like ventilation or lighting control) and delivers personalized recommendations

when automated action is not feasible. The system also contributes to the Smart Readiness Indicator (SRI) framework by extending its catalogue with data-driven health and security impact assessments.

The Health and Security Application consists of the following main components:

Health and Security Consumer Interface: This is the primary integration layer component of the application. It provides real-time KPI capabilities for a variety of indoor environmental conditions, including indoor air quality (IAQ), occupancy levels, temperature, and lighting. Through this integration interface, the outcomes of the app are made visible through the dashboard of the project to facilitate users to view alerts, receive smart recommendations, and review automation actions taken by the system. The interface also offers access to health and security scoring metrics, as well as feedback related to the Smart Readiness Indicator (SRI), helping users understand and improve their home's performance in terms of health and safety.

AI Profiling and Control Engine: Serving as the intelligence core of the application, the AI Profiling & Control Engine is responsible for analyzing user behavior and household usage patterns. It extracts patterns based on daily routines, and occupancy trends, enabling the system to adapt to each household's unique needs. This engine detects deviations from typical behavior that may indicate potential health or security risks, such as prolonged absence during usual occupancy periods or abnormal indoor conditions. Based on these insights and patterns the engine makes decisions to either trigger automated control actions or issue contextual recommendations aimed at improving both comfort and safety.

Automation and Actuation Manager: The Automation & Actuation Manager acts as the bridge between the intelligence layer and the physical building systems, such as smart lighting, HVAC, and ventilation systems. It is tasked with executing automated responses (via the Smart Home and DER Automated Control as mentioned above) to changing indoor conditions, for example by opening windows, activating ventilation fans, or adjusting lighting settings when certain thresholds are met. These actions are based on real-time data and AI-driven decisions that consider user comfort and safety. In cases where automation is not possible or appropriate, the manager generates smart suggestions and routes them to the Consumer Interface, ensuring users are still informed and empowered to act when needed.

Health and Security Data Layer: The Health & Security Data Layer is the real-time integration hub that collects and manages data from a range of sources throughout the home. This includes sub-metering data that tracks energy consumption at the room or device level, as well as environmental sensor data monitoring indoor conditions (e.g., humidity, CO₂ levels, VOCs, temperature, light intensity). Where applicable, it also integrates data from external sources such as weather and air

quality APIs. By fusing these data streams, the component supports contextual decision-making and meaningful visualizations as specified above.

Technical specifications

Real-time monitoring of IAQ and device data via the interface (HSI-01): This feature allows for continuous monitoring of indoor air quality (IAQ) and device performance in real-time, providing users with up-to-date information on their home's health and energy use. It ensures that users are always aware of the indoor environment, helping them stay informed and in control. This covers also updates on SRI indicators

Provision of personalized recommendations for improving health/security (HSI-02): The system provides personalized recommendations to users, based on data analysis of their home environment, to improve health and security. This proactive approach helps users take informed actions to maintain a safe and comfortable indoor environment.

Behavioral analytics using AI (AIP-01): AI analyzes the household's behavior, such as occupancy and comfort settings. Based on these settings it extracts patterns that enable the system to make informed decisions on how to adjust the environment for maximum comfort and health benefits.

Anomaly detection and alert triggering based on deviations from norm (AIP-02): The AI engine detects deviations from normal occupancy or environmental conditions and triggers alerts when something unusual is detected. This feature ensures that any potential health or security risks are quickly flagged for user attention.

Automated control of environmental conditions (AAM-01): This feature automates (via the Smart Home and DER Automated Control tool) the adjustment of environmental factors like ventilation or lighting, responding to real-time conditions to maintain a healthy, secure environment. It minimizes the need for manual intervention while ensuring optimal conditions.

Smart actuation commands based on AI-driven decisions or IAQ thresholds (AAM-02): AI-driven decisions determine when to act on certain environmental factors, such as activating ventilation or adjusting lighting, based on thresholds like air quality levels. It ensures responsive actions are taken to maintain the indoor environment according to the user's preferences.

Fallback recommendation system if automation is not applicable (AAM-03): When automation is not feasible, this system provides users with actionable suggestions to address the situation. It ensures that even without automated intervention, users still have guidance to improve indoor health or security.

Integration with real-time indoor monitoring and sub-metering streams (HSD-01): This feature integrates real-time data from indoor monitoring systems and sub-metering devices via Data Space, ensuring comprehensive tracking of all environmental variables. It

allows the system to understand and respond to conditions that impact health and security in the home.

Calculation of enhanced SRI score based on IAQ and security indicators (HSD-02): The system calculates an enhanced Smart Readiness Indicator (SRI) score by incorporating data related to IAQ and security indicators. This feature provides an objective measure of the home’s overall health and security readiness.

Data exchange with external services (HSD-03): It enables data exchange with external services, to enhance the system’s decision-making and provide more comprehensive environmental analysis. This integration ensures that the system adapts to external conditions for better health and security management.

Detailed interactions

The Health and Security Application operates with a seamless flow of interactions between its components to ensure effective monitoring, control, and automation. The Consumer Interface communicates with the AI Profiling & Control Engine, retrieving analysis results and allowing them to provide info to the dashboard. The AI engine, in turn, sends triggers to the Automation Manager (and then via the Manager to the Smart Home and DER Automated Control tool) based on the generated profiles (e.g., high CO₂ levels during occupancy) to initiate automatic actions, such as adjusting ventilation or lighting, or to generate personalized recommendations if automation is unavailable. The Automation Manager interacts with building systems (via the Smart Home and DER Automated Control tool) to execute control commands or schedules, ensuring optimal environmental conditions. Meanwhile, the Health & Security Data Layer integrates real-time data streams from sub-metering devices and indoor conditions, providing all components with relevant environmental data for decision-making. This data is also fed into the SRI Evaluation Engine, enhancing the Smart Readiness Indicator score based on real indoor air quality (IAQ) and security data.

Through these interconnected components, the system works cohesively to ensure a healthier, safer household environment.

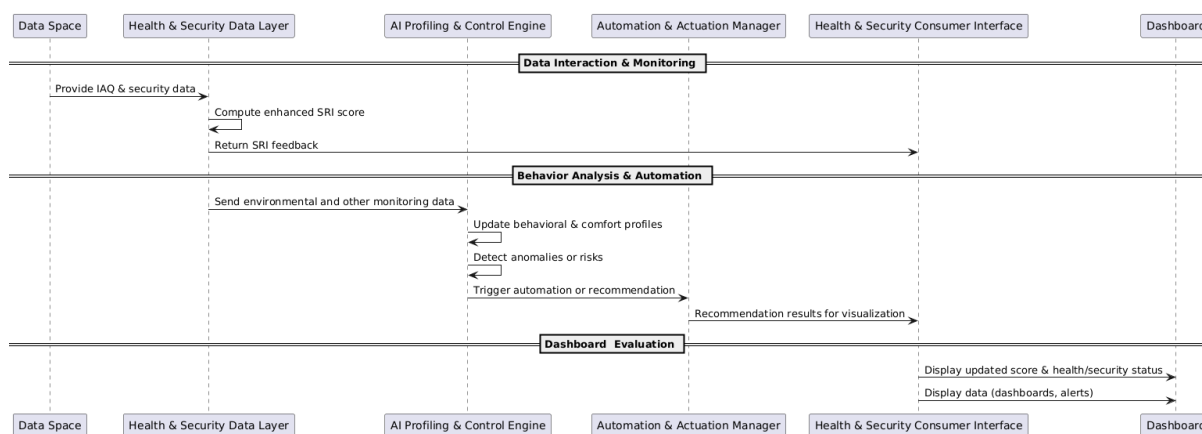


FIGURE 23: HEALTH AND SECURITY APPLICATION

Note: The actuation engine interfaces with the device level control component as mentioned in previous section for triggering actuation in physical assets.

In the following, we list the initial list of data to be consumed by the components made available either from the raw assets or the results of the analytics/DT as stated above.

TABLE 26 DATA/AI NEEDS HEALTH AND SECURITY APPLICATION

Data Artefact	Description
Indoor/outdoor weather data	Environmental data (indoor temperature, humidity, outdoor temperature) to support app modeling task
Indoor/outdoor Air Quality data	Air quality data (indoor VOC, outdoor VOC) to support app modeling task
HVAC/DHW operation data	Operational data from the HVAC/DHW to support app modeling task

4.3.3.4 Asset Sizing and Investment Optimization Application

Overview

The Asset Sizing and Investment Optimization Application helps households/consumers make informed investment decisions to maximize self-consumption by integrating RES (Renewable Energy Sources) assets and enhance flexibility. Common examples of RES include solar power, wind energy, hydroelectric energy, and geothermal energy. The integration of RES aims to reduce greenhouse gas emissions, promote sustainable energy consumption, and enhance energy security.

This Application (through its core component Asset Sizing) intends to incorporate financial data to evaluate investments in RES, storage, and electromobility. For this, the Asset sizing application plan to analyse the pricing of each individual asset and provide the overall financial investment needed from the consumer point of view, but also some important investment metrics (depending on each situation):

- **Cost-effectiveness:** the economic efficiency of an investment, determining whether the financial outlay is justified by the benefits received. This involves comparing the costs of implementing RES with the savings generated over time through reduced energy bills and potential incentives or subsidies.
- **Payback period:** measures the time it takes for an investment to recoup its initial costs through the financial benefits it generates. A shorter payback period indicates a quicker return on investment, which is often more attractive to investors.
- **IRR (Internal Rate of Return):** is a financial metric used to evaluate the profitability of an investment. A higher IRR indicates a more profitable investment.

- ROI (Return on Investment): is a measure of the gain or loss generated by an investment relative to the amount of money invested. ROI provides a simple gauge of an investment's efficiency and is often used for comparing the profitability of multiple investments.

These metrics are crucial for evaluating the financial viability and timeline for returns on investments in renewable energy sources (RES) for households/consumers.

Technical specifications

This section identifies all the technical key features of the Asset Sizing and Investment Optimization Application:

- **Identify user objectives:** the app will be able to request from the User their goals and objectives for the asset sizing, in terms of what assets to invest or what type or limits they are envisioning
- **Create alternative scenarios:** based on the user goals and objectives, the asset sizing application will create multiple alternative scenarios which will be optimized in order to understand which scenarios provide the best results
- **Analyse each alternative scenario:** each of the scenarios will be analysed based on the new added assets. This will include the financial aspect of the added assets.
- **Provide reports based on the analysed scenarios:** The asset sizing application will provide a comprehensive analysis of the scenarios, identifying the necessary investments to be made, its initial cost, cost-effectiveness, payback period, IRR and ROI.
- **User feedback and adjustments:** the users will be able to provide feedback to the recommendations from the asset sizing application, by requesting additional assets or changing some of the initial parameters (objectives and goals) in order to re-analyse possible investments in the household and its financial impact.

Detailed interactions

The Asset Sizing application will interact with 3 different entities: the end-user through the Dashboard, the Household Data Space and the DIGITISE Digital Twin implementation.

- The Dashboard is the main point of contact with the end users, both receiving information from the User and by providing the final reports generated by the Asset Sizing Application.
 - The dashboard will enable the End-User to define their objectives/goals which will be used to parametrize the investment optimization, by defining the Assets the user is interested in investing in, or the total amount of € it is able to use as initial investment.
 - The dashboard will provide the End-User with the report on the investment strategies that will show the assets to be purchased, its costs and the impact in the household energy consumption.

- The DIGITISE Asset Sizing Application will interact with the 3 other components to be able to generate the recommendations to the users by checking prices of the assets, and the impact on the household simulated and optimized by the optimizer. This information (assets, optimizations, etc) will be available as part of the DIGITISE Data Space.
 - The interactions with the Dashboard are the ones mentioned previously, which includes getting parameters and provide final reports to the End-User
 - The DIGITISE Data Space is considered as the main Data Source for the DIGITISE Asset Sizing Application, as it has all the information about the household, and will hold the result of every optimization generated by the DIGITISE Optimizer component.
 - The DIGITISE Digital Twin (DIGITISE Optimizer in schema below) to run all simulations needed in order to understand which investments are possible in the household, based on the parameters collected from the End-Users and from the list of Assets that have potential to improve the overall performance of the household.

The list of interactions is provided below in the diagram.

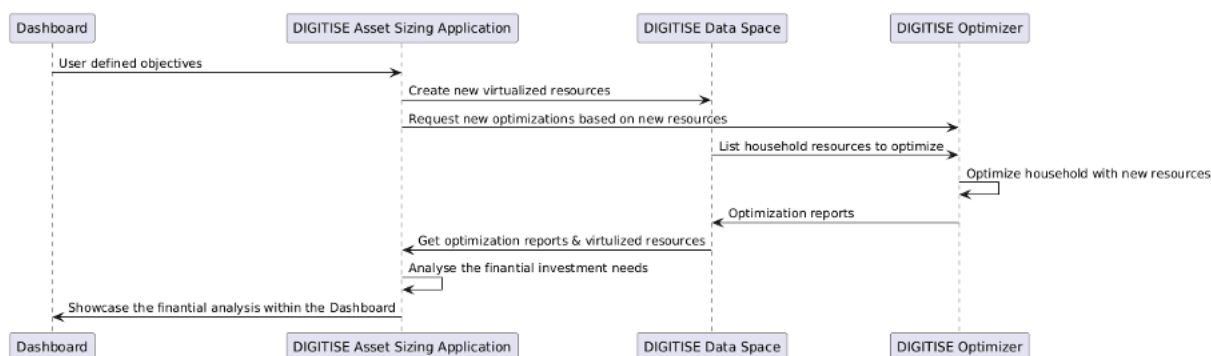


FIGURE 20 – ASSET SIZING AND INVESTMENT OPTIMIZATION APPLICATION

In the following, we list the initial list of data to be consumed by the components made available either from the raw assets or the results of the analytics/DT as stated above.

TABLE 27 DATA/AI NEEDS ASSET SIZING AND INVESTMENT OPTIMIZATION APPLICATION

Data Artefact	Description
HVAC/DHW energy consumption data	Energy consumption data from demand side assets
EV CPs energy consumption data	Energy consumption data from EV CPs as flexible assets
Battery Profiling data	Energy charge/discharge data from batter assets
HVAC/DHW operation data	Operational data from the HVAC/DHW to support DER modeling task

Indoor/outdoor weather data	Environmental data (indoor temperature, humidity, outdoor temperature) to support DER modeling task
Financial data	Access on financial parameter required for the evaluation of the different investments
Economic data	Access on energy economics data required for the techno-economic assessment of the different investments to be examined by the application

4.3.3.5 Behavioural Profiling and Insights Application

Overview

The Behavioural Profiling and Insights Application is a data-driven intelligence platform designed to enable fine-grained analysis of customer behaviour within the household environment. By integrating real-time IoT data streams (e.g., sub-metering, total energy consumption, and indoor environmental conditions) with Household Digital Twin models and personal baseline analytics, the application delivers deep behavioural insights, customer segmentation, and lifestyle profiling. Through clustering, pattern recognition, and lifestyle inference models, the platform helps extract attributes such as demographics, appliance ownership, comfort preferences, and environmental awareness. These insights can support not only personalized services for consumers but also unlock participation in the data economy, allowing trusted data sharing with third-party providers (e.g., marketers, energy providers, and service designers) in a transparent manner. To achieve these goals the Behavioural Profiling and Insights Application comprises of the following three core components:

1. The Insights and Exploration Interface (IEI). This is the interface that offers intuitive access to behavioural insights for both end-users and analysts. First it will be able to enable access to households' behaviour over time through the application dashboard. Additionally, it will support customer clustering and segmentation visualizations and attribute inference reports (e.g. appliance ownership likelihood, environmental profiles). will be generated. Last, it will allow for extraction of lifestyle categorization summaries (e.g. energy conscious, high-tech adopter).
2. The Behavioural Profiling Engine (BPE). This is a software-based system that uses diverse data sources and applies behavioural modelling techniques to generate meaningful insights. It ingests real-time IoT data from smart meters and indoor environmental sensors, which is then contextualized through integration with Household Digital Twin representations. Using segmentation and clustering algorithms, the engine identifies distinct behavioural patterns and consumer profiles. Machine learning and statistical modelling methods are employed to infer key behavioural characteristics, which are continuously refined and enriched over time. This dynamic

process allows for the ongoing update of user profiles with lifestyle indicators and emerging behavioural traits.

3. The Data Economy Gateway (DEG). This is a module that facilitates consumer participation in the emerging data economy by enabling secure and transparent sharing of behavioural insights. It provides APIs that allow authorized third parties to access consumer-derived data, while fully adhering to the data sharing policies and consent models defined in T3.3. Additionally, the DEG supports value attribution and benefit tracking mechanisms, enabling consumers to receive incentives or personalized services in exchange for their data contributions.

Technical specifications

In this section, the detailed technical specifications of the Behavioural Profiling and Insights Application are provided, taking into consideration the list of requirements as derived from D2.1 and further detailed elaboration of the functionality to be delivered as part of the application. The list of core features is provided:

- **Software Interface for behaviour tracking and segmentation (IEI-01)**: This is the data gateway to offer real-time insights into household behavioural patterns, such as energy usage trends, room occupancy, and comfort preferences. Users can explore data over different time periods and across dimensions like seasonality, appliance categories, or routine clusters. This information will be made available through the dashboard to support filtering and drill-down for more granular analysis.
- **Visualization of lifestyle clusters and personal baseline comparisons (IEI-02)**: Handles user grouping based on behaviour, preferences, and inferred lifestyle characteristics, allowing consumers to see how they compare with similar households. Reports include cluster overviews, peer benchmarking, and trend shifts over time. This fosters awareness and engagement by helping users contextualize their lifestyle within broader behavioural patterns.
- **Attribute inference reports (e.g. household type, appliance use, comfort routines) (IEI-03)**: Provides detailed reports on inferred household attributes derived from data patterns and profiling models. These may include estimations of household composition, appliance ownership, or comfort profiles. Reports are updated dynamically as new data becomes available, ensuring users always access the most relevant insights.
- **Real-time fusion of IoT data streams with Digital Twin models (BPE-01)**: Synchronizes live data from sub-metering systems, indoor sensors, and environmental monitors with virtual representations of the household. This integration enables more accurate context-aware behavioural modelling. It also helps distinguish between behavioural signals and structural/environmental constraints.

- **Behavioural segmentation and clustering engine (BPE-02):** Groups users based on behavioural similarities using machine learning techniques. This segmentation supports personalized insights and offerings of service. The engine dynamically adapts to new data and evolving user patterns.
- **Lifestyle profiling and behavioural characteristic extraction (BPE-03):** Uses behavioural data to derive socio-demographic indicators, appliance usage routines, energy comfort preferences, and environmental attitudes. These profiles inform both consumer-facing insights and third-party analytics offerings. The system updates these characteristics as new patterns are detected.
- **Continuous profile enrichment based on observed data and seasonal dynamics (BPE-04):** Maintains evolving user profiles that incorporate seasonal trends, changes in routine, and external influences. The enrichment engine ensures that behavioural insights stay relevant and reflective of actual lifestyle conditions. This enables adaptive services and predictive personalization.
- **Controlled data sharing APIs for third-party service providers (DEG-01):** Exposes a set of secure and permissioned APIs for partners such as energy companies or marketing providers to access behavioural insights. These APIs ensure data is shared only in compliance with user-defined permissions and legal frameworks. Access is logged and monitored for full transparency.

Detailed interactions

The Behavioural Profiling and Insights Application relies on tightly integrated interactions among its core components to deliver personalized, privacy-aware, and intelligent user experiences. The IEI component communicates directly with the BPE to retrieve real-time behavioural insights, visualizations, and lifestyle inferences. Users can interact with this data through intuitive dashboards, provide feedback on the perceived accuracy of lifestyle labels, and opt-in for more customized profiling. In parallel, the IEI also interacts with the DEG, allowing users to manage their privacy preferences, configure data sharing settings, and review who has accessed their data, when, and for what reason. Behind the scenes, the BPE continuously ingests and analyzes time-series data from the IoT infrastructure (e.g., electricity, temperature, occupancy sensors) and contextualizes this information using Household Digital Twin models, enabling fine-grained interpretation of user behaviour—such as appliance usage or comfort routines—within specific household contexts. Once processed, the BPE passes enriched behavioural datasets and inferred user attributes to the DEG for external sharing. This tightly coordinated system ensures that behavioural insights are not only accurate and meaningful but also responsibly governed and transparently shared.

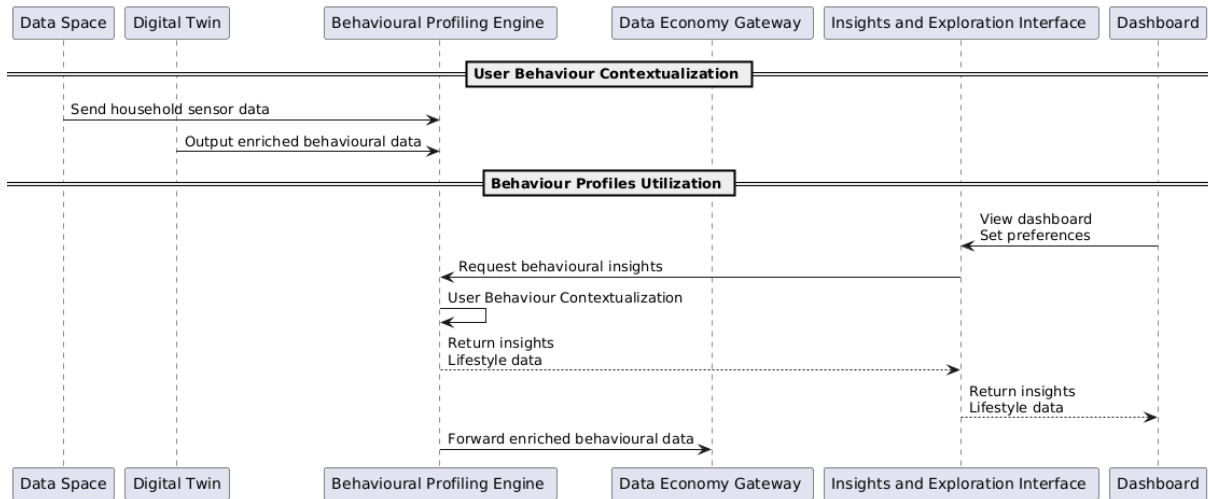


FIGURE 24: BEHAVIOURAL PROFILING AND INSIGHTS APPLICATION

In the following, we list the initial list of data to be consumed by the components made available either from the raw assets or the results of the analytics/DT as stated above.

TABLE 28 DATA/AI NEEDS BEHAVIOURAL PROFILING AND INSIGHTS APPLICATION

Data Artefact	Description
Indoor/outdoor weather data	Environmental data (indoor temperature, humidity, outdoor temperature) to support app modeling task
Building/ HVAC/DHW Energy data	Energy related data from the building environment with focus on sub metering devices
HVAC/DHW operation data	Operational data from the HVAC/DHW to support app modeling task

4.3.3.6 DIGITISE Flexibility Marketplace Application

Overview

The Flexibility Marketplace application offers the ability to prosumers to be actively engaged in flexibility market transactions by establishing bilateral agreements with aggregators through a dedicated environment. Due to the exploitation of the novel distributed ledger technology, relevant flexibility smart contracting mechanisms are provided to prosumers and aggregators, aiming for a trustworthy and transparent service. The three components that comprise the Flexibility Marketplace are listed below.

- **Marketplace User Interface:** The Marketplace UI is the component that allows prosumers and aggregators to interact with each other in the scope of establishing flexibility contracts. From the side of the prosumers there is the possibility to configure their devices' characteristics so as to make them available for

participating in energy flexibility transactions. Aggregators, on the other hand, are equipped with the means to introduce new flexibility contracts, where they can define several participating flexible assets and relevant contract terms for establishing a bilateral agreement between them and prosumers. Prosumers have the chance, through the Marketplace UI, to propose alternative terms to the ones introduced in a contract, as a way of negotiating its details. If an agreement is reached, it is possible to trigger the publishing and signing of a smart flexibility contract on the blockchain via the Marketplace UI, ensuring transparency and integrity of the process. Additionally, both aggregators and prosumers, after the activation of flexibility events, can monitor the performance of the established flexibility contracts, through intuitive graphs and reports offered by the Marketplace UI.

- **Flexibility Configuration and Remuneration Manager:** The Flexibility Configuration and Remuneration Manager serves as the main back-end component of the Flexibility Marketplace. In this scope, it is responsible for any data management task that includes draft contract creation and update, assets' flexibility details configuration, data exchange with external components and more. Another significant functionality of the component is the calculation of the remuneration amounts per prosumer, after the activation of flexibility events, in a way that the consumption profiles of the prosumers are assessed in order for the proper amounts, either revenues or penalties, to be specified.
- **DLT Smart Contract Engine:** The DLT Smart Contract Engine is the one to handle all the Flexibility Marketplace's blockchain transactions with the DLT infrastructure. With information and triggering actions provided through the Marketplace UI, the DLT engine performs transactions on the DLT for important tasks that ensure transparency within the application, namely the smart contract deployment and signing, as well as the publication of the financial details of the remuneration calculation results. The above is achieved by publishing contract terms on the blockchain and further sealing the agreement with a signing procedure as a relevant blockchain transaction, but also by logging the remuneration amounts related to a contract on the chain.

Technical specifications

In this section, the detailed technical specifications of the Flexibility Marketplace are provided, taking into consideration the list of requirements as derived from D2.1 and further detailed elaboration of the functionality to be delivered as part of the application. The list of core features is provided:

- **Flexible assets and contracts listing (MUI-01):** Provides an overview of both the available flexible assets and of the flexibility contracts a user (prosumer/aggregator) is involved, with the possibility of filtering each list based on provided search criteria
- **Flexible asset configuration by prosumers (MUI-02):** Allows prosumers to configure their devices' characteristics in order to make them available for participating in flexibility transactions
- **Flexibility contract initiation and negotiation of terms (MUI-03):** Allows aggregators to introduce a new flexibility contract by defining a set of contract terms, i.e. the associated prosumer and the related assets, contract duration, requested flexible assets' availability schedules, financial terms. Equips also prosumers with the ability to propose alternative contract terms as a way to negotiate the details of the introduced contract.
- **Triggering of smart flexibility contract publishing and signing (MUI-04):** Offers the possibility to aggregators to trigger the publication of a smart flexibility contract on the blockchain which is performed by the DLT Smart Contract Engine, after an agreement has been reached. Similarly, it offers to both aggregators and prosumers the ability to trigger the signing of the published contract
- **Contracts performance visualizations (MUI-05):** Provides intuitive visualizations in the form of informative graphs and reports regarding the performance of established contracts in terms of flexibility provision and financial details after the realization of flexibility events
- **Flexibility contract management (creation and update) (FCR-01):** Provides the management of contract instances during all stages of the contract introduction, negotiation and settlement processes
- **Flexibility asset management (FCR-02):** Offers the way to manage flexible assets instances of the application, mainly for the configuration process of their flexibility details
- **API-based data exchange (FCR-03):** Allows the application to communicate with the DIGITISE Data Space as well as with components from other DIGITISE applications and tools, in order to successfully exchange relevant data
- **Definition of prosumers remuneration amounts (FCR-04):** Calculates the relevant prosumer remuneration amounts, revenues or penalties, after the realization of flexibility events
- **Smart contract deployment and signing (SCE-01):** Allows the publication and signing of a smart flexibility contract on the distributed ledger
- **Logging of remuneration amounts (SCE-02):** Provides a logging capability of the calculated revenues and penalties as blockchain transactions/events

Detailed interactions



By defining the core features per application, the detailed dynamic view of each application shows the interactions among the different components as well as the associated data exchanges. Details on the interactions of the different Flexibility Marketplace components are described below:

- The Marketplace UI interacts mainly with the Flexibility Configuration and Remuneration Manager, in the scope of contract creation and update requests, asset configuration procedure, assets and contract listing and lastly data retrieval regarding past flexibility events and related remuneration information of the established contracts. Another connection with internal components is made with the DLT Smart Contract Engine, through which it is possible to trigger contract deployment and signing transactions on the distributed ledger.
- The Flexibility Configuration and Remuneration Manager, except for the direct connection with the Marketplace UI, exploits an interface with the DLT Smart Contract Engine as well, so as to perform the logging of the remuneration calculation results on the DLT. It also interacts with external components from the DIGITISE environment, like the DIGITISE Data Space, for gathering relevant consumption data, the AI Analytics component for the needed consumption and flexibility forecasts, and finally the VPP Configuration Component of the Portfolio Management and VPP Configuration application, that provides the flexibility disaggregation results.
- The DLT Engine, apart from the interactions described with the Marketplace UI and the Flexibility Configuration and Remuneration Manager, is the only Flexibility Marketplace component to have a direct connection with the DLT infrastructure, where all contract transactions are sent.

Below, two views are provided based on the different actors associated with the Flexibility Marketplace application.

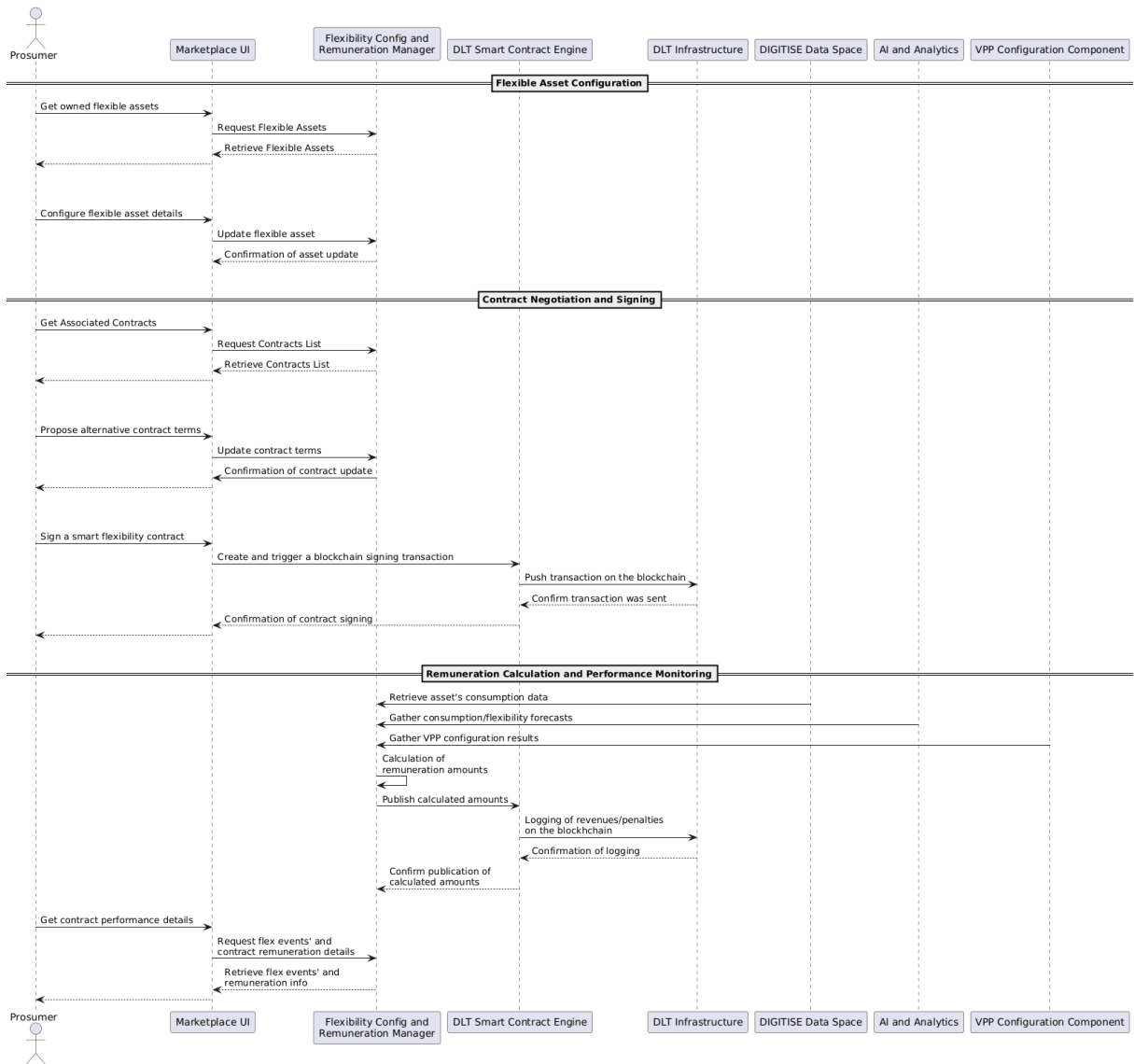


FIGURE 25: FLEXIBILITY MARKETPLACE APPLICATION– PROSUMER VIEW

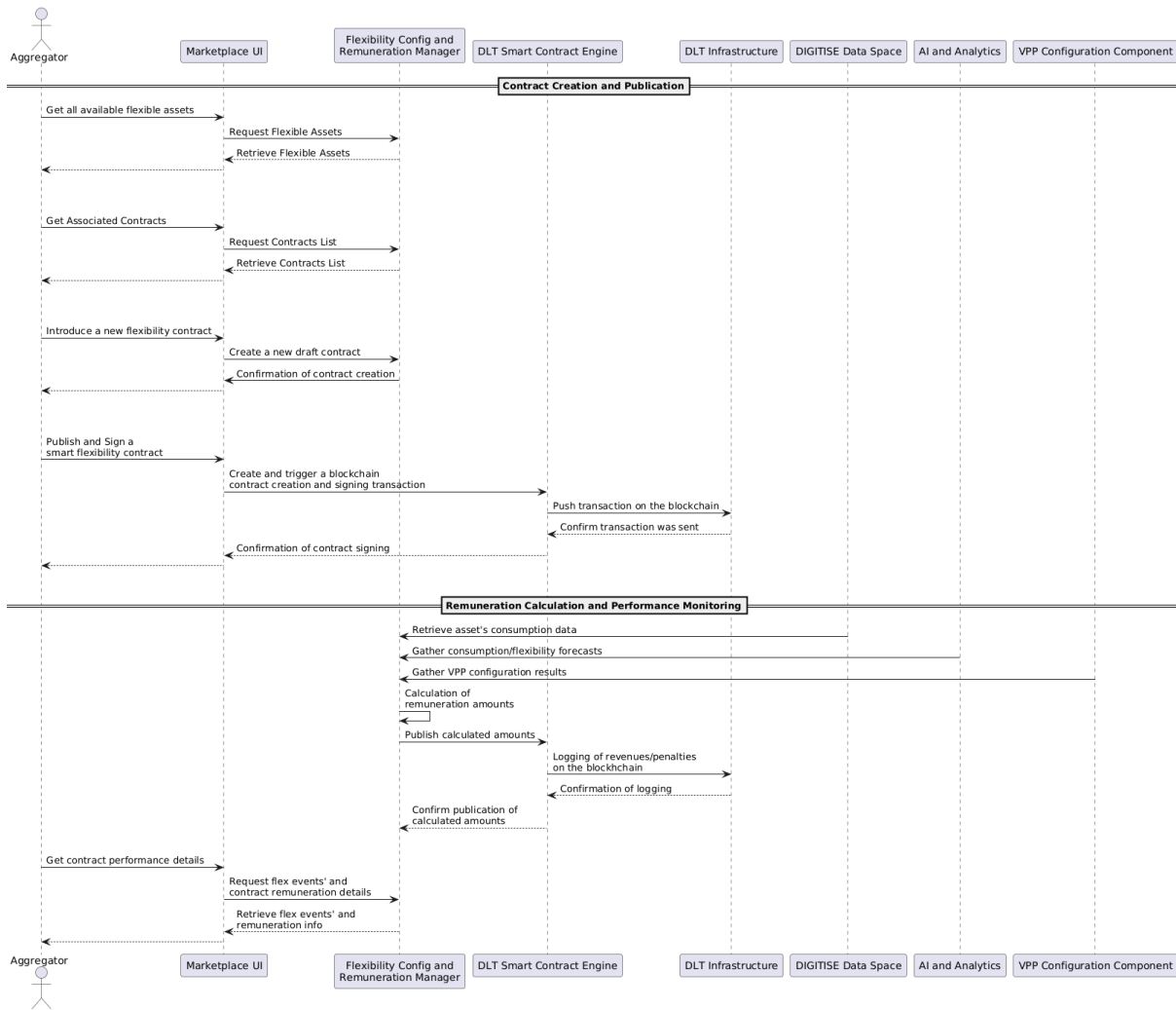


FIGURE 26: FLEXIBILITY MARKETPLACE APPLICATION – AGGR VIEW

The following table includes an initial listing of the different data, raw or as results from the AI Analytics, that will be utilized among the different data transactions:

TABLE 29 DATA/AI NEEDS FLEXIBILITY MARKETPLACE APPLICATION

Data Artefact	Description
Devices' energy consumption data	Consumption data from flexible devices of the household (15min to 1hour granularity)
Devices' static characteristics	Static information of flexible assets, i.e. nominal capacity
Devices' energy consumption forecast	The forecasted consumption of flexible devices from few hours- to day-ahead (15min to 1hour granularity)
Devices' flexibility availability forecast	Estimation of the flexibility potential of the flexible assets (15min to 1hour granularity)

Devices' flexibility	offered	Flexibility amount requested by each device in a period of time, after the disaggregation results of the VPP configuration
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4.3.3.7 Dynamic Portfolio Management and Virtual Power Plant (VPP) Configuration Application

Overview

The Dynamic Portfolio Management and VPP Configuration Tool is designed to assist aggregators in effectively monitoring and managing their portfolio performance to deliver the necessary flexibility to network operators while accommodating the specific characteristics of their customers. This application consists of two core components: the Portfolio Management Component and the VPP Configuration Component.

- The Portfolio Management Component enables aggregators to continuously oversee and manage the performance of their portfolios. This ensures that they can provide the required flexibility to network operators by considering various factors related to their customers, such as activation duration, flexibility capacity, contractual limitations, event locations, and the timing of flexibility availability. By integrating detailed analytics focused on flexibility forecasting and profiling, this component allows for spatio-temporal segmentation and classification of flexibility assets based on their specific characteristics. It also facilitates the formation of suitable clusters of flexibility assets, enabling aggregators to meet the evolving needs of Distribution System Operators (DSOs) for ancillary services.
- The VPP Configuration Component provides advanced Decision Support System (DSS) functionalities that allow for the creation of customized, dynamic Virtual Power Plants (VPPs). These VPPs are tailored to the services requested by network operators and the flexibility traits of associated assets. By utilizing the analysis performed by the Portfolio Management Component, the VPP Configuration Component aligns with key business objectives to optimize the configuration of VPPs for flexibility activation. Furthermore, it continuously monitors the performance of the VPP and dynamically adjusts the initial configuration in real-time if any flexibility sources unexpectedly exit during provision events.

Together, these components enhance the capacity of aggregators to manage flexibility resources efficiently, ensuring reliable service delivery to network operators and optimizing the overall performance of energy systems.

Technical specifications

In this section, the detailed technical specifications of the respective applications are provided, taking into consideration the list of requirements as derived from D2.1 and further the detailed elaboration of the functionality to be delivered as part of the application. The list of core features is provided:

- **Geo-Temporal Flexibility Asset Clustering (PMC-01):** Organizes flexibility assets based on spatial and time-based patterns to improve coordination and dispatch efficiency – Relevant Requirements
- **Business-Oriented Asset Grouping (PMC-02):** Categorizes flexibility assets according to strategic business goals, providing insights for better management and planning– Relevant Requirements
- **Custom Asset Selection for Portfolio Structuring (PMC-03):** Allows manual selection and grouping of assets based on predefined criteria to align with market strategies– Relevant Requirements
- **Flexibility Services for DSOs (VPP-01):** Provides VPP solutions to handle requests from the DSOs on the way to support grid stability and renewable energy integration– Relevant Requirements
- **Dynamic Allocation of VPP Flexibility Assets (VPP-02):** Optimizes the dispatch of flexibility resources, including energy storage, to support the delivery of the services to the overlay network– Relevant Requirements

Detailed interactions

By defining the core features per application, the detailed dynamic view of each application is providing, showcasing the interaction among the different components as well as the associated data exchanges.

Within the Portfolio Management Component, key inputs include flexibility contract details sourced from the Flexibility Configuration and Remuneration Manager and actual flexibility profiling data derived from pre-trained analytics developed in the project (As stated above), to identify and categorize relevant flexibility clusters. The results of the clustering and segmentation analysis performed by the Portfolio Management Component further inform the configuration process. These clusters are then aligned with manual portfolio configurations set by users. Moreover, aggregated flexibility profiles produced by the Portfolio Management Component are shared with the platform, allowing third-party business entities to utilize them for various applications. In the context of the project, there are no overlay market to be considered for the exploitation of aggregate flexibility and thus a simulated environment (Grid Flexibility Layer) will be considered.

Vise versa, the VPP Configuration Component processes input data from multiple sources, including flexibility contract information from the Flexibility Configuration and Remuneration Manager, the actual flexibility as made available from the Portfolio Management Component and the flexibility requests from the simulated environment stated above (Grid Flexibility Layer) in order to perform optimization of flexible assets and elicitation for the provision of flexibility. The disaggregated flexibility requests are directed to the Smart DER Optimizer Component to activate demand response

campaigns. These interactions establish a seamless data exchange framework, ensuring that flexibility resources are effectively profiled, allocated, and activated across different system components.

The visual representation of the aforementioned dynamic view is presented below showcasing at a high level the data interfaces among the different components

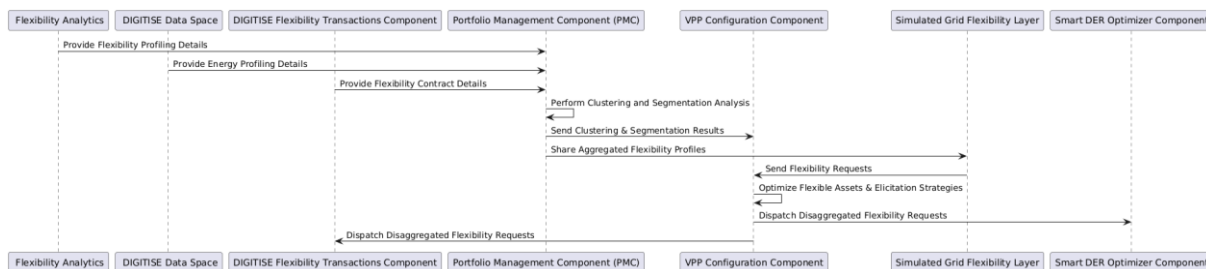


FIGURE 27: VPP CONFIGURATION APPLICATION

In the following, we list the initial list of data to be consumed by the components made available either from the raw assets or the results of the analytics/DT as stated above.

TABLE 30 DATA/AI NEEDS VPP CONFIGURATION APPLICATION

Data Artefact	Description
HVAC/DHW energy consumption data	Energy consumption data from demand side assets (15 min granularity)
EV CPs energy consumption data	Energy consumption data from EV CPs as flexible assets (15 min granularity)
Battery Profiling data	Energy charge/discharge data from batter assets (15 min granularity)
DER Flexibility Profiling	Analyzes Distributed Energy Resources (DERs) such as batteries, EVs to determine their flexibility potential (15 min granularity for the next hours)
Context-Aware Flexibility Profiling	Integrates real-time data, device characteristics, environmental conditions, and occupant behavior to dynamically assess available flexibility of demand side assets (15 min granularity for the next hours)

4.3.3.8 DIGITISE Consumer Application for Personalized Empowerment and Capacity Building

Overview

The DIGITISE Consumer Dashboard is a sophisticated digital platform designed to empower consumers and prosumers with real-time insights, AI-driven analytics, and

automated energy and non-energy management solutions. As a central component of the DIGITISE project, it enhances energy efficiency, promotes sustainability, and encourages active participation in energy markets. By integrating multiple data sources and leveraging artificial intelligence, the platform enables smarter consumption and optimized resource allocation.

A core functionality of the dashboard is its real-time and historical data integration, which consolidates energy usage data from devices, smart meters, and other DERs (EV CPs, local RES etc.). This comprehensive data aggregation allows users to track trends, analyze their energy consumption and generation patterns, and make data-driven decisions to improve efficiency. The platform also features energy forecasting analytics, utilizing the results of the advanced machine learning models to anticipate energy demand, renewable energy production as defined in the analytics layer of the project.

Apart from the statistics over the raw data as presented above, the visualization of insights from the different apps as stated above is considered. To further enhance user engagement, the DIGITISE consumer dashboard offers personalized insights and energy literacy tools provided by the Energy Savings and Self-consumption Optimization application. Users receive tailored recommendations to improve energy efficiency, compare their consumption with similar households, and gain deeper insights into their energy behaviors. These fosters informed decision-making and encouraged more sustainable energy usage.

In addition to energy management, the DIGITISE consumer dashboard includes health and security management functionalities to improve household well-being and safety. By integrating real-time monitoring, the platform provides insights into indoor air quality, humidity levels, and temperature regulation, ensuring a healthier living environment. Users receive alerts on potential health risks, such as poor air quality or excessive consumption impacting thermal comfort. Additionally, the dashboard supports smart security features, including remote monitoring of energy-related anomalies, device malfunctions, and unauthorized energy usage, enhancing home safety. These capabilities not only contribute to energy efficiency but also improve comfort, security, and overall quality of life, making the dashboard a comprehensive solution for smart and sustainable living.

The DIGITISE consumer dashboard also interacts with the Asset Sizing and Investment Optimization Application, a simulation tool that models various energy investment scenarios. This feature enables users to explore the impact of installing solar panels, battery storage, or making behavioral adjustments, allowing them to optimize their investments and long-term savings. Another essential capability of the DIGITISE consumer dashboard is its market and flexibility services integration, which seamlessly connects consumers to demand response programs and energy flexibility marketplace. Through this

feature, users can show participation in demand response program following enrolment in flexibility marketplaces and get insights about monetizing their flexibility.

Overall, the DIGITISE consumer dashboard will serve as the central interface for monitoring and managing all applications and services within the DIGITISE ecosystem. (a) In terms of visualization, the dashboard will provide interactive graphical representations of simulation results, usage statistics, household performance indicators, and scenario insights. This will offer users a comprehensive view of the system's behavior and the impact of various configurations. (b) For the configuration of input parameters, users will be able to define and edit key variables and attributes related to households through user-friendly forms and dynamic input fields. This ensures proper preparation of the system for executing simulations or other DIGITISE functionalities.

Technical specifications

This section outlines the detailed technical specifications of the respective applications, incorporating the requirements identified in D2.1. Additionally, it elaborates on the functionalities to be delivered as part of the application. The key features are listed below:

- **User-Friendly Visualization and Control:** Include interactive dashboards with dynamic graphs, widgets, and real-time alerts to provide users with a clear overview of energy usage, savings opportunities, and performance insights.
- **Real-Time and Historical Data Integration:** Aggregate data from devices, smart meters, and electric vehicles to provide live monitoring and historical trend analysis for energy consumption and generation.
- **AI-Driven Energy Forecasting Analytics:** Provide short-term AI-based forecasts for energy demand, production to enable proactive energy management.
- **Personalized Recommendations and Comparisons:** Deliver personalized insights by comparing historical energy use, similar households' consumption patterns, and forecasting future energy needs. Also, behavioural profiling insights will be made visible through the app.
- **Automated Energy Optimization and Insights:** Provide suggestions about energy-saving actions, as defined by the Energy Savings and Self-consumption Optimization Application and automate adjustments for peak efficiency and cost savings.
- **Personalized non-energy data and tailored output:** Provide personalized user data, tailored recommendations, notification and actions, as defined by the Health and Security Management Application
- **The Asset Sizing and Investment** will provide a comprehensive overview of household consumption profiles and energy data, presenting personalized investment recommendations in RES, storage, and e-mobility, along with financial indicators such as ROI, IRR, and Payback Period, based on real data and simulation scenarios through the Household Digital Twin.

- Flexibility and Demand Response Features: Enable users to get insights to monitor information related to their participation in DR and flexibility programs, but also a portal to the marketplace that allows their active engagement in the flexibility marketplace.

Detailed interactions

After all functional and non-functional requirements of the applications have been defined in D2.1, the interaction of the DIGITISE Dashboard with all applications to be deployed during the project is outlined below. A detailed dynamic view of the DIGITISE Dashboard is provided, showcasing the interactions among the various modules and the associated data exchanges. More specifically:

1. Users will be able to log in to the DIGITISE Consumer Dashboard using their login credentials.
2. Each user, depending on their association with a demonstration premise, will have access to building, device, and sensor information, and will be able to display both real-time and historical data by requesting it from the Data Space
3. As an additional feature, users will be able to interact with specific applications developed as part of the DIGITISE project. These applications include:
 - Energy Savings and Self-consumption Optimization
 - Health & Security Management
 - Behavioral Profiling & Insights
 - Asset Sizing and Investment Optimization
 - Flexibility Marketplace
4. By selecting one of the aforementioned applications, users will be able to view predefined KPIs, visualize them, and receive tailored suggestions or proposals generated by each application, in alignment with its purpose, Figure X+1, Figure X+2 and Figure X+3.

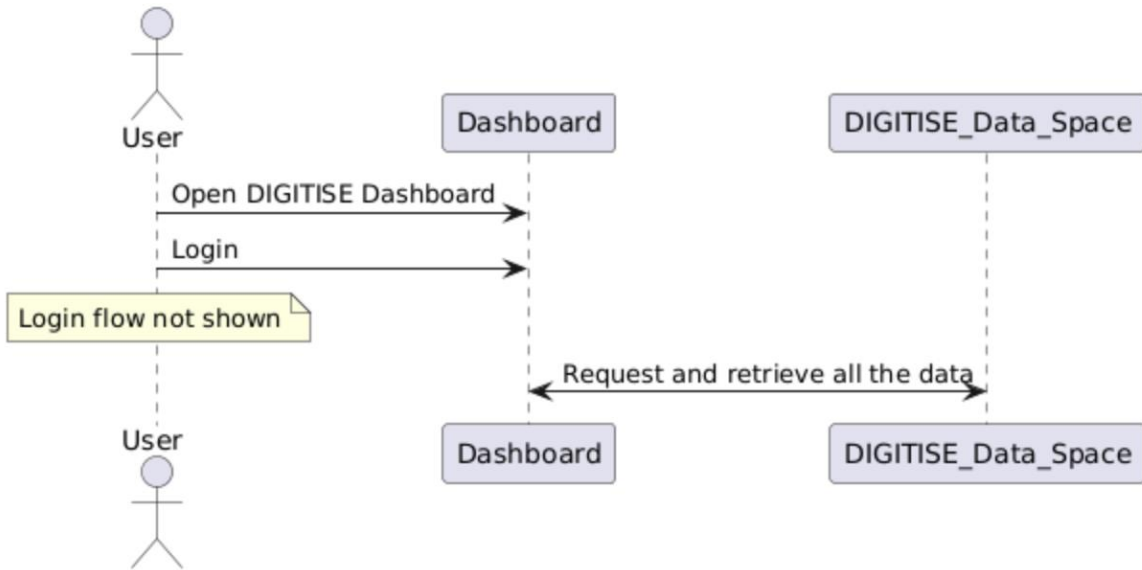


FIGURE 28: DIGITISE CONSUMER DASHBOARD –I

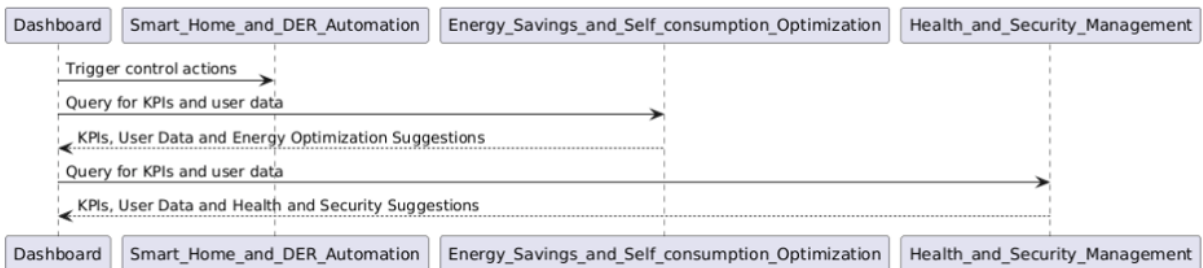


FIGURE 29: DIGITISE CONSUMER DASHBOARD –II

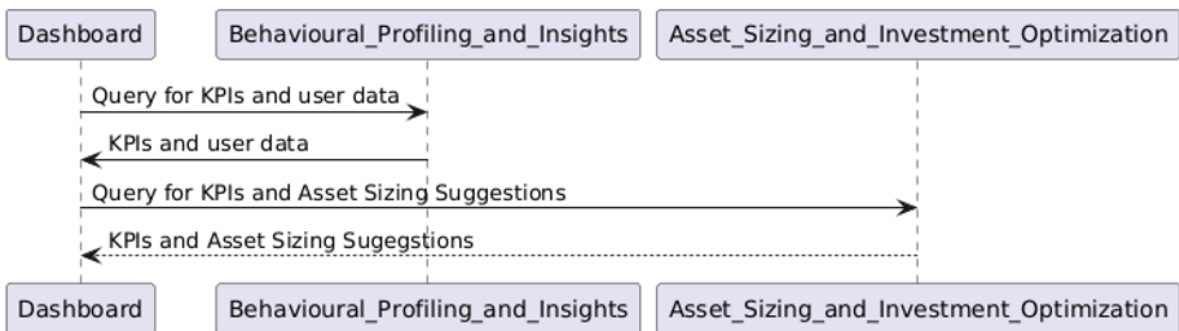


FIGURE 30: DIGITISE CONSUMER DASHBOARD–III



FIGURE 31: DIGITISE CONSUMER DASHBOARD –IV

The list of data that will be retrieved by the DIGITISE Consumer Dashboard is summarized in the table below:

TABLE 31 DATA/AI NEEDS DIGITISE CONSUMER DASHBOARD

No	DIGITISE Application	Input	Output
1	Smart Home and DER Automation	N/A	Trigger Control Actions
2	Energy Savings and Self-consumption Optimization	a) Consumer/prosumer identification b) Data range	a) Energy profiles b) Energy optimization recommendations c) Real-time and historic KPIs
2	Health and Security Management	a) Consumer/prosumer identification b) Data range	a) Real-time data for various sensor data b) Message/Alert to user about settings alteration c) Visualization of status and scores
3	Behavioral Profiling and Insights	a) Consumer/prosumer identification b) Data range	a) Message/Alert to user about user preferences completion
4	Asset Sizing and Investment Optimization	a) Consumer/prosumer identification b) Data range c) user configuration settings	a) technical evaluation of the different scenarios as configured b) economic evaluation of the

			different scenarios as configured
5	Flexibility Marketplace	a) Consumer/prosumer identification b) Date range	A) Flexibility events related to the given consumer, b) Flexibility request/provision info and financial details for the given time period

4.4 DIGITISE Development and Deployment roadmap

After defining the core modules that make up the DIGITISE system, along with their associated functionalities, each partner responsible for developing a specific module also establishes the framework for its components. This framework takes into account interoperability considerations related to communication and interaction with other DIGITISE components.

The following table presents a list of pre-existing technologies (as mentioned in the DoA), highlighting the available software developments that will also be considered in the project.

TABLE 32 PRE-EXISTING TECHNOLOGIES FOR DIGITISE

DIGITISE Software Module	Existing Software Module	Responsible Partner	Description
DIGITISE Data Space Components for Data Interoperability and Governance, Data Security and Sovereignty, Data Sharing Access Policy, Privacy and Data Sharing	SYNERGY Data Collection & Governance Service Bundles	SUITE5, UBITECH, CIRCE	The big data platform developed in the H2020-SYNERGY project will be extended to form the DIGITISE data space environment. More specifically, the Data Collection and Governance service bundles will be further extended and enhanced with additional data ingestion, mapping and cleaning functionalities. Furthermore, advanced access policy control mechanisms will be further enhanced and formalized to address the sovereignty needs of consumers. Moreover, advanced data policy sharing and marketplace management processes will set the Data Exploration and Marketplace component.

<p>DIGITISE Analytics</p>	<p>AI</p> <p>SYNERGY & BEYOND Baseline Personal and Energy analytics</p>	<p>SUITE5, UBITECH, CIRCE</p>	<p>The DIGITISE Baseline Analytics will complement the developments performed in H2020-SYNERGY and H2020-BEYOND, to deliver a wider range of baseline analytics on the way to facilitate the extraction of insights and knowledge that will further enable the realization of added value digital services. The pool of baseline energy and flexibility analytics will be enhanced with fine grained models to incorporate the high granularity data streams made available in DIGITISE project. In addition, a set of personal baseline analytics will be made available in the project.</p>
<p>DIGITISE Business Apps</p>	<p>Several early versions of the apps</p>	<p>SUITE5, UBITECH, CIRCE, UCD, UNP, APPART</p>	<p>As stated also in the DoA "The services and applications to be delivered by DIGITISE will step on similar developments performed. Even though baseline implementations are already available, the existing solutions will require significant elaboration in order to address the DIGITISE user experience and deliver real value to the variety of end-users".</p>

Then, and taking into account the detailed specifications as provided above, the development details are reported. We must point out that this is the current status and updates will apply once we progress with the development activities.

TABLE 33 DEVELOPMENT ROADMAP FOR DIGITISE

Software Component	Development Plan
<p>Data Collection Component</p> <p>Data Harmonization Component</p> <p>Data Curation Component</p> <p>Data Anonymizer Component</p> <p>Access Policies Management Component</p> <p>Data Marketplace Component</p> <p>Data Exploration Component</p> <p>Data Retrieval Component</p> <p>Operations Monitor</p>	<p>This is a series of services to be considered at the level of the data space implementation. The overall development of the functionality will be performed based on Node.js as the backend runtime, allowing to build scalable and high-performance server-side applications using JavaScript. With its non-blocking, event-driven architecture, it is well-suited for real-time applications, APIs, and microservices. On the frontend, Vue.js provides a progressive JavaScript framework for building interactive and dynamic user interfaces. For styling, TailwindCSS offers a utility-first</p>

	<p>approach to CSS, enabling rapid UI development with minimal custom styling.</p> <p>For some analytics functionalities to be incorporated in some components (i.e. data curation), both Pandas and NumPy are considered as potential candidates in efficiently handling and processing datasets.</p> <p>Towards supporting the establishment of a DLT enabled data marketplace, Ethereum, serves as a decentralized blockchain platform that enables smart contracts and decentralized applications (dApps). It provides a secure and trustless environment where different entities can deploy self-executing contracts without intermediaries. Complementing Ethereum, OpenZeppelin Contracts, licensed under MIT, offers a robust library of reusable, secure, and audited smart contract components.</p> <p>Together, Ethereum and OpenZeppelin empower DIGITISE to build decentralized, secure, and scalable blockchain marketplace to support transition to data economy.</p> <p>Together, these technologies provide a well-integrated, modern stack that enables efficient, scalable, and visually appealing web application development.</p>
<p>Execution Master</p>	<p>This is a series of services to be considered at the level of the data space processes execution. The overall development of the functionality will be performed based on Node.js as the backend runtime, allowing to build scalable and high-performance server-side applications using JavaScript. Moreover, specific libraries to promote the integration of real-time data streaming using Apache Kafka and MQTT protocols, are pivotal for handling the large-scale, low-latency requirements of energy data systems within the DIGITISE framework.</p>
<p>Data Storage Component</p>	<p>Towards the delivery of the data storage layer, different technologies are considered to support the different processes.</p> <p>PostgreSQL is a powerful, open-source relational database to store the configuration details of the different processes to be executed in the data space environment. When it comes to object storage, MinIO stands out as an optimized, cloud-native solution offering. It is widely used to store large-scale unstructured data. Moreover, MongoDB offers a</p>

	<p>NoSQL document-oriented approach to allow for the efficient handling of dynamic and evolving data structures. The aforementioned large volume databases are complemented by an Elasticsearch instance serving as a log and event data storage for further facilitating efficient search and data retrieval.</p> <p>Security and secrets management are handled effectively by Vault, a system designed to store and control access to sensitive credentials such as API keys, passwords, and encryption keys. It is commonly used in enterprise environments to ensure secure authentication, encryption key lifecycle management, and role-based access control for cloud-native infrastructure.</p> <p>SpiceDB provides fine-grained authorization capabilities, enabling them to manage complex access control policies at scale.</p> <p>Each of these databases plays a crucial role in DIGITISE architecture, catering to specific use cases that require relational integrity, real-time speed, flexible data models, secure secret management, scalable storage, and advanced search and analytics capabilities.</p>
Resource Management	<p>Towards the deployment of the data space environment, this will be based on Kubernetes, licensed under Apache License 2.0, as a powerful open-source container orchestration platform that automates the deployment, scaling, and management of containerized applications. Kubernetes is widely used for microservices architectures, cloud-native applications, and DevOps workflows, offering auto-scaling, service discovery, and rolling updates to streamline application lifecycle management.</p> <p>Complementing Kubernetes, KEDA (Kubernetes Event-Driven Autoscaling), also under Apache License 2.0, extends Kubernetes' scaling capabilities by allowing applications to scale dynamically based on real-time workloads and external event sources. KEDA integrates seamlessly with Kubernetes' Horizontal Pod Autoscaler (HPA) and supports scaling based on message queues, event streams, cloud service metrics, and custom triggers. Together, Kubernetes and KEDA provide a scalable and flexible infrastructure for the DIGITISE data space, enabling</p>

	efficient workload management and seamless scaling based on demand.
Identity Provider	Identity management in DIGITISE will be based on Keycloak to provide a centralized authentication and authorization solution for applications and services. As an open-source identity and access management (IAM) system, Keycloak supports Single Sign-On (SSO), to enable users to log in once and access multiple applications without needing to reauthenticate. Keycloak integrates seamlessly with OAuth 2.0, OpenID Connect (OIDC), and SAML 2.0, allowing secure authentication across various platforms. For authorization, Keycloak offers Role-Based Access Control (RBAC) and Attribute-Based Access Control (ABAC), ensuring granular security policies based on user roles, attributes, and context.
AI Configuration Component	The AI Configuration Component is responsible for managing the setup and configuration of AI models, ensuring that they are properly defined, tracked, and ready for execution. To achieve this, tools such as MLflow or TensorBoard can be used to handle model tracking, version control, and experiment management. Additionally, KubeFlow could be leveraged to automate machine learning workflows within a Kubernetes environment, ensuring that configurations are applied consistently across distributed systems. For real-time configuration access and management, technologies such as Vue.js can be employed to build dynamic user interfaces, allowing users to interact with the AI configurations. We have to point out that different development implementations will be considered as this is a conceptual component with different partners contributing to the delivery of the configuration environment of the analytics workflows.
AI Execution Component	Complementing the AI Configuration Component, the AI Execution Component is responsible for running the AI models and processing the data to produce actionable insights. This component needs to support real-time data streaming, efficient execution, and high-throughput processing. Different AI Frameworks (i.e. TensorFlow, PyTorch) will form the core of the execution environment, enabling the deployment of machine learning models for

	both training and inference. For distributed model execution and parallel processing, Apache Spark can be integrated to scale model training across multiple nodes, ensuring that the system can handle large volumes of data while maintaining performance.
AI Models Storage Component	Secure and scalable storage solutions like PostgreSQL or Minio are essential for storing configurations and model metadata. We must point out that the storage layer for the AI models handling will follow the principles of the Data Storage layer as presented above.
DIGITISE Household Level Digital Twin (UBITECH)	For the Simulation Engine, the Arras Energy simulation tool, known in the past as GridLabD, will be the framework with which the different household models will be defined and with which the execution of the requested scenarios will be performed. For configuring the needed input for the simulation tool and managing the different processes before and after the execution of a simulation, FastAPI framework will be employed as part of the Configuration Engine. The framework will be accompanied by one or more databases, i.e. PostgresDB as a relational one for hosting static information like metadata of the executed simulations, and a noSQL or object storage, like MongoDB (GridFS) and minIO will be considered for storing execution results. For supporting background (except from the features offered by FastAPI) and scheduled tasks, Celery accompanied by a Redis broker will be employed. Leveraging the capabilities of the FastAPI framework, an API will be built for the API Connector, through which the needed interactions with the DIGITISE applications and the Data Space will be achieved.
Energy Savings and Self-consumption Optimization Application (CIRCE)	The Energy Savings and Self-consumption Optimization Application focuses on optimizing the utilization of self-generated energy in prosumer households. It integrates the short-term forecast for energy consumption and production profiles from the AI Execution Component with storage management and available flexibility to enable continuous optimization. Real-time data from metering systems, IoT devices, and electric vehicles (EVs) support dynamic decision-making to prioritize self-consumption, thus reducing reliance on external energy sources and

	<p>minimizing operational costs. As key outputs, this application will provide consumption profiles (from the grid, PV, batteries, and EV), battery and EV state of charge, and recommendations for control strategies for flexible devices. To support its optimization logic and control execution, the application employs several stacks, including: (a) Python, with libraries such as PuLP, Pyomo, Pandas, and NumPy, for modeling and solving linear and mixed-integer optimization problems related to energy dispatch, storage scheduling, and flexible load shifting; (b) Flask or FastAPI for building lightweight REST APIs to expose optimization results and receive input parameters (e.g., forecast data, device availability); (c) Redis and Celery for managing asynchronous tasks and periodic execution of optimization routines.</p>
<p>Smart Home and DER Automated Control</p>	<p>To achieve its desired functionalities, the Smart Home and DER Automated Control application incorporates advanced technologies, such as: (a) Nest (NodeJS) for the back-end, which is a robust framework for creating efficient, dependable, and scalable server-side applications; (b) OpenAPI layer for handling the communication with the physical assets (and the dedicated gateways) towards supporting the execution of control actions (c) PostgreSQL for data storage. PostgreSQL is employed as the relational database for operational data (e.g., the mapping of the gateways to the different users), supporting that way the execution of the control actions to the physical assets.</p>
<p>Health and Security Application (UCD)</p>	<p>The Health and Security Application is a custom application explicitly implemented for the scope of DIGITISE. It is a microservice-based application, composed of four microservices. Each service will be implemented using Python, Python-based APIs, and will be containerized using Docker containers. In more detail, we will use PySpark for data aggregation and pre-processing, FastAPI for the interaction between the AI automation engine and the Smart DER Controller.</p>
<p>Asset Sizing and Investment Optimization Application (UNP)</p>	<p>The Asset Sizing App is a server-side application designed to provide investment recommendations for household optimization. It utilizes NestJS, a Node.js framework, for</p>

	<p>efficient API interactions and seamless integration with external systems. The app communicates with the Dashboard to deliver insights, results and recommendations, connects with the Household Digital Twin to retrieve real-time household data, and works with the Optimizer Component to evaluate potential new assets and its impact on the energy consumptions and efficiency of the household. Local Data is stored in MongoDB, a flexible NoSQL database that enables dynamic and scalable management of investment-related information. This architecture ensures efficient processing and informed decision-making for users seeking to optimize their household assets.</p>
<p>Behavioural Profiling and Insights Application (UCD)</p>	<p>The Behavioural Profiling Application is a custom application explicitly implemented for the scope of DIGITISE. It is a microservice-based application, composed of three microservices. Each service will be implemented using Python, Python-based APIs, and will be containerized using Docker containers. In more detail, we will use PySpark for data aggregation and pre-processing, Python-based machine learning models for behavioural contextualization and behavioural profiling. We will use PostGRES SQL to store our intermediate processed data and interservice communication metadata. The resulting data will be exposed via Rest API.</p>
<p>DIGITISE Flexibility Marketplace Application (UBITECH)</p>	<p>The Marketplace UI, as the main interface for users' engagement in the flexibility markets, will be developed with the latest version of the Angular framework and will be enhanced with the usage of the web3.js library for integrating smoothly with web3 browser-based wallets and blockchain transactions. Different visualizations of the flexibility contract activation details will be rendered using the d3.js and ApexCharts.js libraries. The Flexibility Configuration and Remuneration Manager, with the role of the main back-end interface of the Flexibility Marketplace, will be based on Django web framework which will be supported by the django-rest-framework.py and Python's requests.py library for communication with external components and REST API-like functionalities. The web3.py library will be also exploited to interact with the blockchain</p>

	<p>and the deployed smart contracts. A PostgresDB will be the relational database to hold data during the negotiation and the establishment of contracts as well as user-specific information. In the core of the DLT Smart Contract Engine, a private Proof-of-Authority network will be configured for testing purposes in the scope of the DIGITISE project, using go-ethereum (geth), a Go implementation of Ethereum. For the development, testing and deployment of smart contracts' processes of the DLT Smart Contract Engine, the Hardhat framework will be utilized. Solidity, supported by Ethereum, will be the language with which the different smart contracts and their functions will be expressed.</p>
<p>Dynamic Portfolio Management and Virtual Power Plant</p>	<p>To achieve its desired functionalities, the Dynamic Portfolio Management and Virtual Power Plant Configuration application incorporates advanced technologies, such as: (a) Nest (NodeJS) for the back-end, which is a robust framework for creating efficient, dependable, and scalable server-side applications; moreover, state-of-the-art optimization libraries will be utilized to facilitate VPP formation, (b) VueJS on the front-end, enabling custom interface creation and the visualization of VPP formation outcomes, and (c) PostgreSQL and Elasticsearch for data storage. PostgreSQL is employed as the relational database for operational data (e.g., energy and flexibility attributes, strategy parameters, and cluster configurations), while Elasticsearch functions as the indexing engine, supporting efficient data aggregation and segmentation.</p>
<p>DIGITISE Consumer Application for Personalized Empowerment (APPART)</p>	<p>Backend</p> <p>The backend is a custom application explicitly implemented for the scope of DIGITISE. It is a JAVA based application utilizing the Spring Boot framework, and it is containerized for easier deployment and management via a Kubernetes cluster.</p> <ul style="list-style-type: none"> • Spring boot: Spring boot is an open-source JAVA-based framework that allows developers to create standalone applications called micro-services effectively and quickly. It provides configuration on different levels, such as the Java Beans, and offers out-of-the-box integrations e.g. database integrations. It has an integrated dedicated

application server (Jetty by default), allowing easy containerization through Docker. Accompanied by the large Spring community, it is suitable for producing real-time, production-ready applications. Being part of the Spring framework, it has many components embedded by default, allowing more to be added on demand. For the scope of this project, the following components are utilized:

- Spring Security: This is the de facto framework for securing Spring-based applications. It provides customizable authentication and authorization functionalities and protection from attacks like cross-site request forgery and clickjacking.
- Spring Web: Spring framework for quickly creating and customizing REST APIs.
- Docker: The spring boot application will be containerized into docker containers for easier deployment and management. The container will be based on the eclipse-temurin:17-jre-alpine docker image and will be accompanied by Java version 17 to support its running.
- Swagger: Swagger describes and triggers the REST APIs in a human (or machine) readable manner through an easy-to-use graphical interface. Within the project's scope, it is used for development purposes to facilitate the integration of the use case applications with the data collector REST APIs.

The visualization portal utilizes the internal REST API to visualize the KPIs and data from devices and sensors of the demonstration partners. The execution is displayed through intuitive dashboards. Data is available in both graphical and tabular formats. Additional functionalities are provided for privileged users, such as user management and access control. The portal will be developed using JavaScript/TypeScript, leveraging the Angular framework. UI components from PrimeNG (an open-source theme),

	along with some custom UI components, will be used to meet the platform's visualization requirements. The portal will be containerized using Docker, and its container will be orchestrated within a Kubernetes cluster.
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Note: The various components that form the overall DIGITISE platform involve a range of diverse development processes and frameworks used by the project partners. To ensure these components work seamlessly together, a web services-based integration approach has been adopted. Each partner will develop their individual components by utilizing existing or new development modules, with integration ensured through a shared data model and an agreement on system interfaces. The detailed interface specifications will be included as part of the development and integration activities in WP3-WP6.

Along with the development view as presented above, the details about the deployment of the different solutions are provided below. The deployment view is primarily concerned with physical implementation, covering components, hardware, network connections, and other physical constraints. The analysis is divided into two main parts: (a) the deployment of IoT solutions responsible for interfacing with physical systems and gathering data, and (b) the deployment of the DIGITISE ICT software solution as a whole.

The deployment of IoT gateways (though not part of the core deployment view of the project as the delivery of the IoT gateways is out of the core architecture) will vary depending on the demo site. Detailed deployment information is provided in D6.1, but a brief overview is provided here, emphasizing network requirements and runtime needs, which are further analyzed per demo site:

- At the MYT demo site (acting as the Living lab of the project), the installation will involve one gateway device per building, where the relevant software will be installed to ensure connectivity with the different devices (IoT equipment to support both monitoring and control) and the DIGITISE data space. The details about the software installation and the network configuration details will be reported in D6.1. Additional connectors to the PV and battery systems in place will be configured to support connectivity with the DIGITISE data space,
- For the Miwenergía site, the deployment will involve installing IoT system adapters on Raspberry Pi devices, ensuring network configurations following D6.1 guidelines. Since the sensors and actuators via the gateway devices are already connected to a platform managed by Miwenergía, the focus will be on developing a software module to transfer data from this platform to the DIGITISE data space. This platform also ensures controllability with smart assets in place.

- For the ZEZ site, the installation will involve one gateway device per building, where the relevant software will be installed to ensure connectivity with the different devices (IoT equipment to support both monitoring and control) and the DIGITISE data space. The details about the software installation and the network configuration details will be reported on D6.1. Additional connectors to the PV and battery systems in place will be configured to support connectivity with the DIGITISE data space,
- In the ARDEN pilot, the installation will involve one gateway device per building, where the relevant software will be installed to ensure connectivity with the different devices (IoT equipment to support both monitoring and control) and the DIGITISE data space. The details about the software installation and the network configuration details will be reported on D6.1. Additional connectors to the PV and battery/EV systems in place will be configured to support connectivity with the DIGITISE data space,

The DIGITISE ICT software platform will be developed using a microservices-based approach, where different software bundles will be deployed as microservices and interconnected over the internet. This section outlines the initial hardware requirements for the various software modules:

- DIGITISE Data Space: Requires an 8th generation Intel i7 (quad-core equivalent VM), 8 GB RAM, 512 GB SSD, and Ubuntu Server 20.04 LTS or Debian 11.
- DIGITISE Data Repository: Same hardware requirements as the Data Broker.
- AI-based Analytics Engine: Requires an Intel i7 (32 GB RAM, 512 GB SSD) with Ubuntu Server 20.04 LTS.
- DIGITISE Household Level Digital Twin (UBITECH): Virtual processor – vendor: qemu, model: x86-64-v2-AES, 16 GB RAM, 500 GB SSD, Ubuntu 24.04.2 (Noble Numbat)
- Energy Savings and Self-consumption Optimization Application: Requires an 8th generation Intel i7 (quad-core equivalent VM), 8 GB RAM, 512 GB SSD, and Ubuntu Server 20.04 LTS or Debian 11.
- Smart Home and DER Automated Control: Requires an 8th generation Intel i7 (quad-core equivalent VM), 8 GB RAM, 512 GB SSD, and Ubuntu Server 20.04 LTS or Debian 11.
- Health and Security Application (UCD): Requires an Intel® Core™ 14th Gen i7 14700KF (20-Core, 61MB Cache, 2.5GHz to 5.6GHz Turbo Boost Max 3.0), with 64 GB: 2 x 32 GB, DDR5, 5200 MT/s memory and 2 TB, M.2, PCIe NVMe, SSD storage
- Asset Sizing and Investment Optimization Application (UNP): Intel Core i7 (7th Gen), 32GB RAM, 50GB SSD Storage, GeForce RTX 3070 8GB RAM
- Behavioural Profiling and Insights Application (UCD): Requires an Intel® Core™ 14th Gen i7 14700KF (20-Core, 61MB Cache, 2.5GHz to 5.6GHz Turbo Boost Max 3.0),

with 64 GB: 2 x 32 GB, DDR5, 5200 MT/s memory and 2 TB, M.2, PCIe NVMe, SSD storage

- DIGITISE Flexibility Marketplace Application (UBITECH): Virtual processor – vendor: qemu, model: x86-64-v2-AES, 8 GB RAM, 500 GB SSD, Ubuntu 24.04.2 (Noble Numbat)
- Dynamic Portfolio Management and Virtual Power Plant (VPP): Requires an 8th generation Intel i7 (quad-core equivalent VM), 8 GB RAM, 512 GB SSD, and Ubuntu Server 20.04 LTS or Debian 11.
- DIGITISE Consumer Application for Personalized Empowerment: Requires an 8th generation Intel i7 (quad-core equivalent VM), 8 GB RAM, 512 GB SSD, and Ubuntu Server 20.04 LTS or Debian 11.

This microservices approach allows for both distributed and centralized deployments based on the demo partners' needs. A more detailed deployment plan will be included in future work tasks (in WP3) as part of integration, testing, and refinement efforts.

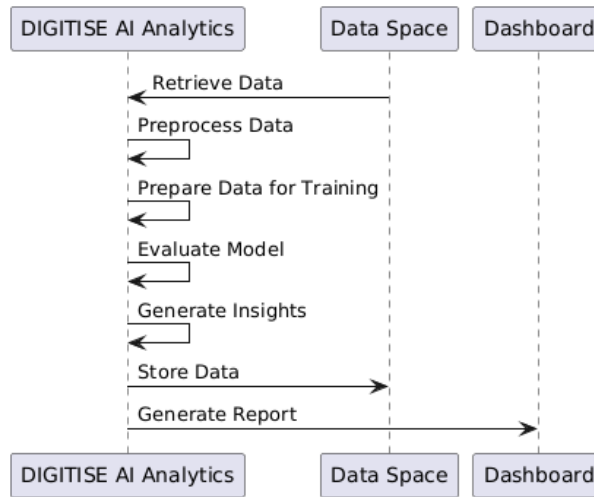
4.5 DIGITISE Dynamic View definition

In this section, the different business-oriented use cases as defined in D2.1 (and provided in Annex I) are further elaborated to showcase the connection with the different systems to be delivered in the project, driving that way the development and demonstration activities of the project. This is a high-level view of the overall DIGITISE solution as part of the architecture methodology (and thus complements the detailed use case sequence diagrams as provided in previous section), and the overall presentation covers a short overview of the workflow and the sequence diagram presentation.

UC -05: Tailored AI-driven insights and analytics that provide individuals with personalized insights

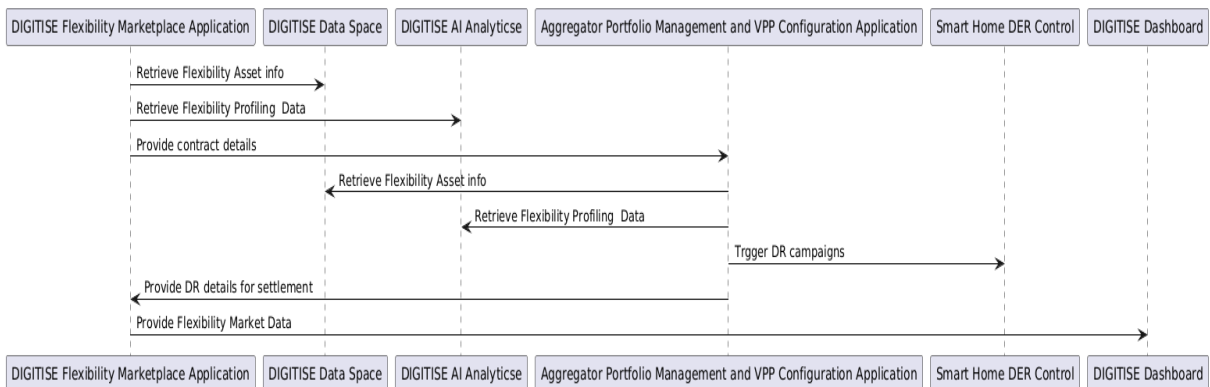
UC -06: Advanced AI-powered tools and models designed to analyze energy-related aspects

This workflow illustrates the DIGITISE AI Analytics module, which retrieves data from the Data Space, processes and analyzes it to generate insights, stores the results, and delivers insights to the DIGITISE Dashboard for user visualization.



UC -07: Aggregator Portfolio Management for enhanced flexibility provision
 UC -08: Flexibility Marketplace operation for enhancing prosumers enrolment in energy markets

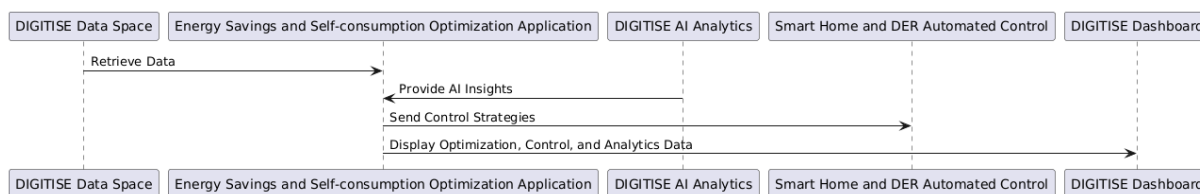
This workflow illustrates the DIGITISE Flexibility Marketplace Application, which coordinates with the Data Space, AI Analytics, and Aggregator tools to retrieve flexibility asset and profiling data, manage contract and market information, and trigger Demand Response (DR) campaigns. The outcomes are communicated to smart home control systems for direct control and the results from participation in the Flexibility Marketplace Application visualized via the DIGITISE Dashboard.



UC -09: Innovative approaches and tools aimed at reducing energy consumption
 UC -10: Optimized Self-Consumption for Enhancing Energy Efficiency

This workflow illustrates the interaction between the Energy Savings and Self-consumption Optimization Application and other DIGITISE components. It retrieves data

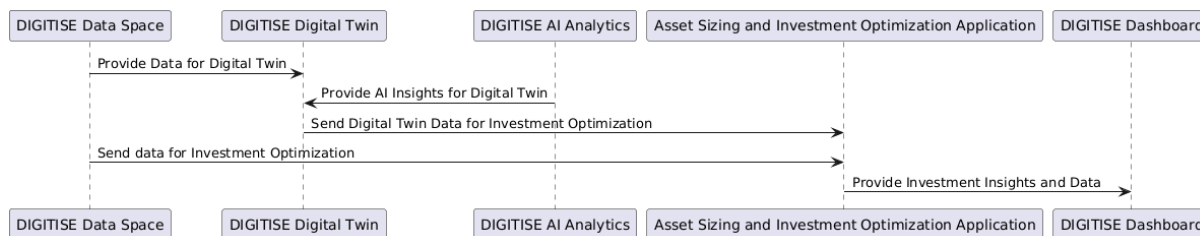
from the Data Space, leverages AI Analytics to generate insights, sends optimized control strategies to the Smart Home and DER Automated Control system, and delivers optimization and analytics outputs to the DIGITISE Dashboard for user visualization.



UC -11: Enhanced Energy Management through Household Digital Twin

UC - 12: Tailored solutions designed to accurately assess and recommend optimal asset size for consumers

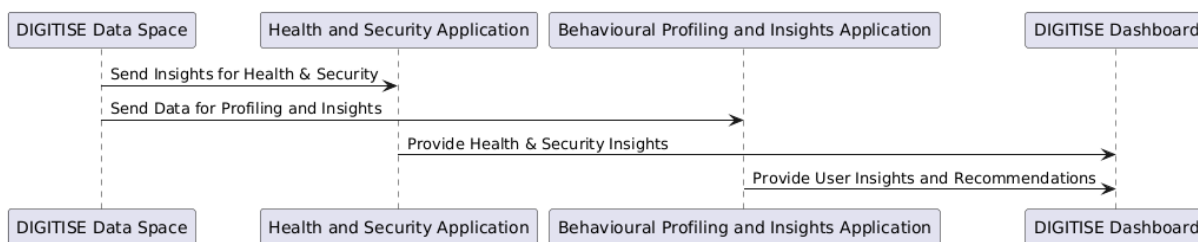
This workflow illustrates the interaction between the Asset Sizing and Investment Optimization Application and other DIGITISE components. It retrieves data from the Data Space, incorporates AI-generated insights and the results from the Digital Twin, sends digital twin and investment optimization data to the Asset Sizing and Investment Optimization Application, and delivers investment insights and data to the DIGITISE Dashboard for user visualization



UC -13: Integrated Health and Security Monitoring Solution

UC -14: Providing actionable insights for personalized experiences, targeted interventions, and improved user engagement

This workflow illustrates the interaction between the Behavioral Profiling and Insights Application and Health and Security Application with other DIGITISE components. Both apps retrieve behavioral and contextual data from the Data Space, leverage analytics to generate personalized insights and recommendations, send relevant health and security insights and deliver user-centric analytics and recommendations to the DIGITISE Dashboard for visualization and engagement.



All in all, the dynamic view of the DIGITISE solution brings together all other perspectives by showcasing real-world use cases and user interactions with the system. By utilizing use cases, sequence diagrams, and narrative descriptions, it illustrates how the system operates in different contexts, effectively connecting abstract design concepts towards the implementation of the DIGITISE solution as a practical implementation.

5 Summary and Conclusions

This deliverable, D2.2 - DIGITISE Evaluation Protocol, Novel Market Models and Architecture Design, lays the groundwork for the robust implementation, performance assessment, and future scalability of the DIGITISE platform. It brings together three core pillars: performance evaluation, market model assessment, and system architecture design. First, in section 2 it introduces a comprehensive measurement and verification framework, built around a wide range of Key Performance Indicators (KPIs). These KPIs, categorized under energy, social, business/economic, technical, and environmental dimensions, reflect the multifaceted impact of the platform. A total number of 40 KPIs defined to set the demonstration and evaluation framework of the project. They are mapped to individual use cases to ensure traceability and meaningful evaluation, supported by standards-based methodologies that are considered to support the KPIs calculation.

Second, the deliverable provides a detailed analysis of current and emerging energy and flexibility market models across Europe. It highlights operational structures, integration efforts into balancing platforms (FCR Cooperation, PICASSO, MARI, TERRE), and the uneven development of Local Flexibility Markets (LFMs). It identifies regulatory and technical gaps while setting the stage for co-created, demo-driven flexibility product definitions relevant to the DIGITISE vision.

Third, it presents the DIGITISE architecture design, featuring a modular, interoperable, and privacy-aware structure. This architecture integrates AI-powered analytics, energy and non-energy applications, and Data Space components to set the functional details of the DIGITISE solution. It also includes the development and deployment roadmap aligned with

project needs and milestones. Moreover, the dynamic view of the system is provided linking the different use cases of the project with the architecture components.

In conclusion, this deliverable establishes a coherent framework that supports the effective deployment and impact evaluation of the DIGITISE platform. It ensures that the technical, market, and architectural elements are fully aligned with the project's objectives and paves the way for the development and demonstration activities in WP3–WP6.

Note: While this deliverable provides a concrete and detailed version of the documentation, it should be considered as an almost final reference. A final, consolidated version incorporating updates related to Key Performance Indicators (KPIs), flexibility products, and system architecture refinements will be delivered in D2.3. These updates will reflect further developments based on stakeholder feedback, demo site progress, ongoing technical progress, and evolving market insights gathered throughout the project duration.

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7 Annex I– List of Use Cases

We present the list of use cases as reported in D2.1 for reference

<p>UC1: Enhanced Data Governance and Handling Practices</p> <p>This use case enhances data governance and management across the energy value chain. Data providers need flexible, customizable methods to integrate diverse data sources and collect data in various states. During the design phase, they should access a wide range of ingestion and harvesting methods, including batch uploads, third-party APIs, and PubSub streaming. Predefined ingestion and governance templates, along with real-time data harvesting via open-standard connectors, streamline the process. Additionally, data curation and characterization techniques further improve data governance and handling.</p>
<p>UC2: Seamless Semantic Data Mapping and Harmonization</p> <p>This use case aims to seamlessly map and harmonize diverse energy data sources into a Common Information Model (CIM) for interoperability, consistency, and improved usability across systems and stakeholders. A key step is defining the DIGITISE information model, which integrates various energy data models, schemas, and ontologies to enhance semantic interoperability.</p>
<p>UC3: Peer-to-peer data assets sharing and trading through a smart data contract management environment</p> <p>This use case enables a decentralized framework for data sharing and trading in the energy sector through smart data contracts. It provides a secure, transparent, and automated environment for energy producers, consumers, and third-party providers to manage and exchange DIGITISE-related data. Smart contracts regulate access and transactions based on predefined conditions, enhancing trust, efficiency, and security.</p>
<p>UC4: End-to-end data security safeguarding and privacy preservation</p> <p>This use case ensures end-to-end data security, from collection to processing, preventing unauthorized access and breaches. It integrates privacy preservation mechanisms to protect sensitive information and comply with GDPR and other regulations. Authentication protocols and data anonymization will safeguard data while ensuring accessibility only to authorized entities, supporting a secure digital transformation in the energy sector.</p>
<p>UC5: Tailored AI-driven insights and analytics that provide individuals with personalized insights</p> <p>This use case provides personalized AI-driven insights into energy consumption, empowering consumers to make informed decisions. By analyzing real-time data from smart meters, IoT devices, and non-energy factors like occupancy and ambient conditions, AI models generate tailored reports on energy behavior, comfort preferences, and occupancy patterns. These insights help users optimize energy use, enhance comfort, and receive recommendations for health and security improvements. The results are integrated into relevant digital services and applications for seamless access.</p>

UC6: Advanced AI-powered tools and models designed to analyze energy related aspects

This use case focuses on Energy AI Analytics to help stakeholders manage complex consumption patterns and volatile energy production. AI models will analyze energy data for demand and generation profiling, short-term forecasting, and context-aware flexibility assessments at the consumer and DER levels. By leveraging personalized AI insights, these tools provide accurate baselines for energy exchanges and flexibility transactions. Multiple AI implementations ensure adaptability to diverse data types, timeframes, and market needs. Embedded explainable AI features enhance transparency and trust among consumers, prosumers, and market participants.

UC7: Aggregator Portfolio Management for enhanced flexibility provision

This use case enables aggregators to optimize energy portfolio management and enhance flexibility services for the grid. By pooling small-scale producers, consumers, and prosumers, aggregators support demand response and balancing. The system will enhance forecasting, scheduling of distributed energy resources, and participation in flexibility markets. Improved management capabilities will help aggregators efficiently meet grid demands, ensure system reliability, and maximize the value of flexibility services for grid operators.

UC8: Flexibility Marketplace operation for enhancing prosumers enrolment in energy markets

This use case focuses on the DIGITISE Flexibility Marketplace, enabling prosumers to participate in flexibility transactions with aggregators or local energy communities (LECs). By leveraging flexible assets like energy storage and EVs, prosumers can monetize their flexibility through market engagements. Smart contracts and distributed ledger technologies (DLTs) ensure secure and transparent transaction settlements, automatically verifying flexibility delivery. DIGITISE AI analytics provide precise baselining of demand, generation, and flexibility, ensuring fair and accurate compensation. Tailored user interfaces allow prosumers and aggregators to monitor contract performance, optimizing engagement and maximizing financial and energy independence benefits.

UC9: Innovative approaches and tools aimed at reducing energy consumption

This use case explores how businesses and individuals can use innovative technologies to reduce energy consumption and promote sustainability. It focuses on smart energy management systems, IoT-enabled devices, AI-driven optimization, and renewable energy integration. These solutions enable real-time monitoring, analysis, and optimization of energy use, leading to cost savings, lower carbon footprints, and regulatory compliance. Predictive analytics for energy demand and supply, along with dynamic consumption adjustments, further enhance efficiency and sustainability.

UC10: Optimized Self-Consumption for Enhancing Energy Efficiency

This use case optimizes self-generated energy utilization in prosumer households by leveraging consumption and production profiles, storage, flexibility, and AI-driven energy forecasts. Real-time data from metering systems, IoT devices, and EVs enable continuous optimization to prioritize self-consumption, reducing reliance on external

sources and lowering costs. Automated control strategies and performance assessments ensure energy is used efficiently, promoting cost-effective and sustainable energy management.

UC11: Enhanced Energy Management through Household Digital Twin

This use case focuses on developing a Household Digital Twin, an open-source digital representation of household energy systems for real-time monitoring, optimization, and management of consumption, generation, and storage assets. By integrating real-time data from meters, IoT devices, and energy systems, it enhances consumer energy literacy and enables human-centric decision-making. Key functionalities include (i) real-time asset monitoring, (ii) context-aware control strategies for energy use, and (iii) continuous re-optimization to maximize self-consumption and reduce costs. AI-driven analytics ensure alignment with consumer preferences and business objectives, empowering data-driven energy management.

UC12: Tailored solutions designed to accurately assess and recommend optimal asset size for consumers

This use case empowers consumers to actively participate in the energy transition by exploring future scenarios involving investments in renewable energy, renovations, storage, and EV assets. It also integrates real-time pricing from retail stores to calculate economic ROI and recommends the most cost-effective, energy-efficient solutions, helping consumers make informed investment decisions.

UC13: Integrated Health and Security Monitoring Solution

This use case explores the benefits of smart automation in households, enabling prosumers to enhance health and security through data-driven insights. By analyzing data from both energy and non-energy services, the framework provides personalized predictions and recommendations, empowering prosumers to make informed decisions. Additionally, it offers insights to improve consumer understanding of non-energy aspects in a smart home environment.

UC14: Providing actionable insights for personalized experiences, targeted interventions, and improved user engagement

This use case provides prosumers with personalized recommendations to improve their behavior profiles, energy literacy, and overall living conditions. It leverages automated tools that analyze current prosumer data and suggest actionable improvements. An intuitive application UI presents insights from household smart appliances, making it easy for prosumers to track analytics and optimize their energy usage and lifestyle.

8 Annex II- Architecture Linkage to standard based approaches

As stated in the DoA, the DIGITISE architecture considers relevant reference architectures (aligning with DERA 3.1, IDS RAM v4.2[27]) on deriving the technical specifications of the key components and their functionalities. The two different architecture schemas are depicted

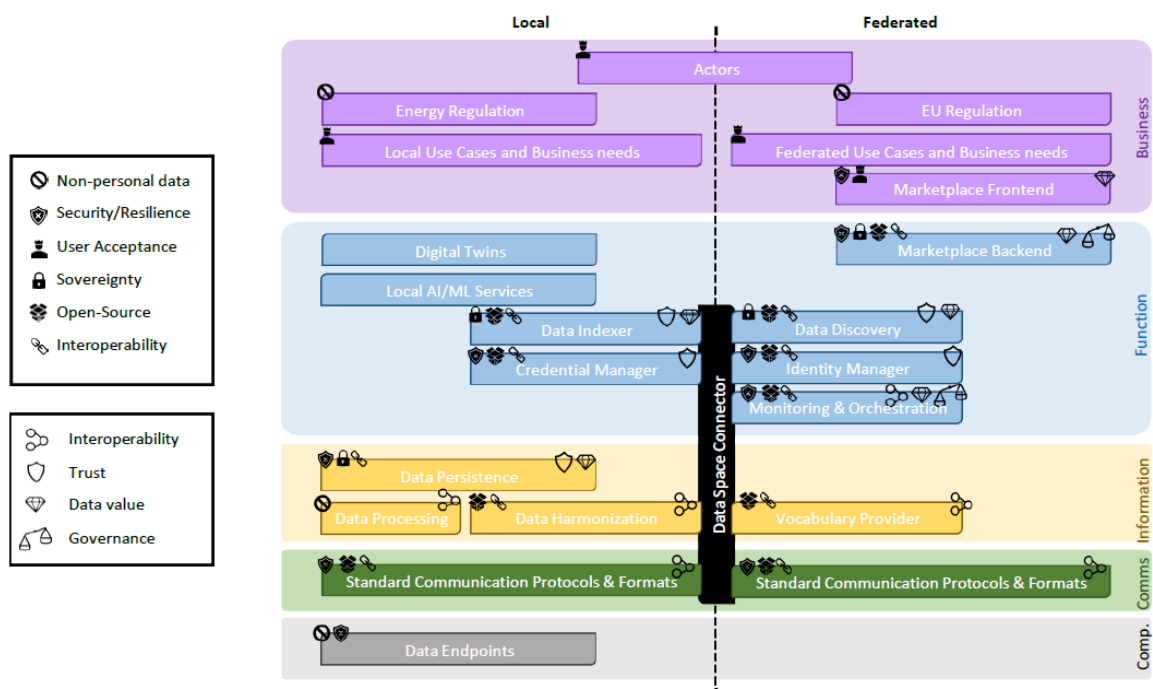


FIGURE 32: DERA 3.1 ARCHITECTURE OVERVIEW

Starting with DERA 3.1, the reference architecture begins to address functionalities related to the data space as defined in the project. At the component and communication layers, further details will be provided in D3.1, including the definition of standard models and formats. At the information layer, the specified services are clearly aligned with the Data Collector, Mapper, and Storage components identified in the DIGITISE project.

At the function layer, an Identity Manager component supports credentials management, while indexing functionalities enable metadata handling. The marketplace functionality, supporting search and retrieval capabilities, is also reflected in the DIGITISE architecture. Importantly, AI/ML services are included as part of the architectural framework, alongside the integration of multiple Digital Twin (DT) models within the DIGITISE DT implementation.

Finally, a suite of business applications will be developed in the project to align with the needs of local use cases and business requirements, taking into account the roles of different actors and the regulatory context.

The IDS Reference Architecture Model (IDS-RAM) v4.2, developed by the International Data Spaces Association (IDSA), provides a comprehensive framework for secure, sovereign, and standardized data exchange in distributed data ecosystems and thus mainly linked with the Data Space functionality of DIGITISE.

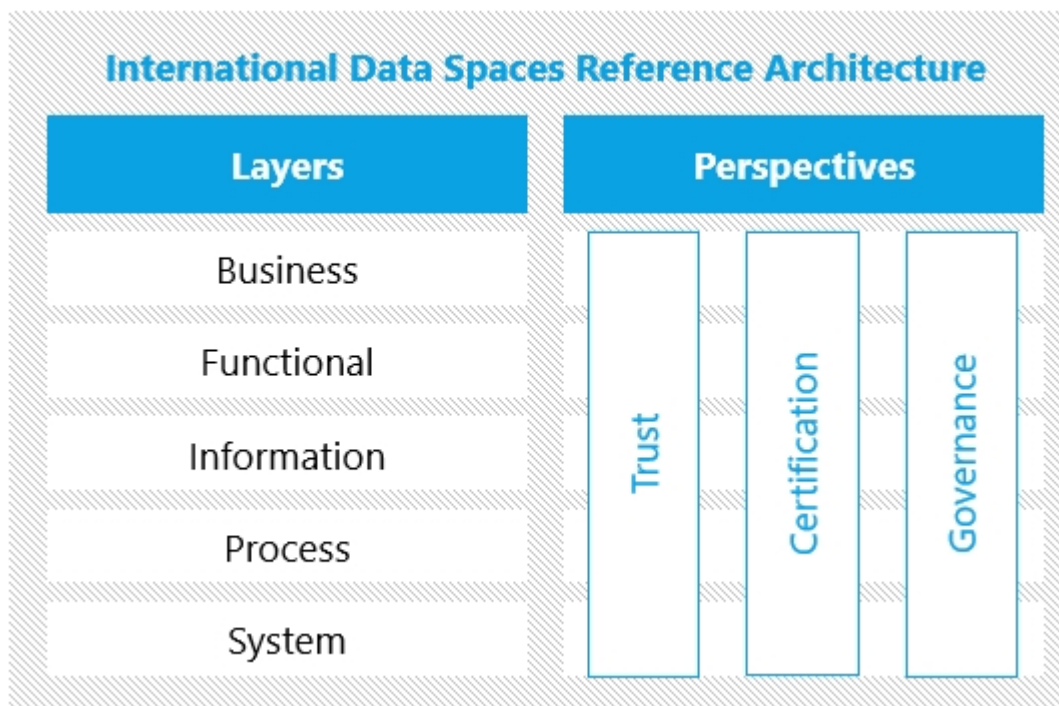


FIGURE 33: IDS RAM v4.2 ARCHITECTURE OVERVIEW

The architecture is structured into six key layers, each defining the functional building blocks required to establish a trusted data space:

At the business layer, IDS-RAM defines the roles and responsibilities of all participants in a data space—such as data providers, data consumers, brokers, and app developers—alongside the rules that govern their interaction as specified also in DIGITISE data space. The functional layer translates these business requirements into a concrete set of services and components. It introduces essential building blocks such as identity management systems, usage control mechanisms (Access policy), metadata brokers (metadata management), and clearing houses (data marketplace, all of which are designed to support trusted data sharing as supported in DIGITISE.

Moving to the information layer, IDS-RAM v4.2 promotes semantic interoperability through common ontologies, metadata standards, and machine-readable policy expressions (e.g., ODRL). This layer will be extensively analyzed in T3.1 of DIGITISE.

The system layer details the technical realization of IDS concepts, focusing particularly on the IDS Connector—the trusted technical interface through which data is exchanged, key feature that is considered in the Data Marketplace of DIGITISE. To operationalize these components, the process layer provides clear definitions of data interaction patterns, such as how participants on board negotiate data usage contracts, initiate secure data exchanges, and validate transactions. More details will come in T3.3 and the definition details of the marketplace functionality.

Finally, the security layer underpins the entire framework with robust mechanisms for confidentiality, integrity, access control, and trust assurance. Within DIGITISE dedicated components are delivered to enhance data sovereign and control, ensuring that every data exchange complies with the highest standards of data privacy and data governance.

All in all, the design principles of DERA 3.0 and IDS-RAM v4.2 have been considered in the definition of the various components of DIGITISE. Special reference is made to the Data Space implementation, although the rest of the system components also comply with the architectural principles outlined above. Further alignment will be supported through the project's active participation in relevant initiatives (e.g., BRIDGE).