STREAMING FLEXIBILITY TO THE POWER SYSTEM

D6.3 - REPORT ON SCALABILITY AND REPLICABILITY

Delivery Date: September 2026

STREAM

STREAMING FLEXIBILITY TO THE POWER SYSTEM

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This project has received funding from the European Union's Horizon Europe research and innovation programme under the grant agreement N° 101075654.

More information available at https://stream-he-project.eu/

Title	Document Version
D6.3 - Report on Scalability and Replicability	1.0

Project Number	Project Acronym	Project Title
Grant agreement N°: 101075654	STREAM	STREAM: Streaming flexibility to the power system

Contractual Delivery Date	Actual Delivery Date	Deliverable Type*-Security**
September 2026	M48	R-PU

*Type: P: Prototype; R: Report; D: Demonstrator; O: Other.

**Security Class: Public - fully open (automatically posted online); Sensitive - limited under the conditions of the Grant Agreement; EU classified - RESTREINT-UE/EU-RESTRICTED, CONFIDENTIEL-UE/EU-CONFIDENTIAL, SECRET-UE/EU-SECRET under Decision 2015/444

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Abstract

This deliverable presents the scalability and replicability analysis of the STREAM ecosystem across the four pilot sites, and the roadmap to ensure that the solutions are replicable and scalable. The results of the analysis show that, although some adaptations would be required, they have high replicability and scalability potential, being the heterogenous local flexibility market regulatory landscape and the lack of standardisation the main barrier that hinders replicability across Member States.

Keywords

Replication, scalability, SRA, flexibility, interoperability, standardisation, flexibility, local flexibility markets, opportunities, barriers, enabling conditions.

Revision	Date	Description	Author (Organisation)
V0.1	20.04.2026	ToC of the document ready	Daniel Pastor Pascual (ETRA)
V0.2	06.05.2026	Introduction and methodology sections	Daniel Pastor Pascual (ETRA)
V0.3	01/09/2026	SRA for STREAM tools prepared. To be reviewed by the relevant partners	Daniel Pastor Pascual (ETRA)
V0.4	10/09/2026	Common opportunities and barriers, and replication roadmap sections completed	Daniel Pastor Pascual (ETRA)
V0.5	11/09/2026	Document reviewed by relevant partners.	Daniel Pastor Pascual (ETRA), Diego García-Casarrubios Gálvez (ETRA), Klemen Kosovinc (KOL), Bernardo DiChiara (OPT), Janez Gregor Golja (UL), Jan Jeriha (UL), Denis Sodin (COMS), Javier Zelaya (OMIE), Peter Korencan (IND), Darja Skrt Georgiev (CYG)
V0.6	11/09/2026	Adjustments integrated and document homogenized. Deliverable ready for peer review.	Daniel Pastor Pascual (ETRA)
V0.7	25/09/2026	Document reviewed by IRI and VTT as peer reviewers.	Jan Jeriha (IRI), Matti Aro (VTT)
V1.0	28/09/2026	Feedback coming from peer reviewed addressed. Document ready for submission.	Daniel Pastor Pascual (ETRA), Diego García-Casarrubios Gálvez (ETRA)

EXECUTIVE SUMMARY

This report presents the analysis conducted by the partners in order to investigate the scalability and replicability of the STREAM solutions (Scalability and Replicability Analysis, SRA).

The technologies developed to establish the required ecosystem to deploy Local Flexibility Markets (LFMs) are mainly tested and demonstrated in specific pilot sites. In order for the results of these projects to be compatible and adaptable with real-world power systems and LFMs, scalability and replicability dimensions need to be considered. Scalability can be defined as the ability of a system to change its scale to accommodate with the various requirements of different scale systems. On the other hand, replicability characterizes the solution's ability to be adapted by a power system at another location or time. SRA analysis is important in order to identify the factors that impose barriers for the scaling-up and replicating smart grid solutions. The basic factors are the technical, the economic, the regulatory and the acceptance of stakeholders.

Up to now, there is not a very consistent and strictly defined methodology for the SRA conducted in smart grids projects. A recent effort to provide a set of general guidelines for SRA was conducted by BRIDGE initiative, and specifically by the Task Force on Replicability and Scalability. The outcome of this initiative was a report, the guidelines and suggestions of which are also followed for the STREAM SRA methodology.

For the purposes of STREAM SRA, following the steps of the BRIDGE methodology, it was decided that the technical, regulatory and social dimensions were mostly relevant and, thus, more important to be investigated. The economic dimension is out of scope in this deliverable and is assessed in D6.2. Applying a qualitative approach and using the architectures of the tools, the final tool development decisions and the barriers that occurred during the deployment procedure, each STREAM tool was assessed. The main goal of this assessment was to identify aspects of the tools that could potentially have an impact on the replication capability of them.

The assessment is synthesized in a series of common opportunities and barriers, that can facilitate or hinder, respectively, the scalability and replicability of the tools. From a technical perspective, the modular and cloud-based architecture, reusable forecasting models, use of standard data formats and protocols, and the availability of smart-meter and SCADA systems facilitates scalability and replicability. However, differences in data formats and granularity, access to legacy DSO systems, increasing data-processing requirements, and the need to adapt forecasting and optimisation models to different assets and user profiles may require adaptation efforts. From a regulatory perspective, the increasing support for Local Flexibility Markets (LFMs), together with the growing role of energy communities and aggregators, provides an enabling environment, although differences in market rules, participant roles, flexibility products, and device registration and prequalification processes remain important barriers to replication. Finally, intermediaries such as energy communities, aggregators and others can facilitate end-user engagement and reduce technical and knowledge barriers, while stakeholder acceptance, training, organisational adaptation and the dependence on intermediaries may affect the scalability of user participation.

The results of the evaluation are presented at the end of the analysis as a set of steps that need to be taken into consideration for the exploitation of the tools to ensure their scalability and replicability. This roadmap is not an evaluation of the performance of the tools nor an assessment of whether they have met the specified project requirements or not, but a list of procedures and adaptations that can potentially facilitate the up-scale and replication of the tools in real-world deployments.

Response to the recommendations from the review

As indicated in D5.1 and throughout this deliverable, the tools already used, in general, standard data formats that facilitate the integration of data sources and communication with devices. To ensure that more robust and up to date standards are incorporated in the STREAM tools, a standardisation

strategy is provided in Section 5.1.3, being a key factor to ensure the replicability of the STREAM tools in different contexts.

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1 INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

The objective of this deliverable is to analyse the scalability and replicability factors of the tools developed in the STREAM pilot sites, and to define their replication roadmap as part of T6.4 – Synthesis, scaling up and replication.

This deliverable covers the tools developed in the technical work packages (WP2, WP3 and WP4) and demonstrated in WP5.

All partners have contributed to this document. Technical partners have provided inputs for the technical analysis, research centres, Market Operators, DSOs and TSOs have contributed to the regulatory analysis, and energy communities together with technical partners have provided inputs to the social analysis. Its main objective is to identify the technical, social and regulatory aspects that could possibly have an impact on the replication of the STREAM solutions to other European sites and to different contexts.

1.2 SCOPE OF THE DOCUMENT

This document analyses the technical, social and regulatory factors affecting the replicability and scalability of the tools developed in the pilot sites. The economic analysis is not included, as it is covered in D6.2 (economic impact assessment).

The deliverable also includes a replication roadmap and standardisation strategy aimed at supporting the deployment of the solutions across Member States.

1.3 STRUCTURE OF THE DOCUMENT

In Section 2, the report initially presents the general methodology proposed by the BRIDGE initiative, and specifically by the Task Force assembled in order to investigate how SRA is approached by different projects and to propose some guidelines. STREAM followed the proposed guidelines and adapted them in the analysis of the STREAM tools. The methodology and its application to the tools deployed in the different pilot sites are presented in Section 3. Section 4 provides the synthesis of the main findings across STREAM pilots and tools, identifying common opportunities and barriers, and the key differences across the different implementations. Finally, Section 5 provides the roadmap to ensure scalability and replicability of the tools, highlighting the standardisation strategy that will be a key aspect for ensuring interoperability of the tools across Member States.

2 SCALABILITY AND REPLICABILITY ANALYSIS METHODOLOGY

2.1 SCALABILITY AND REPLICABILITY DEFINITIONS

During the STREAM project, each pilot site has developed, deployed and demonstrated a set of complementary tools and services aimed at enabling local flexibility markets (LFMs) and flexibility aggregation for ancillary services provision. These tools have been successfully deployed and demonstrated at pilot site level in real operational conditions (as reported in D5.1), so they can be considered as a solid basis for assessing their potential deployment beyond the pilot environments.

However, the successful demonstration of a solution at pilot scale does not necessarily guarantee its applicability in different contexts or at a larger scale. Therefore, analysing the scalability and replicability of the STREAM ecosystem is essential to identify the technical, regulatory, economic and social factors that may facilitate or hinder its wider adoption. This analysis, referred to throughout this deliverable as the Scalability and Replicability Analysis (SRA), provides the basis for defining recommendations and a roadmap towards broader deployment of local flexibility markets. Within the context of STREAM, the following definitions are adopted:

- **Scalability** can be defined as the ability of the STREAM ecosystem to expand its deployment while maintaining its expected functionality and performance. This includes supporting a larger number of users, flexibility assets, market participants, geographical areas and market operations, as well as extending the portfolio of services offered by the ecosystem.
- **Replicability** refers to the capability of transferring and adapting the STREAM ecosystem to different contexts, such as other distribution networks, regions or countries. Replicability therefore considers the technical, regulatory, social and market adaptations required to successfully deploy the proposed solutions under different conditions.

2.2 BRIDGE SRA METHODOLOGY DESCRIPTION

The methodology used for the SRA in the STREAM project is based on the efforts of the BRIDGE initiative, where a Task Force on Replicability and Scalability was formed in order to develop common guidelines to perform SRAs and develop ideas on how to define the scope and implementation of a toolbox/repository of past experiences, best-practices and necessary data. The outcome of this initiative was a report, the guidelines and suggestions of which are also followed for the STREAM SRA methodology [1].

According to this report, the structure of the SGAM is used as the backbone for the definition of the SRA guidelines. This model has become a standard and it has proven useful to provide a common framework to conceptualize and compare different smart grid projects in Europe. However, since in the STREAM project the SGAM architecture has not been defined, a simplified version of the SRA methodology will be approached considering the interactions of the tools with external systems, tools and actors following the architectures defined in D2.1 for sENC, D3.1 and D3.2 for sDATA, D3.3 for sGRID and sPLAN, D4.1 for sFLEX and device registry, and D4.2 for sMART. At Figure 1 the steps of the proposed methodology are presented.

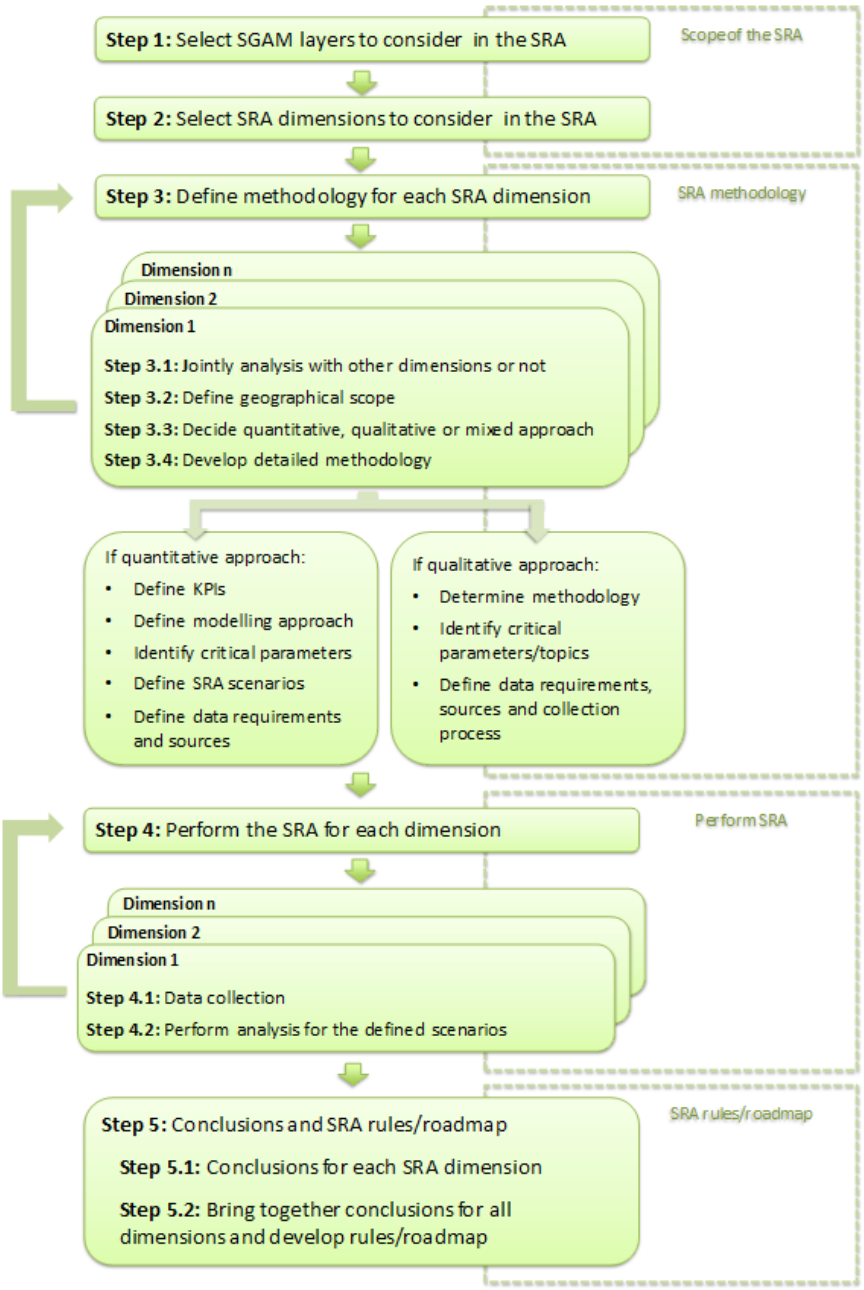


Figure 1: Steps of the proposed BRIDGE methodology

The first two steps are to ***define the scope*** of the SRA, which means that it is required to select the SGAM layers of interest, and also the SRA dimensions that will be investigated. The SRA dimensions to be assessed can be: Regulatory analysis, Economic analysis (CBA), Business models, Stakeholders perspectives, Software scalability, Software replicability, ICT scalability, ICT replicability and Hardware.

Following, the third step is the definition of the methodology that will be followed for each SRA dimension selected. In this, the developers first need to consider whether they will follow a qualitative or quantitative approach and accordingly to define the appropriate aspects, based on their decision. For example, quantitative analysis requires the definition of KPIs. In both cases, however, the identification of critical parameters is necessary.

The fourth step is the application of the SRA methodology that was defined for each dimension. During the progress of this step, it might be necessary to go back and re-assess parts of the initial methodology.

Finally, the last step of the guideline is to draw conclusions and deliver the SRA roadmap. This means that the results of the previous step are analysed (per dimension or jointly) and from this analysis a set of rules should be defined. These rules are, in fact, conclusions on the most important aspects that affect the scalability or the replicability of the solutions studied.

2.3 ADAPTATION TO STREAM

As previously stated, in the STREAM project the SGAM architecture has not been developed. Instead, simplified architectures for each of the tools and use cases diagrams have been developed, stating the interactions of the tools with assets, actors and other systems. Therefore, the BRIDGE SRA methodology has been slightly adapted, not considering the SGAM layers but identifying the main interactions and dependences of the tools through their architectures and use cases UML diagrams. This adaptation is reflected in Figure 2.

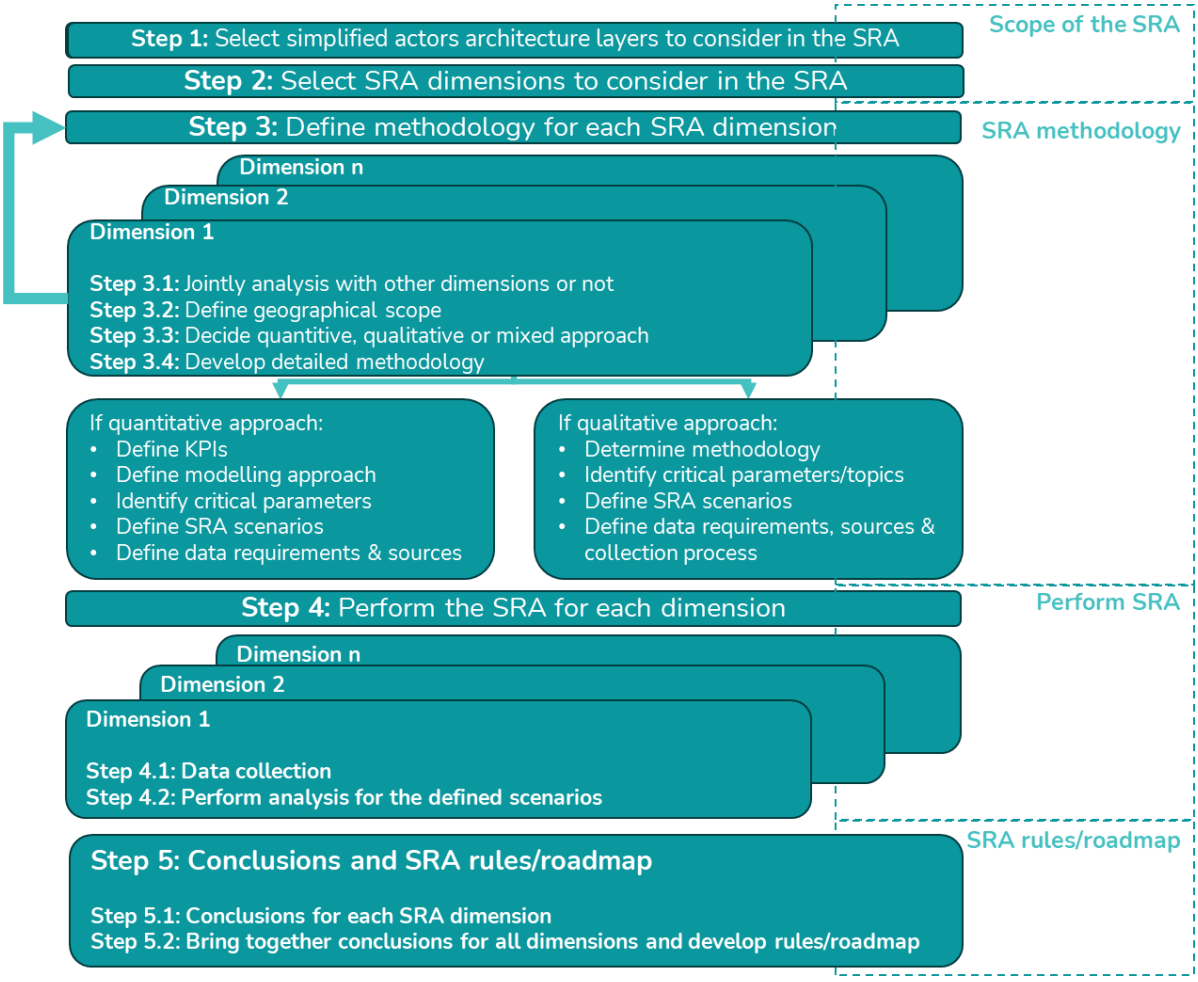


Figure 2: Steps of the proposed BRIDGE methodology adapted to the STREAM project.

The next step was to identify the dimensions to consider in the analysis for each of the tools. For this deliverable, the technical analysis has been performed for all the tools, the regulatory analysis has been performed for the market-facing tools, with the greatest depth for sMART, as it is the one most affected by the national regulations for flexibility markets, and is complemented with the policy recommendations report prepared under T4.4 - Regulatory aspects of local flexibility markets. The

social dimension has been also studied for the sENC and sFLEX tools, which are the ones that require interaction with end-users. The economic and business models dimensions have not been considered in this document as they are fully covered in D6.2Economic impact assessment.

Once the dimensions and the tools analysed in each of them have been identified, it was necessary to decide the geographical scope, which in this case is the EU Energy Market, and whether the analysis would be quantitative or qualitative. A quantitative analysis, despite useful and revealing in some cases, is not always applicable or appropriate for the investigation of the impact of a factor. Even more, for the technical dimension a quantitative approach, using for example simulation, can be significantly complex without necessarily providing sufficient information. It needs to be distinguished, here, the difference between quantitative testing of an algorithm or module from a software, which in the concept of STREAM means the developed tools. It is certainly much more trivial to simulate scenarios regarding the capabilities of a specific algorithm/module of a software (e.g., the power flow module using different number of nodes of the grid) from designing and executing simulation scenarios that could give insight on the whole software. Especially in terms of ICT scenarios this could be quite of a complex procedure. Having this in mind, it was considered that a qualitative approach would be more useful and insightful for the purpose of the analysis and, for that, a ***qualitative*** approach was adopted.

The next step was to identify data sources, interfaces across tools, interactions with end-users, regulations and social factors affecting the different dimensions of the analysis. For the data sources, interfaces across tools and interactions with end-users, the definition and representations of the use cases defined in D2.2 were analysed to identify the technical factors affecting the replicability and scalability of the tools. Additionally, the architectures of the tools represented in D2.1 (sENC) [2], D3.1 (sDATA) [3], D3.3 (sPLAN and sGRID) [4], D4.1 (sFLEX and Device Registry) [5] and D4.2 (sMART) [6] were also analysed since they provided further details on the data sources and the interactions with other tools, as well as the deployment of the tools reported in D5.1 [7]. This analysis was finalized with the results of D5.1 – Demonstration activities report, were the final interactions of the tools and the real deployment and integration with assets and the interactions of the end-users was ultimately demonstrated. For the regulatory analysis, the policy recommendations reported under T4.4 have been used as a basis for identifying the factor affecting the deployment of the sMART tool in the different countries, and for the social aspect the interactions between sENC and sFLEX and end-users have been analysed to derive the factors affecting for the social replicability and scalability.

Based on the information gathered from the project documentation and validated through dedicated workshops with the pilot sites, the SRA was performed for each of the selected dimensions. The analysis identifies the main technical, regulatory and social factors that may enable or hinder the wider deployment of the STREAM ecosystem. The dimensions considered and the factors analysed are presented in the following section.

2.4 DIMENSIONS AND FACTORS ANALYSED

During the aforementioned workshops, the partners completed an assessment matrix, for each tool and dimension, identifying the extent to which each factor was addressed during the project (fully addressed, partially addressed, not addressed or not applicable). The workshops also served to identify the main barriers and enablers associated with each factor, providing the basis for the roadmap presented later in this deliverable. To support the discussions, the partners were provided with a questionnaire containing guiding questions for each dimension, together with a set of representative scenarios illustrating possible scalability and replicability challenges. The following subsections describe the three analysed dimensions and the general factors considered in the SRA, as well as the questions and scenarios presented to the partners.

2.4.1 Technical dimension

The technical dimension includes the factors that describe if the solution is inherently scalable or replicable, considering the ICT and software subdimensions. The following scalability and replicability factors affecting the technical dimension were identified:

- **Scalability factors:**
  - **Modularity:** provides the ability to add, or the limits of adding, new components in scaled-up solution.
  - **Technology evolution:** Ability of the solution to scale by leveraging technological progress (e.g. computing power, cloud resources, data processing capabilities, availability of devices), without requiring major redesigns or disproportionate cost increases.
  - **Interface design:** allows the solution to increase the number of interactions with other components, solutions and equipment.
  - **Software integration:** ability of a solution to scale-up integrating new systems and actors with minimal additional development effort.
  - **Existing infrastructure:** scalability of the solution at hardware level, scaling the solution without the need for significant additional hardware, communication or control system upgrades.
- **Replicability factors:**
  - **Standardisation:** compatibility of the solution with established standards.
  - **Interoperability:** easiness of the solution to interact with other components, networks, systems and devices.
  - **Network configuration:** at which extent the solution relies on given resources and infrastructure (DERs, EVs, DSO network assets, etc.).

The scenarios and questionnaire presented to guide the partners were:

- **Scenarios:**
  - **User scaling:** If user numbers / size of the grid increased 10x, what technical challenges might appear?
  - **Assets scaling:** How would the solution handle a significant increase in connected assets?
  - **Integration of new devices or systems:** How easily could new devices or systems be added?
  - **Peak operation:** What technical limitations or risks could occur during peak operation?
- **Questionnaire:**
  - Which one of the previous factors you identify as already embedded in the tools? Which ones do you consider not applicable to the solution?
  - What technical limitations have you encountered/do you foresee to increase the number of users?
  - What obstacles do you foresee to replicate the tools in different grids/countries?
  - What standards and protocols have you used in the tools?

2.4.2 Regulatory dimension

The regulatory dimension seeks to understand if the solution can be deployed and replicated under different regulatory frameworks related to flexibility provision. To do so, it was identified which regulations would affect the deployments in the different pilot sites. In the Slovenian, Spanish and Italian pilot sites, where the activation of flexibility for LFMs were demonstrated, the regulation related to congestion management through the establishment of LFMs was considered, while in the case of the Slovenian pilot and the Finnish pilot, were the use case of flexibility activation for ancillary services provision was demonstrated, the regulation for demand response was analysed. The policy recommendations report developed under T4.4 has been also used as a starting point for this assessment. In this case, for each factor it was analysed if the solutions can be deployed under the current regulatory framework, if they would need adaptation to be compliant with the current regulatory framework or if it was not feasible under current regulation. The following factors were considered for these use cases:

- **Scalability factors:**
  - **Regulatory maturity:** existence of regulatory framework or sandbox, and clarity of the role of the DSO as flexibility buyer. The regulatory maturity enables the solution to scale from a piloting application, incorporating a limited number of assets and users, to a large-scale deployment, including several assets and users.
  - **Alignment with existing market mechanisms:** compatibility of the tool with the participation rules in balancing, congestion management, ancillary services provision, etc., avoiding double payments.
- **Replicability factors:**
  - **Dependence on national regulation:** if the solution assumes specific unbundling, an active role of the DSO or legal existence of the aggregator.
  - **Flexibility product definition:** if the products are too adapted to a specific DSO and the easiness to redefine them in other frameworks.

The following scenarios and questionnaire were presented to the partners:

- **Scenarios:**
  - **Replication in another country:** What legal or market barriers do you anticipate in a different region or country?
  - **Regulatory evolution:** How would changes in rules, licensing or tariffs affect the solution?
  - **Market participation changes:** How adaptable is the solution to different flexibility products or market rules?
- **Questionnaire:**
  - **Regulatory maturity**
    - Can you deploy this solution today under current regulation?
    - If not, what exactly blocks it?
    - Regulatory frameworks about local flexibility markets and other dynamic tariffs?
  - **Market compatibility**
    - Does your solution use existing ancillary services markets/products? Yes, we're testing FCR-D (up/down)
    - Could you use additional product (e.g., aFRR, mFRR)

- **Replication**
  - What would need to change to deploy this in another country?
  - Is there any regulatory barrier that would completely prevent replication?

2.4.3 Social dimension

The social dimension analyses the human factors that may affect the scalability and replicability of the proposed solutions by investigating at which extent the society is ready to embrace a solution. The assessment focuses on the tools requiring direct interaction with end-users, namely sENC, sFLEX and the Device Registry. Accordingly, the analysis considers the role of Energy Communities in the Spanish and Italian pilot sites, and the role of aggregators in the Slovenian and Finnish pilot sites, identifying the factors that may influence user participation, acceptance and engagement. The following factors were considered:

- **Scalability factors:**
  - **User engagement model:** measures if the usage of the tool is too manual or complex.
  - **Economic attractiveness perception:** clarity of the revenues end-users would perceive and price stability with the increase of users participating in the market.
  - **Digital skills required:** level of digital skills required to use the tools and technical support required.
  - **Operational complexity for participants:** number of decisions the user must take.
- **Replicability factors:**
  - **Societal acceptance of flexibility provision in different countries:** different cultural attitude to participation.
  - **Transferability of engagement strategies:** easiness of replicating the engagement strategy (e.g., as an aggregator, energy communities, etc.).
  - **Role of intermediaries:** dependence on cooperatives or communities.

The following scenarios and questionnaire were presented to the partners:

- **Scenarios:**
  - **High participation:** How would users respond if more users are included in the tools?
  - **Low engagement or passive users:** What risks arise if users are less active or have fewer digital skills?
  - **New cultural context:** What challenges might appear when replicating the solution in a country or region with different social attitudes toward energy markets or automation?
  - **Operational complexity for participants:** What user actions or decisions could become a barrier as the solution scale?
- **Questionnaire:**
  - What engagement strategies have worked well and are scalable?
  - What social barriers have you faced?
  - What role does intermediaries play and how would this affect to the replication?
  - Is there any social acceptance aspect that could limit the replication?

3 SRA FOR STREAM TOOLS

3.1 sENC

3.1.1 Overview of the tool

sENC in the STREAM project is the tool for the management of the EnC member assets, thus providing services normally linked to an aggregator. The tool aggregates the flexibility from flexibility assets to send bids to the local flexibility market. sENC has been deployed in the Spanish and the Italian pilot sites.

3.1.1.1 Spanish pilot site

To make the technical analysis of the sENC tool in the Spanish pilot site, the architecture defined in D2.1 [2] is analysed:

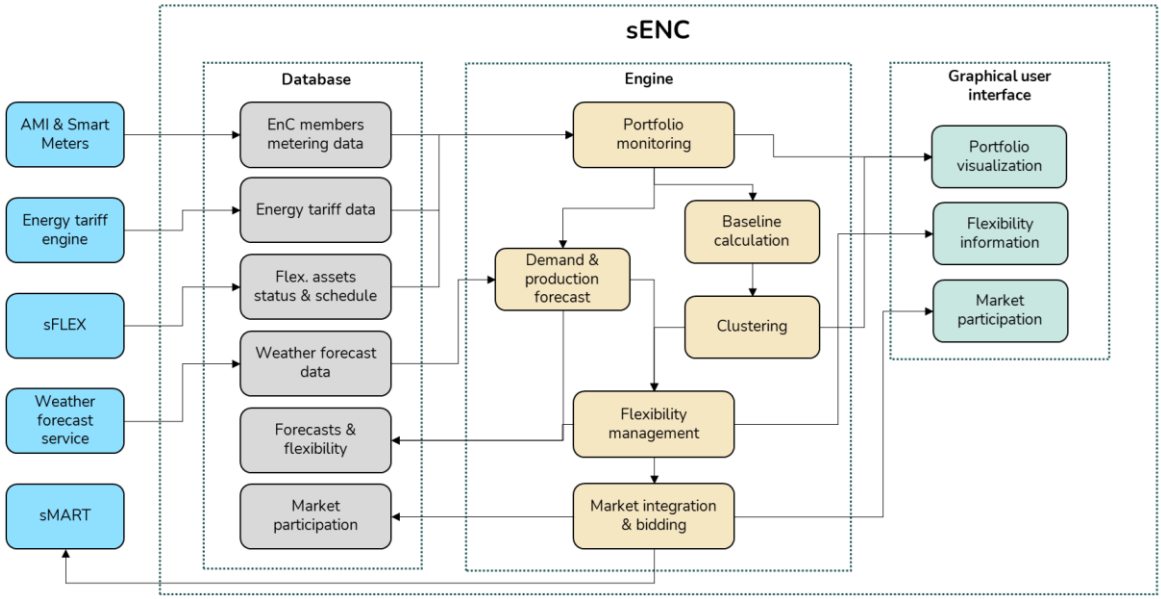


Figure 3: sENC architecture in the Spanish pilot

From the previous figure, it can be observed that the main pilot-specific data source used by sENC is **the AMI and smart meter infrastructure**, which provides the energy consumption and generation measurements of the prosumers and PV self-consumption installations connected to Enercoop's distribution grid. This interface mainly affects replicability, as the communication mechanisms and data models depend on the DSO infrastructure and the available metering systems at each deployment site. It also impacts scalability, since increasing the number of prosumers and distributed energy resources (DERs) proportionally increases the communication load and the computational effort required by the different forecasting modules. Therefore, this interface is analysed in the following sections.

The remaining data sources have a lower impact on the SRA. Energy tariff information is manually introduced through the graphical user interface (GUI), making it independent of external interfaces. Weather forecast data is obtained from an external provider using standard services and, therefore, does not represent a location-specific dependency that could limit the deployment of the solution in other regions.

Regarding the interaction with other STREAM tools, sENC exchanges information with **sFLEX** and **sMART**. The interaction with sFLEX is optional, as both tools can independently access the required information through the same service in charge of retrieving AMI data. Therefore, no direct

dependency between the two tools is required for their operation. On the other hand, the interaction with sMART is essential, since sENC retrieves information about open flexibility market sessions, submits flexibility bids and receives the market results. The replicability and scalability of these interactions depend on the characteristics and interfaces of the target market platforms.

From the internal engine layer, the baseline calculation is the component with the strongest dependency on the characteristics of the deployed flexibility assets, thus being affected by the network configuration factor. The required input data varies according to the DER technology:

- For prosumers, the module requires historical consumption and generation profiles together with weather forecasts.
- For PV installations, generation profiles and weather forecasts are required.
- For batteries and EV chargers, the integration is performed through sFLEX and is therefore analysed in Section 3.2.

Although the required inputs vary depending on the DER technology, the baseline calculation methodology for electricity consumption is largely technology-independent, since it relies on historical consumption patterns and day-type classification rather than on consumer-specific characteristics as sENC is meant mainly for citizen energy communities. Therefore, the same approach can be applied to residential, commercial or industrial consumers with only minor adaptations.

Since sENC interacts with the LFM platform (sMART), and could potentially be connected to other market platforms, the **regulatory dimension** is relevant for assessing its scalability and replicability.

In sENC, the **social dimension assessment** is highly relevant since, although prosumers and generators are not expected to directly interact with the tool as it is managed by the EnC manager or the aggregator, their engagement and willingness to provide flexibility is critical to enable the aggregator to have a large enough portfolio to provide flexibility in the market.

3.1.1.2 Italian pilot site

In the Italian pilot, sENC is a portfolio optimisation tool for aggregators and EnCs. As presented in Figure 4, in the Italian pilot, the tool does not retrieve any data from the pilot site directly, but communicates with sFLEX to retrieve data from the water pump digital twin and the residential HVAC flexibility estimation. In addition, sENC communicates with sGRID to receive transformers loading and PV generation forecasts. Finally, the tool communicates with sMART to receive flexibility requests for the aggregator to participate in the LFM.

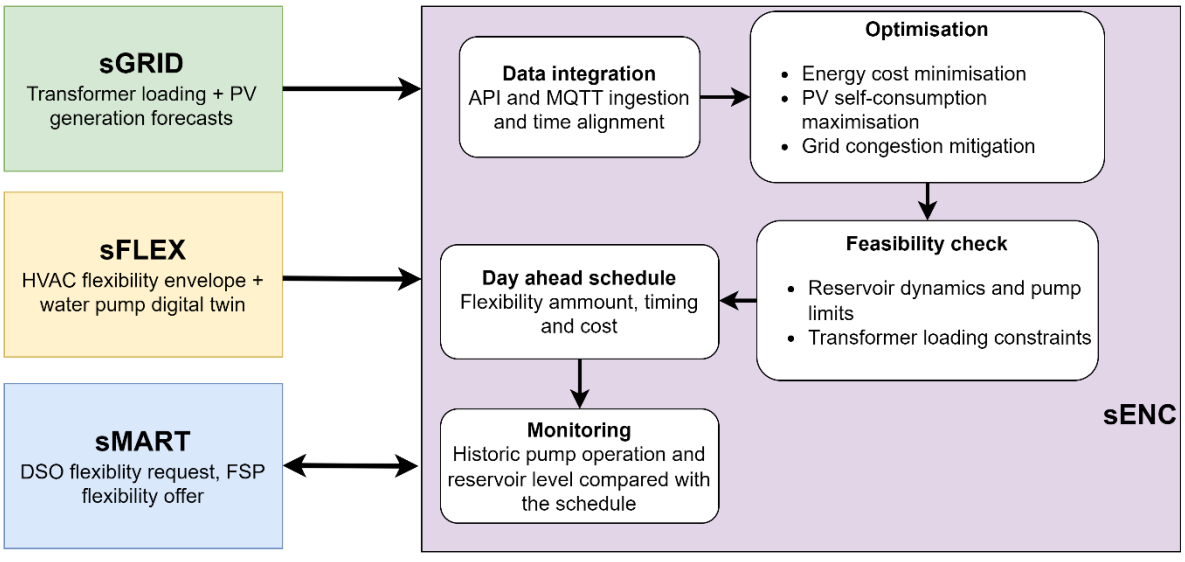


Figure 4: sENC architecture in the Italian pilot

Internally, the tool is composed of optimisation modules responsible for generating day-ahead schedules for the available flexibility assets, particularly the water pumping station. The optimisation can be configured according to different objectives, including electricity cost minimisation, maximisation of local renewable energy self-consumption, and congestion mitigation. The tool also manages residential HVAC flexibility information provided by sFLEX and incorporates it into the optimisation process.

For the technical assessment, the following aspects must be considered:

- Interactions with sGRID and sFLEX.
- Interface with sMART.
- Scalability and replicability of the optimisation modules.

Similarly to the Spanish pilot, the **regulatory and social dimensions** are also relevant to sENC.

3.1.2 Technical dimension assessment

Based on the previous sections, the following aspects have been identified as the main technical factors affecting the scalability and replicability of sENC:

- Software replicability of the integration with sGRID and sFLEX.
- ICT and software scalability and replicability of the integration of pilot data sources (AMI and smart meters).
- ICT scalability and replicability of the communication with external tools and market platforms.
- Software scalability and replicability of the baseline calculation for different DER technologies.
- Software scalability and replicability of the optimisation modules.

As a next step, these identified aspects of the tool are examined with respect to the main factors that affect the ICT and Software scalability and replicability, as presented at the previous chapter.

3.1.2.1 ICT Scalability and replicability

ICT scalability

From the **technology evolution** perspective, the scalability of sENC is expected to improve over time as cloud computing infrastructures, optimisation libraries, communication networks and smart metering technologies continue evolving. Higher computational resources allow larger forecasting workloads to be processed, while the increasing deployment of smart meters and IoT-enabled devices provides richer and more granular data without requiring changes to the solution. Since the optimisation and baseline calculation modules are basically software calculations and scheduling algorithms, improvements in computational resources and cloud services will directly benefit the performance of the solution.

From the **existing infrastructure perspective,** sENC does not present significant scalability limitations. In the case of the Spanish pilot, this is mainly due to the fact that the tool is deployed as cloud microservices on Kubernetes, allowing computational resources to be increased horizontally according to the number of connected users, assets and forecasting tasks. Consequently, scaling up the solution mainly requires allocating additional computing, storage and networking resources, without requiring architectural changes or modifications to the application itself. In the case of the Italian pilot, the optimisation process is executed in cloud environments and can benefit from additional computational resources when larger flexibility portfolios or additional optimisation variables are incorporated.

From the **interface design** perspective, increasing the number of assets and market participants proportionally increases the number of interactions with both data sources and sMART. On the data acquisition side, the tool can ingest measurements through different communication mechanisms (FTP for most of the AMI data, MQTT for smart meters with IoT capabilities and standard APIs), demonstrating that the internal processing is independent of the underlying communication technology. On the market side, the interaction with sMART is performed through well-defined interfaces for retrieving market sessions, submitting flexibility bids and receiving market results. The interface with sMART is designed in a way that the number of communication exchanges does not increase with the increase of market participants, since the same communication file includes the data for all the units registered in sENC.

ICT replicability

- Interaction of tool with data sources

As previously mentioned, the communication protocols used in sENC are, mainly, FTP for most of the data sources, which is the standard communication protocol for energy measures data exchange in the Spanish energy system between a DSO and a third-party, and MQTT for smart meters with IoT capabilities. While the FTP ensures replicability in the Spanish energy system, MQTT facilitates replicability across Member States, ensuring the replicability from the **standardisation** point of view.

Regarding **interoperability**, it depends on the communication protocol of the metering system. As previously mentioned, the use of FTP ensures interoperability in the Spanish energy system, while the implementation of MQTT for smart meters with IoT capabilities enables interoperability with these kinds of meters. However, plug-and-play interoperability ultimately depends on the communication capabilities of the metering infrastructure.

Finally, the **network configuration** factor is not relevant to the ICT replicability.

- Interaction with sGRID and sFLEX

In the Italian pilot, the communication with sGRID and sFLEX is based on standard software interfaces through APIs, facilitating the replication of the communications from the **standardisation** perspective. However, adaptations might be required when connecting to different forecasting and flexibility management tools depending on the information and data models provided by the external tool, limiting the **interoperability** of the tool from this perspective.

Finally, the **network configuration** factor is not considered relevant for ICT replicability.

- Interface with local flexibility market platform (sMART)

The communication with sMART is performed through the sMART connector using AMQP, which is an open and widely adopted messaging protocol. From the **standardisation** perspective, the use of AMQP facilitates the technical replication of the communication across different environments, as it is independent of the underlying software implementation. Although there is currently no harmonized communication standard for Local Flexibility Markets at European level, the use of a standard messaging protocol ensures that the communication mechanism itself does not constitute a barrier for replication.

Regarding **interoperability**, the use of AMQP enables interoperability with any local flexibility market platform supporting the same messaging protocol. Therefore, the communication can be replicated with limited effort, while any additional adaptations required are mainly related to the application layer rather than to the ICT infrastructure.

Finally, the **network configuration** factor is not considered relevant for ICT replicability.

- Baseline calculation for different DER technologies

This aspect is not related directly to the ICT replicability since it refers mainly to the data models and, thus, to the software dimension. The data between modules inside the tool are encapsulated according to a specified messaging structure, and then, exchanged through the selected messaging scheme. Therefore, in this layer this aspect does not impose any issue.

3.1.2.2 Software scalability and replicability

Software scalability

The factors affecting the software scalability of the tool are mainly the modularity and the software integration.

From the **modularity** perspective, as it can be seen in Figure 3, the architecture of the tool is modular by design, with the different components working in parallel and independently (e.g., the market integration is not highly dependent on the number of assets as they are aggregated in the previous modules). This allows for an easy implementation of additional modules, and limits the increase of computational efforts when scaling-up the solution as not all the modules are affected by the increase in the number of community members and assets.

From the **software integration** perspective, the baseline calculation and optimisation modules are affected by scalability requirements. As the number and typologies of flexible assets, optimisation variables and constraints increases, additional computational resources may be required and solving times may increase.

Software replicability

- Interaction of tool with data sources

In the Spanish pilot, it has been agreed that a common model for data representation needs to be used. The implemented model is based on the Common Information Model, CIM, (IEC 61968). The specific wrapper implemented for each data source converts the local data model (which is a proprietary data model of the DSO) into the CIM representation, which then is encapsulated in MQTT payloads and published. In terms of **standardisation**, using a public and not a proprietary standard is crucial for the replicability of the tool and its capability to seamlessly integrate various data sources. The only issue that lays in this, is that the CIM is a quite complex ontological representation and it has not yet been adopted widely. Also, the conversion between the custom data model into CIM is not always a simple and straightforward process and it can include various barriers (for example a proprietary data model needs to be available to the developer of the wrapper, otherwise, the vendor of the data source equipment needs to agree to develop or provide appropriate API). This makes the wrapper a possible caveat of the replication.

Regarding **interoperability**, the use of the wrapper to convert proprietary data models into CIM facilitates the plug-and-play capabilities of sENC.

Finally, the **network configuration** is not expected to have an impact on the replication.

- Interface with local flexibility market platform (sMART)

Currently, the European Commission is implementing the OpenADR (IEC 62746-10-1) as the standard for demand response and flexibility data exchange. However, although some countries and initiatives are already using this standard, its implementation remains heterogenous across Europe. Furthermore, since OpenADR 3.0, which provides enhanced support for distributed energy resources (DERs), was only released in late 2023, its use in the STREAM project during the definition of specifications and the development of market modules was not contemplated. Therefore, the data model exchanged between sENC and sMART is platform-specific, meaning that adaptations would be required to connect to other market platforms. This implies a barrier to the **standardisation** from the software replicability perspective. However, the pilot sites already use data models based on JSON or

XML, which are widely used. Although market-specific adaptations would be necessary, the use of these formats does not constitute a significant barrier to replication.

The same limitation affects **interoperability**, as integration with another LFM platform would require adaptations to the exchanged data model to the interfaces supported by the target platform.

Finally, the **network configuration** is not relevant for the interaction with sMART.

- Integration of sGRID and sFLEX outputs

In the Italian pilot, sENC relies on the outputs coming from sGRID and sFLEX for running the optimisation engine, namely the transformer loading and PV generation forecast from sGRID and the water pump digital twin and HVAC flexibility estimations from sFLEX.

From the **standardisation** perspective, the data models exchanged are specific to the STREAM ecosystem and would potentially require adaptations when integrating the outputs from different forecasting and flexibility management tools, implying replicability barriers in terms of data models.

Similar barriers affect **interoperability**, as integrating alternative forecasting tools, digital twins or flexibility estimation services would require adapting the exchanged data structures and semantic definitions.

Regarding the **network configuration**, replicability may be affected by the availability and characteristics of flexible assets. While HVAC flexibility estimations can be replicated by recalibrating the models with local consumption and temperature data, and forecasting inputs can be regenerated for different networks, the water pump digital twin requires a dedicated representation of the physical asset and its operational constraints.

- Baseline calculation for different DER technologies

Since the baseline calculation is part of the internal components of the tool, **standardisation** and **interoperability** are not relevant.

Finally, regarding **network configuration**, the baseline calculation depends on the portfolio of DER technologies available in the pilot site. While the consumption baseline algorithm can be applied to different consumer typologies, asset-specific flexibility calculations are required for controllable resources such as PV installations, batteries or EV chargers. Furthermore, it also depends on the configuration of the installations. For example, the flexibility calculation differs between hybrid PV+BESS systems and standalone PV and BESS installations. Therefore, replicating the solution in environments with different flexibility assets (wind turbines, other types of batteries, HVACs, etc.) and configurations may require implementing additional asset-specific models, although these can be integrated independently thanks to the modular architecture of sENC.

- Optimisation engine

Since the optimisation engine is part of the internal components of the tool, **standardisation** and **interoperability** are not relevant.

However, regarding **network configuration,** the optimisation engine depends on the characteristics and operational constraints of the flexible assets considered. Different flexibility resources, network constraints and optimisation objectives may require adapting the input parameters and constraints of the optimisation problem. Nevertheless, the optimisation methodology itself remains independent of the specific pilot configuration and can therefore be replicated with limited effort.

3.1.3 Regulatory dimension assessment

The analysis considers the role of the different actors participating in the flexibility market, the applicable European and national regulatory frameworks, and the way in which sENC interacts with the market platform. Based on these aspects, the assessment focuses on the regulatory conditions

that may facilitate or constrain the deployment of sENC at a larger scale and its adaptation to other regulatory and market environments.

Regulatory scalability

The factors affecting the regulatory scalability are the regulatory maturity of the target market and alignment with other existing market mechanisms.

From the **regulatory maturity** perspective, although EU regulation promotes standardisation of flexibility products through the [8], it leaves their detailed specification largely to national regulatory frameworks, as also stated in the Network Code on Demand Response [9]. Although in some European countries LFMs are already established and operational, there is still no common regulatory framework defining their detailed implementation across Member States. In most countries such as Spain, regulatory sandboxes and demonstration projects are being used to test the implementation of local flexibility markets, while their full-scale commercial operation is still under development, limiting the scalability of this solution in terms of LFM deployments.

From a regulatory perspective, **alignment with other market mechanisms** depends primarily on the eligibility requirements established for aggregators and other market participants, including minimum bid sizes, prequalification requirements and rules governing the interaction between different markets. From the technical perspective, sENC is capable of adapting to the different requirements. Furthermore, sENC is ready to detect if the asset has participated in other markets, being ready to prevent double remuneration.

Regulatory replicability

The factors affecting the regulatory replicability are the dependence on national regulation and the flexibility product definition.

Regarding the **dependence on national regulation**, as previously explained there is still a lack of harmonisation of the local flexibility market rules across Member States. However, this does not necessarily mean that sENC cannot be replicated in other countries, as it can be used by already established and regulated roles and entities. Some modifications would be required in terms of defining the rules of the market to be able to participate depending on the national requirements. Consequently, the main adaptation is not expected to concern the core functionality of sENC, but the configuration of the market participation rules and requirements applicable to the entity using the tool.

This is closely related to the **flexibility product** definition. Although the flexibility product depends largely on national regulatory frameworks and, in some cases, are established by the DSOs, the design of sENC is flexible enough to easily incorporate different products, including long-term products and short-term products with different time granularity. This creates a potential barrier to replication, as flexibility products may differ between national markets and may also be defined according to the specific needs of individual DSOs.

3.1.4 Social dimension assessment

Since sENC is operated by EnCs, the assessment focuses on this type of user, analysing how the tool and the EnC model facilitate the acceptance and participation of its members and the extent to which this model can be transferred to other contexts.

Social scalability

The social factors affecting scalability are how the user engagement model facilitates the engagement of new users, the economic attractiveness for end-user to participate in this markets, digital skills required and the operational complexity.

Regarding the **user engagement model**, the EnC acts as an intermediary between the tool and its members, providing an established channel to engage new users and explain the benefits of participating in flexibility markets. EnCs are already established in many Member States and can use their existing communication channels to reach prosumers and encourage their participation. This approach was demonstrated in STREAM through newsletters and dedicated workshops with EnC members, showing that the existing relationship between the EnC and its members can facilitate the engagement of additional users as the flexibility portfolio grows.

Regarding the **economic attractiveness** of LFMs for end-users, in the piloting phase of sENC, end-users perceived virtual compensations without compromising their comfort. The use of EnC assets as main flexibility providers, and the P2P market approach which does not imply any actual activations but just optimizes the revenues from the collective self-consumption installations, ensure that end-users perceive economic incentives without any comfort payoffs. The results therefore indicate that participation can provide perceived economic benefits without requiring significant changes to users' normal operation or comfort, which can facilitate the acceptance of the solution as the number of participating users increases.

From the **digital skills** required to use the tool, the tool automatically detects open sessions and prepares and sends the flexibility offers to the market. Therefore, the end-user interacting with the tool, in this case the EnC manager or the aggregator, does not require any special skills to use the tool, although a basic understanding of flexibility markets is required to interpret the information provided by the tool and supervise its operation.

This is also closely related to the **operational complexity** of the tool. Since no decision is required by prosumers, and the tool itself is capable of operating automatically in the market, decisions are not necessary from the end-user. The role of the EnC manager is mainly to supervise the operation of the tool and intervene, when necessary, for example if an automated decision could negatively affect the operation or comfort of the assets. This limited operational burden facilitates the integration of additional users without proportionally increasing the complexity of the overall process.

Social replicability

The social factors identified as relevant for the replicability of sENC are the social acceptance in different countries, the transferability of engagement strategies and the role of intermediaries.

In terms of **social acceptance in different countries**, the maturity of EnCs varies significantly across Member States, as identified in [10]. While EnCs are established and socially accepted in many countries, their level of consolidation and their ability to engage members differ considerably. The social impact assessment also indicates that end users are generally willing to provide flexibility, although economic incentives are an important factor influencing their participation. This requirement is addressed by the sENC model through the possibility of obtaining revenues from flexibility provision. Therefore, the social model demonstrated in the Spanish pilot is considered replicable in countries where EnCs are sufficiently established, although the engagement approach may need to be adapted to the maturity and characteristics of the local EnC ecosystem.

The **transferability of engagement strategies** is therefore closely linked to the maturity of EnCs in the target country. Communication channels such as newsletters, workshops and dedicated information sessions can be transferred to other contexts, while the specific content and incentives presented to end-users may need to be adapted to local market conditions and user expectations.

Finally, regarding the **role of intermediaries**, the EnC or aggregator plays a key role in the sENC model by acting as the interface between end users and the flexibility market. This dependency can represent a barrier to replication in contexts where no suitable intermediary exists or where the role of aggregators or EnCs is not sufficiently established. However, it can also be considered an opportunity, as these actors can facilitate the engagement of end users and enable them to access new revenue

streams without requiring direct interaction with flexibility markets. Consequently, the replicability of the social model is favoured where established EnCs or aggregators can assume this intermediary role.

As overall conclusion, the identified barriers are not independent from each other. In particular, regulatory and technical conditions are often interrelated, as the absence of common market rules and interfaces can limit the replication of otherwise technically mature solutions. Similarly, social and regulatory factors influence the scalability of aggregation models, as the availability of suitable intermediaries and sufficiently attractive remuneration mechanisms affects the ability to increase the number of participating users.

3.2 sFLEX

3.2.1 Overview of the tool

sFLEX is the STREAM tool designed to manage flexibility assets and enable their participation in local flexibility markets (LFMs) and ancillary services. The tool has been implemented in the four pilot sites, resulting in different configurations adapted to the specific assets, flexibility services and market mechanisms targeted in each pilot. While the implementations share the common objective of estimating, managing and/or activating flexibility, their architectures and functionalities differ depending on the pilot context. The following subsections provide an overview of each implementation, highlighting the characteristics relevant for the subsequent scalability and replicability assessment.

3.2.1.1 Slovenian pilot site

The sFLEX tool in the Slovenian pilot site is designed to enable the planning and real-time management of energy assets for their participation in both LFMs and ancillary services, in particular mFRR. This includes in the pilot, among others, Reduxi devices connected to BESS, cold storage rooms, mills, PVs and EV chargers.

To do so, the tool has the following modules. The **communication with IoT devices** monitors the assets in real-time (RT) and sends activation commands according to the results of the **portfolio optimization**, which integrates the data coming from the communication layer and optimizes the setpoints of the flexibility. The **flexibility services module** is responsible for the administration, activation and communication of flexibility assets. The resulting flexibility offers and market information are exchanged with the market platforms through the **energy markets module**, which also receives the results of the markets.

The main external interactions are therefore with the flexibility assets, which are done either directly through their **IoT interfaces** for industrial assets or indirectly through **sDATA** for the EV chargers and with **sMART** and the **TSO platform** for LFM and mFRR services provision respectively. The tool is mainly used by **industrial asset managers**, while activation of the assets is automatic.

Figure 5 illustrates the Slovenian sFLEX architecture and the interactions across modules and with other tools.

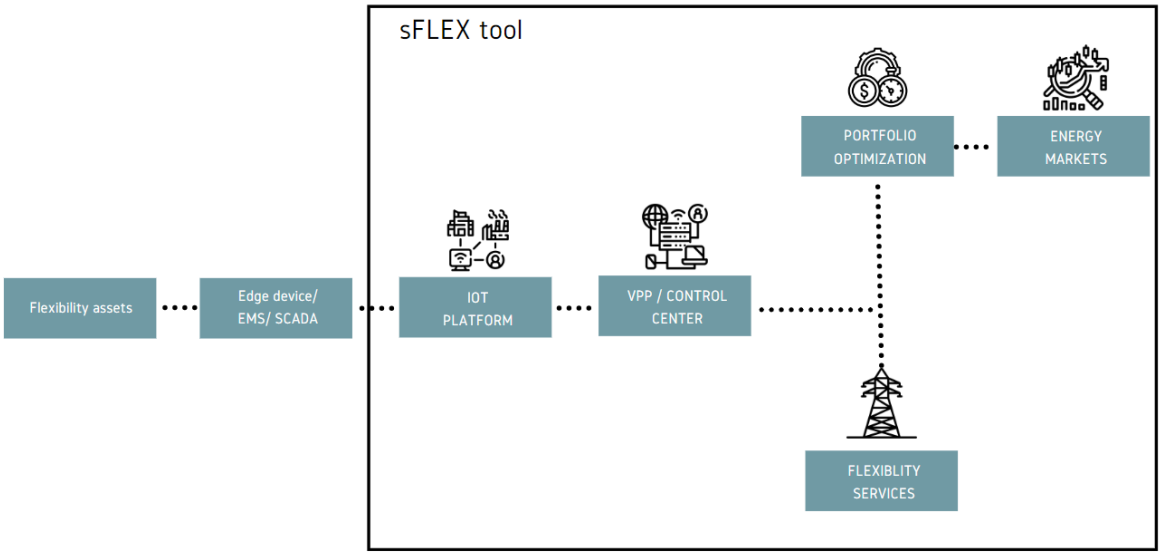


Figure 5: sFLEX architecture in Slovenian pilot site

3.2.1.2 Spanish pilot site

In the Spanish pilot site, sFLEX is deployed to manage medium- and large-scale flexibility assets and enable their participation in local flexibility markets. The implementation focuses on PV+BESS installations and EV charging stations, which are managed as individual flexibility assets and can submit flexibility offers to sMART.

The solution includes the following modules. The **Asset Monitoring module** provides real-time information from the flexibility assets through IoT connections, while the **Data Analytics and Schedule module** processes historical and operational data to model and forecast the behaviour of the installations. Based on these results, the **Flexibility Management module** estimates the flexibility that can be provided by each asset. The implementation also includes specific functionalities for **peak shaving** in the PV+BESS installation and **fault detection and diagnostics** to identify potential asset malfunctions. Finally, the **Market Integration module** interfaces with sMART to support device registration and prequalification, as well as the submission of flexibility bids and reception of market results.

The main external interactions are therefore with the **flexibility assets through their IoT interfaces** and with **sMART** for participation in the local flexibility market. The tool is primarily used by the **flexibility asset manager, owner of the flexibility asset**, while the flexibility assets are managed automatically according to the market outcomes and the operational constraints considered by the solution.

Figure 6 illustrates the Spanish sFLEX architecture and the interactions across modules and with other tools.

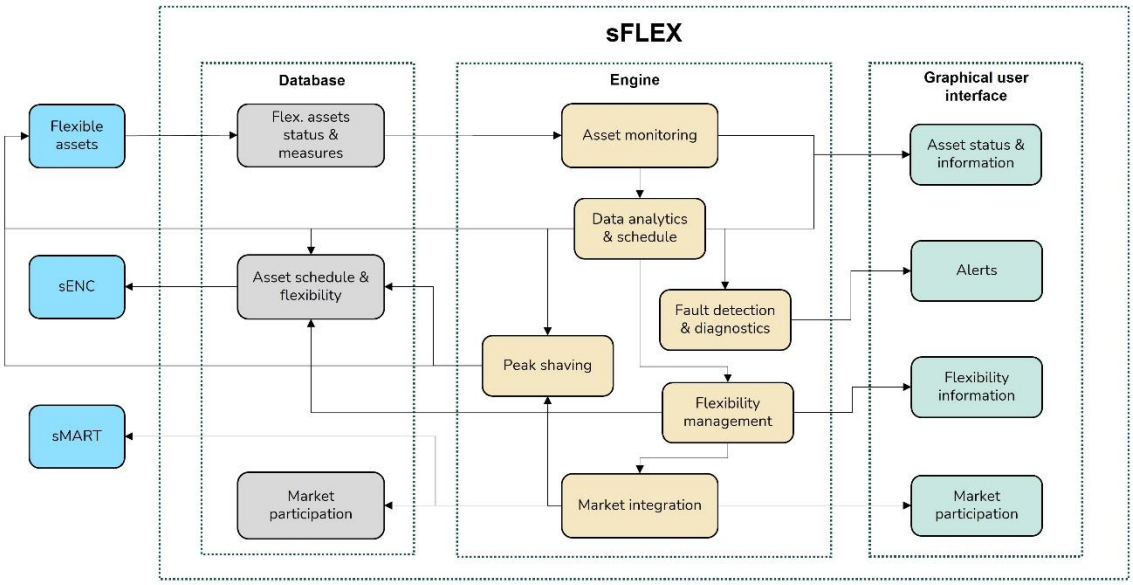


Figure 6: sFLEX architecture in Spanish pilot site

3.2.1.3 Italian pilot site

In the Italian pilot, sFLEX is responsible for estimating and quantifying the flexibility potential without compromising the comfort of the users. This information is sent to sENC, which aggregates the flexibility estimates at EnC level for participating in the market.

The solution includes the following modules. The **data integration module** ingests the data coming from sDATA, which communicates with the assets. This data is sent to the **load disaggregation module**, in charge of estimating flexibility by identifying the portion of electricity consumption attributable to HVAC systems, and to the **water pumping station digital twin** that estimates the flexibility that can be provided based on several factors such as reservoir level, estimated water consumption, etc.

The main external interactions of the tool are mainly with **sDATA** for data retrieval and with **sENC** for sending individual flexibility to be aggregated. **End-users do not directly make use of the tool** since it's mainly a backend for internal computations.

Figure 7 illustrates the Italian sFLEX architecture and the interactions across modules and with other tools.

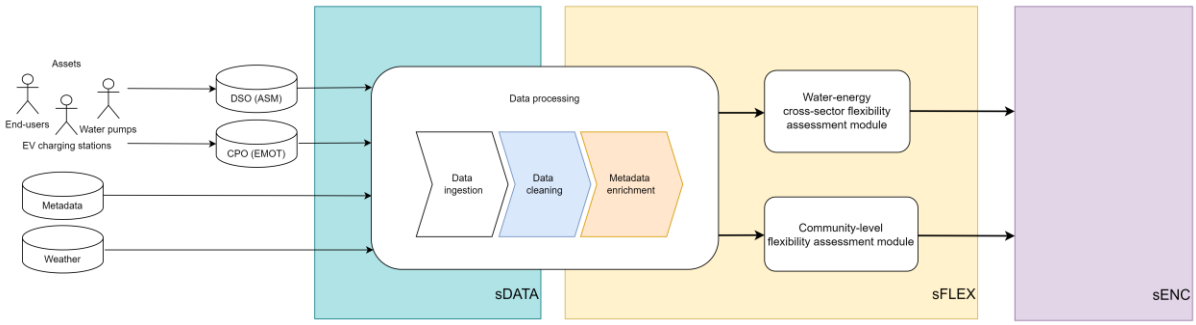


Figure 7: sFLEX architecture in Italian pilot site

3.2.1.4 Finnish pilot site

In the Finnish pilot, sFLEX implements flexibility services for the TSO by aggregating heating and other controllable assets into a single flexibility portfolio.

The solution comprises several modules. The **OW Controller** is an edge device installed at the flexibility assets and incorporates the **sFLEX Client**, which collects and sends real-time data to the sFLEX Server and receives flexibility activation commands. The **Control Software** translates these commands into control actions for electric radiators and electric floor heating. The **sFLEX Simulator** models room heating based on measurements and control data, providing the inputs required by the **sFLEX Manager** to estimate the amount of flexibility that can be offered to the TSO. During periods with active bids, the **sFLEX Server** monitors grid frequency and triggers the activation or deactivation of the assets when required. The **sFLEX TSO Connector** prepares and sends flexibility bids to the TSO platform, simulated in the STREAM prototype, while the **sFLEX Analyzer,** not yet deployed, will compare the estimated and actual power consumption and will adjust the simulation parameters to improve the accuracy of subsequent flexibility estimates.

The main external interactions are therefore with the **flexibility assets through the OW Controllers**, with **sDATA** for data storage, and with the **TSO platform** for submitting FCR-D bids and receiving market results. The activation of the flexibility assets is performed automatically based on the signals received by the sFLEX Server.

Figure 8 illustrates the Finnish sFLEX architecture and the interactions across modules and with other tools.

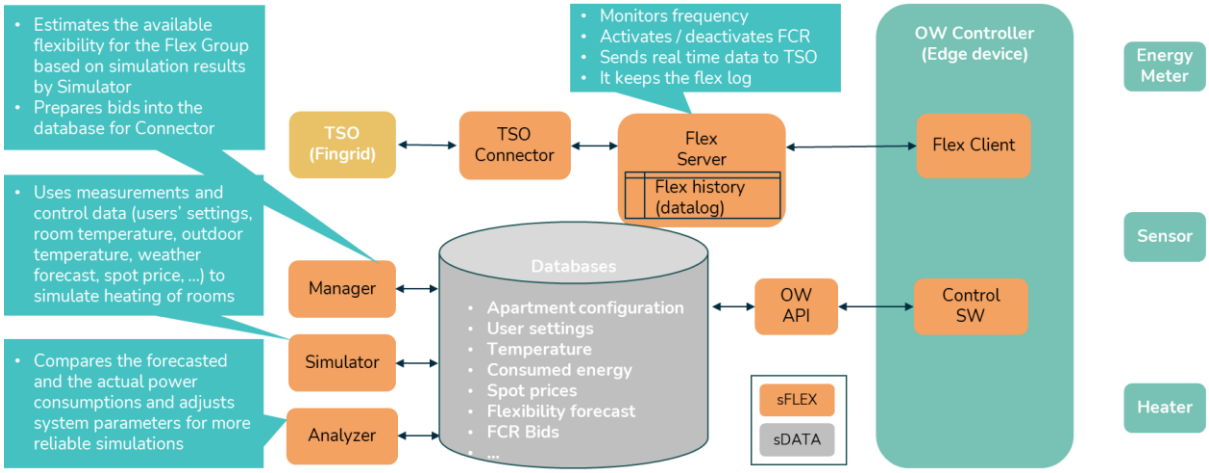


Figure 8: sFLEX architecture in Finnish pilot site

3.2.2 Technical dimension assessment

Similarly to sENC, for sFLEX the technical dimension assessment begins with the identification of the pilot-specific data sources, the interactions with external systems and the internal modules.

For the pilot-specific data sources, it should be highlighted that the Italian sFLEX does not obtain the data directly from the assets, but through sDATA. As regards to the others, the main data sources are the same for all of them, being the IoT devices and controllers installed in the assets. This communication with the assets will affect replicability since the interface with the IoT device will depend on the type of asset, the brand and the model, and also the scalability, since additional IoT devices will imply the configuration of additional interfaces and increase the associated communication workload.

Regarding the interactions with external systems, sFLEX communicates with market platforms (sMART and/or TSO ancillary services platforms) in Slovenia, Spain and Finland, with sDATA for data retrieval and storage in Slovenia, Italy and Finland, and with sENC for aggregation and market participation in Spain and Italy. The replicability and scalability of these interactions depend on the characteristics and interfaces of the target market platforms, and on the configuration of sENC for Italy and Spain. The interaction with sDATA will be analysed in Section 3.7.

From the internal layers, although the naming differs in the different pilot sites, we can group them in two different groups that are common across the four pilot sites:

- Flexibility calculation and optimisation, that will depend on the configuration of the asset, the typology of the installation (e.g., asset installed in an industry, standalone asset, hybrid PV+BESS installation, asset installed in a household, etc.). This module affects the software replicability and scalability of the tool
- Market integration and connection, which enables the communication with market platforms. This module is part of the interaction with external sources and will therefore be assessed as part of the ICT replicability and scalability.

Based on the previous analysis, the following aspects have been identified as the main technical factors affecting the scalability and replicability of sFLEX:

- Scalability and replicability of the integration with IoT interfaces.
- Replicability of the interface with local flexibility market platforms (sMART) and TSO ancillary services platforms.
- Replicability of the flexibility calculation and optimisation for different assets and installation typologies.
- ICT and software scalability of the platform when increasing the assets connected to sFLEX.

As a next step, these identified aspects of the tool are examined with respect to the main factors that affect the ICT and Software scalability and replicability, as presented at the previous chapter.

3.2.2.1 ICT Scalability and Replicability

ICT scalability

The factors affecting the ICT scalability of the tool are mainly the technology evolution, the existing infrastructure and the interface design.

From the **technology evolution** perspective, the scalability of sFLEX is expected to improve over time as cloud computing capabilities, communication networks and edge computing technologies continue evolving. Higher computational resources allow larger forecasting workloads to be processed, while increasing the edge computing capabilities would reduce the computational requirements of sFLEX and reduce communication latency.

From the **existing infrastructure** perspective, sFLEX does not present significant scalability limitations in general, since, similarly to sENC, the four pilot sites have deployed sFLEX in the cloud, allowing computational resources to be increased horizontally according to the number of connected users, assets and forecasting and optimisation tasks. Consequently, scaling up the solution mainly requires allocating additional computing, storage and networking resources, without requiring architectural changes or modifications to the application itself. However, in the case of the Finnish pilot site, as they require the OW controller to be installed in the premises of the user, incorporating additional assets would require the installation of additional controllers, representing an additional infrastructure requirement when scaling up the solution. The same applies to the Slovenian pilot site, which requires the installation of Edge controllers for actuation on the assets.

From the **interface design** perspective, increasing the number of assets and market participants proportionally increases the number of interactions with both data sources, sMART and TSO platforms. On the data acquisition side, sFLEX can ingest measurements through different communication mechanisms, mainly MQTT, AMQP and Modbus, although integrating additional assets may require the configuration of additional interfaces depending on the asset and communication technology. The interaction with sMART is performed through well-defined interfaces

for retrieving market sessions, submitting flexibility bids and receiving market results. The interface with sMART is designed in a way that the number of communication exchanges does not increase with the increase of market participants, since the same communication file includes the data for all the units registered in sFLEX for both the Slovenian and Spanish pilot. Similarly, regarding the connection with TSO platforms, the Finnish and Slovenian implementations can integrate additional assets without requiring a separate market interface for each asset, as the assets are managed as part of an aggregated flexibility portfolio. Therefore, the main scalability impact is related to the increase in data volume and the processing and communication workload instead of the number of market interfaces.

ICT replicability

- Interaction of tool with IoT devices

The communication protocols used by sFLEX to communicate with IoT devices are, in general, standard protocols in the three relevant pilot sites (Italy excluded, since data is retrieved through sDATA), including MQTT, REST APIs, OCPP and Modbus. Therefore, the interaction with IoT devices is considered replicable from the **standardisation** perspective.

Regarding **interoperability**, it depends on the communication capabilities and protocols supported by the underlying devices. The use of standard protocols facilitates interoperability with a wide range of devices in the Slovenian and Spanish pilots. However, plug-and-play interoperability ultimately depends on whether the specific device supports the required protocol and exposes the necessary data and control functionalities. In the Finnish pilot, interoperability is more limited since the solution relies on proprietary controllers installed at the flexibility assets which also involves the use of proprietary protocols.

Finally, regarding the **network configuration**, no significant barriers have been identified in the Slovenian and Spanish implementations, as the communication architecture can be deployed over standard IP-based networks. The Finnish implementation does, however, require the deployment of a proprietary controller at the asset premises. This represents an additional hardware/infrastructure dependency, rather than a specific network configuration requirement.

- Interface with local flexibility market platform (Slovenian and Spanish pilots) and TSO platforms (Slovenian and Finnish pilots)

The communication with sMART is performed through the sMART connector using AMQP in Spain and REST APIs in Slovenia, both of which are open and widely adopted communication technologies. From the **standardisation** perspective, the use of standard communication protocols facilitates the replication of the communication across different environments, as it reduces dependence on a specific underlying software implementation. However, there is currently no harmonised communication standard for local flexibility market data exchange at European level. Therefore, while the communication protocols themselves do not constitute a significant barrier to replication, adaptations to the specific interfaces and communication requirements of other market platforms may still be required.

For the connection to TSO platforms, both the Slovenian and Finnish pilots use the communication mechanisms established by the respective TSO. From the **standardisation** perspective, this facilitates replication within the corresponding national market, although replication to other countries may require adaptations to the communication interfaces and protocols specified by the relevant TSO.

Regarding **interoperability**, the use of standard communication protocols facilitates interoperability with market platforms supporting compatible protocols. However, interoperability also depends on the specific interfaces and technical requirements implemented by each market platform or TSO. Therefore, the communication can generally be replicated without major ICT barriers, while additional adaptations may be required at the interface/application level.

Finally, the **network configuration** factor is not considered relevant for ICT replicability.

- Flexibility estimation and optimisation

This aspect is not related directly to the ICT replicability since it refers mainly to the data processing and, thus, to the software dimension. The data between modules inside the tools are encapsulated according to a specified messaging structure, and then, exchanged through the selected messaging scheme. Therefore, in this layer this aspect does not impose any issue.

3.2.2.2 Software Scalability and Replicability

Software scalability

From the **modularity** perspective, as it can be seen in the previous figures, the sFLEX architectures are modular by design, with the different components working in parallel and independently. This facilitates the implementation of additional modules and the integration of additional assets, and limits the increase in computational efforts when scaling-up the solution as not all the modules are affected by the increase in the number of assets. Additionally, adding assets to the portfolio does not necessarily compromise the overall performance of the other assets.

This modularity also facilitates **software integration,** since new functionalities can be incorporated as independent services without affecting the existing modules. For instance, additional forecasting algorithms, support for different asset typologies or optimization functionalities can be integrated while preserving the existing communication interfaces and internal workflows. This reduces the effort required to extend the tool and minimizes the impact of future developments on the overall architecture. However, modules performing flexibility estimation, forecasting and portfolio optimisation may experience increased computational workloads as the number and heterogeneity of assets grows, potentially requiring additional computational resources or optimisation for very large portfolios.

Software replicability

- Interaction of tool with data sources

Regarding **standardisation**, the availability of standard data models depends on the specific data source and communication technology. Some interfaces, such as OCPP for EV chargers, define standardised message structures, while other commonly used communication technologies, such as MQTT, REST APIs or Modbus, do not by themselves define the semantics or structure of the exchanged data. Therefore, the degree of software replicability depends on the specific data model exposed by each asset or data source and on the effort required to map it to the internal representation used by sFLEX.

Regarding **interoperability**, the use of standard communication protocols facilitates the integration of data sources and flexibility assets using compatible interfaces. However, interoperability at software level also depends on the data model and semantics provided by each source.

Finally, the **network configuration** is not expected to have an impact on the replication.

- Interface with local flexibility market platform (Slovenian and Spanish pilots) and TSO platforms (Slovenian and Finnish pilots)

Similarly to sENC, the implementation of data models for local flexibility markets is heterogeneous across Europe. Therefore, the data model exchanged between the sFLEX instances of each pilot and their sMART is platform-specific, meaning that adaptations would be required to connect to other market platforms. This implies a barrier to the **standardisation** from the software replicability perspective. Similarly to sENC, the adaptation effort is expected to be limited to implementing adaptations to additional market platforms, without requiring major development effort.

On the contrary, the participation in ancillary services benefits from a higher degree of harmonisation than local flexibility markets. European balancing regulations define common characteristics for standard balancing products, while European balancing platforms provide common frameworks for the exchange of balancing energy. This facilitates the replication of the software logic required to represent and manage balancing bids and activations. However, this harmonisation does not imply the existence of a single software interface or data exchange API across all TSOs. Therefore, some TSO-specific adaptations may still be required. This is reflected in Finnish sFLEX, which uses Fingrid's standard, which is shared across Northern countries, and based on the ENTSO-E framework with some national adaptations. Therefore, deploying sFLEX in other European countries may require minor adaptations to the relevant TSO interfaces and communication requirements, but no major development effort is expected.

The same limitation affects **interoperability**, as integration with another LFM platform would require adapting the exchanged data model to the interfaces supported by the target platform. Similarly to standardisation, interoperability is more straightforward for TSO platforms. However, technical interoperability is still dependent on the specific interfaces and technical requirements established by each TSO, including communication mechanisms, message structures and prequalification procedures. Therefore, sFLEX can be replicated to other TSO environments, but the TSO connector may require adaptations to comply with the specific technical requirements of each platform.

Finally, the **network configuration** is not relevant for the interaction with sMART and TSO platforms.

- Flexibility estimation and optimisation

Since the flexibility estimation and optimisation is part of the internal components of the tools, **standardisation** and **interoperability** are not relevant.

Finally, regarding **network configuration**, the software replicability of sFLEX is affected by the different characteristics and operational constraints of the flexibility assets. The four pilot implementations support different asset typologies, including PV and BESS, EV chargers, industrial loads, HVAC systems, water pumping stations and heating systems. Consequently, the flexibility calculation and optimisation algorithms require asset-specific models, parameters and operational constraints.

3.2.3 Regulatory dimension assessment

Since sFLEX interacts with the LFM platform (sMART) in the Spanish and Slovenian pilot site, and with the TSO platform for ancillary services provision in Slovenia and Finland, and could potentially be connected to other market platforms, the regulatory dimension is relevant for assessing its scalability and replicability. The analysis considers the role of the different actors participating in the flexibility market, the applicable European and national regulatory frameworks, and the way in which sFLEX interacts with the market platforms. Based on these aspects, the assessment focuses on the regulatory conditions that may facilitate or constrain the deployment of sFLEX at a larger scale and its adaptation to other regulatory and market environments.

Regulatory scalability

From the **regulatory maturity** perspective, the situation for LFM participation is similar to that explained for sENC. Regarding the participation in TSO ancillary services, the regulatory framework is sufficiently mature and allows the use of tools such as sFLEX to support aggregations participating in these services.

From the **alignment with other existing market mechanisms**, sFLEX can potentially be applied to other ancillary services and wholesale markets due to its capabilities. For instance, the Finnish deployment of sFLEX is also planned to support participation in aFRR and mFRR. However, some adjustments may be required to ensure that the tool can comply with the specific requirements of

each market, including product definitions, bidding and activation processes, and other market-specific rules.

Regulatory replicability

The factors affecting the regulatory replicability are the dependence on national regulation and the flexibility product definition.

Regarding the **dependence on national regulation,** LFM participation remains dependent on the regulatory framework applicable in each country, as the definition of roles, procurement mechanisms and participation conditions is not yet fully harmonised at European level. For instance, in the Slovenian pilot, Slovenia's participation in the MARI platform for mFRR means that the tool could be readily replicated in other countries participating in the same platform, as they follow common requirements for mFRR services [11]. Similarly, in the case of Finland, the integration of ancillary service markets across the Nordic countries facilitates the replication of the tool across these markets. Minor adaptations may nevertheless be required when extending the tool to other European regulatory frameworks.

From the **flexibility products** definition perspective, again, the same that was explained in sENC can be applied to sFLEX for LFMs. For ancillary services, the common regulatory frameworks and harmonised requirements described above facilitate the adaptation of the tool to different national market products. The definition and sequencing of several ancillary services are harmonised across EU Member States, which facilitates the replication of sFLEX across different national contexts. In these cases, replicability is expected to depend primarily on technical adaptations required to comply with market-specific data models, communication protocols and operational requirements, rather than on fundamental changes to the flexibility products supported by the tool.

3.2.4 Social dimension assessment

The social dimension is not as relevant as for sENC, as sFLEX is either a tool that is used directly by the aggregator (OPT in Finland and KOL in Slovenia) or by the energy community manager (ENER in Spain). However, the different factors of the social dimension affect indirectly to the prosumers and other potential end users, being necessary to perform the social scalability and replicability assessment.

In the case of Italy, the social dimension is not considered relevant as the tool is not directly used by any end user, serving as an optimization layer for sENC.

Social scalability

The social factors affecting scalability are how the user engagement model facilitates the engagement of new users, the economic attractiveness for end-user to participate in this markets, digital skills required and the operational complexity.

Regarding the **user engagement model**, door to door engagement is required to engage individual users according to the business model for Slovenia and Finland. However, this is part of their commercial planning and business development. For the case of the Spanish pilot, sFLEX is offered to the same users as for sENC, being the energy community the streamliner for user engagement.

From the **economic attractiveness perspective**, in the case of the Slovenian and Spanish pilot the users directly benefit economically from their participation in LFMs and ancillary services. For the case of Finland however, the compensation from ancillary services provision is solely remunerated to the aggregator, being the end user benefitted from non-economic incentives (e.g., higher energy consumption granularity and accurate analytics, better data).

Regarding the **digital skills required**, sFLEX does not require advanced technical skills from end users. Depending on the pilot, users mainly define operational constraints or preferences, while the aggregator manages the tool and its participation in the market. The tool therefore abstracts most of the technical complexity associated with flexibility management and market participation.

The same applies to the **operational complexity**, as flexibility activation and market participation are either managed by the aggregator or performed automatically by the tool. This limits the operational burden placed on end users and facilitates the integration of additional users as the portfolio grows.

Social replicability

The social factors identified as relevant for the replicability of sFLEX are the social acceptance in different countries, the transferability of engagement strategies and the role of intermediaries.

In terms of **social acceptance in different countries,** sFLEX is designed to respect the operational constraints defined by the users and to provide flexibility without interfering with the normal operation of the assets. This facilitates acceptance by users, although the perceived benefits and concerns associated with flexibility provision may vary depending on the type of asset and local context.

From the **transferability of engagement strategies** perspective, in the case of the Slovenian and Finnish pilot, the commercialisation strategy can be used in any other country, being easily replicable. For the case of the Spanish strategy through the energy communities, similarly to sENC communication channels such as newsletters, workshops and dedicated information sessions can be transferred to other contexts, while the specific content and incentives presented to end-users may need to be adapted to local market conditions and user expectations.

Finally, regarding the **role of intermediaries**, the role of the aggregator or Energy Community is particularly relevant for ancillary services, as aggregation is generally required to reach the minimum bidding capacity and to manage participation in the TSO market. In this case, the intermediary acts as the interface between end users and the market platform. For LFMs, however, the need for an intermediary depends on the size and characteristics of the flexibility portfolio. In the Slovenian and Spanish pilots, the assets managed by sFLEX are sufficiently large to participate directly in the flexibility market, meaning that an intermediary is not necessarily required from a technical perspective.

3.3 DEVICE REGISTRY

3.3.1 Overview of the tool

The Device Registry (DR) is a web-based platform used in the Slovenian pilot for registering and prequalifying devices participating in LFMs. It serves as the central registry of flexible assets, maintaining key information such as device characteristics, location, and prequalification status, which are essential for bid validation within sMART. The architecture of the tool is represented in Figure 9.

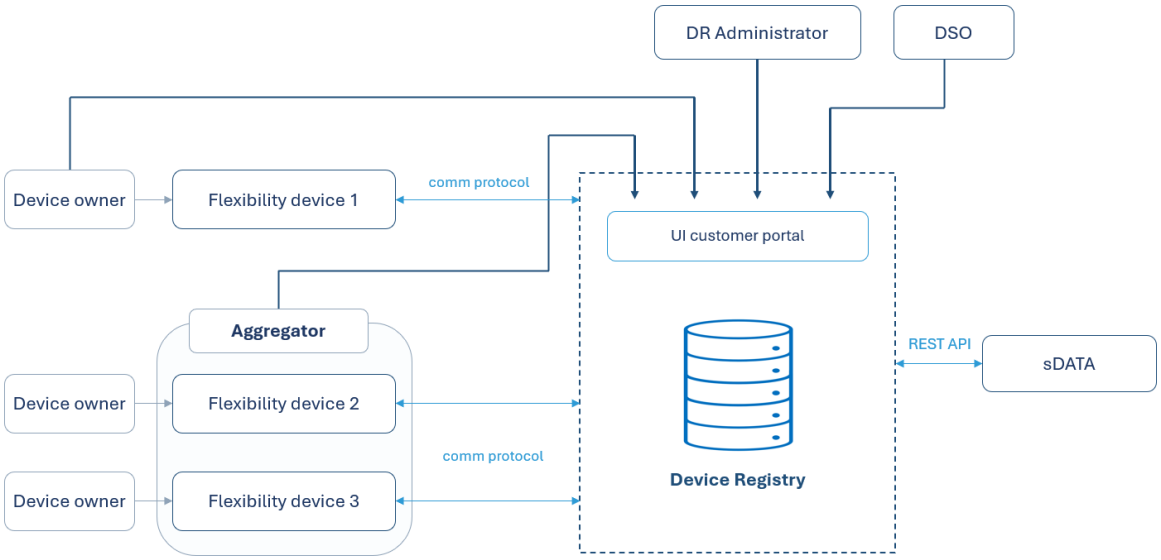


Figure 9: Device registry architecture

The tool communicates externally with flexibility devices to perform activation tests within the required boundaries and assess their registration and prequalification status. It also exposes device metadata, prequalification status and operational information through APIs. Within the STREAM architecture, it is directly integrated with **sDATA** which acts as the central data exchange layer and provides access to device metadata and operational time-series information for other STREAM tools. Finally, the DR is accessed by its users (aggregators, Flexibility Device Owners (FDOs) and DSOs) to register and manage flexibility devices.

3.3.2 Technical dimension assessment

The main data sources for the Device Registry are the flexibility devices themselves. Communication with each device must be established to exchange operational data and execute prequalification tests. Therefore, the scalability and replicability of the Device Registry depend primarily on the diversity and number of connected assets, as well as the communication protocols they support. Although the platform is designed to support multiple communication technologies and can be extended with additional protocols, increasing heterogeneity of connected devices may increase integration effort and operational complexity.

Regarding the interactions with external systems, the Device Registry exposes device metadata, prequalification status and other relevant information through a standard API. Within the STREAM architecture, this is used for the integration with sDATA, while also allowing integration with other platforms and services within the ecosystem. The information exchanged through these interfaces is ultimately required to support participation in local flexibility markets. The interaction with external systems is not expected to constitute a significant barrier to scalability or replicability, although adaptations may be required to support different market implementations.

Regarding the internal layers, the Device Registry is device-agnostic, meaning that its internal processes are independent of the type and location of the devices. Increasing the number of devices does not require changes to the internal software architecture. **Therefore, although a larger number of devices may increase operational workload, it does not introduce a fundamental scalability limitation at the software level.** The internal layers can therefore be considered scalable and replicable by design.

In summary, the following aspects should be assessed from the technical dimension perspective:

- Replicability and scalability of the interface with flexibility devices for prequalification testing.
- Replicability and scalability of the interface with external systems and data exchange platforms (e.g., sDATA).

Therefore, only the ICT scalability and replicability will be assessed, while the software layer does not constitute a significant barrier for scalability and replicability.

ICT scalability

The factors affecting the ICT scalability of the tool are mainly the technology evolution, the existing infrastructure and the interface design.

From the **technology evolution** perspective, the scalability of the device registry is expected to be affected when new communication protocols, technologies and edge-computing approaches emerge. This may require adjustments to support new communication methods and device types. However, increasing standardisation of communication protocols is expected to facilitate interoperability and support the integration of future technologies. Regarding the **existing infrastructure**, as the device registry is deployed in the cloud, increasing the number of devices would not require fundamental changes to the infrastructure, as scaling up the solution mainly requires allocating additional computing, storage and networking resources, without requiring architectural changes or modifications to the application itself.

From the **interface design** perspective, increasing the number of assets would require configuring the communication interfaces for the additional assets. However, these configurations can be implemented without significant modifications to the core functionality of the tool, and no significant impact on overall performance is expected.

ICT replicability

- Interface with flexibility devices for prequalification testing

From the **standardisation** perspective, the device registry incorporates a wide range of standard protocols to communicate with the flexibility devices. This includes MQTT, OpenAPIs, IEC 60870-5-104, Modbus, IEEE 2030.5 and others. The connection to each asset is established based on the supported communication protocol. Therefore, standardisation is not expected to constitute a significant barrier to replicating the device registry's interface with flexibility devices, although additional integration effort may be required for specific device types and protocols.

Regarding **interoperability**, it depends on the communication capabilities and protocols supported by the underlying devices. The use of standard protocols facilitates interoperability with a wide range of devices, and the tool is designed to support connection to different types of assets. However, plug-and-play interoperability ultimately depends on whether the specific device supports the required protocol and exposes the necessary control capabilities.

Finally, regarding the **network configuration**, no significant barriers have been identified.

- Interface with external systems and data exchange platforms

Currently, the device registry exchanges information with sDATA through a REST API, which is an open and widely used communication protocol. From the **standardisation** perspective, the use of standard communication protocols facilitates the replication of the communication across different environments, as it reduces dependence on a specific underlying software implementation. The information exchanged through this interface is required by local flexibility market platforms and related services. However, there is currently no harmonised communication standard for local flexibility market data exchange at European level. Therefore, while the communication protocols themselves do not constitute a significant barrier to replication, adaptations to the specific

information exchange requirements of different platforms and market implementations may still be required.

Regarding **interoperability**, the use of standard communication protocols facilitates interoperability with platforms supporting compatible protocols. However, interoperability also depends on the specific interfaces and technical requirements implemented by each market platform, TSO, or related service consuming data. Therefore, interoperability is not expected to constitute a major ICT barrier, although additional adaptations may be required at the interface/application level.

Finally, the **network configuration** factor is not considered relevant for ICT replicability.

3.3.3 Regulatory dimension assessment

Since the Device Registry supports the registration and prequalification of assets participating in LFMs, the tool is sensitive to the regulatory dimension, as the information required for device registration and the requirements applicable to the prequalification process are highly dependent on the applicable regulatory framework.

Regulatory scalability

The factors affecting the regulatory scalability are the regulatory maturity of the target market and alignment with other existing market mechanisms.

Regarding the **regulatory maturity**, currently there are no formally regulated procedures for prequalification, qualification and baseline definition, just guidelines to be adopted by LFM operators. This limited regulatory maturity may hinder the scalability of the Device Registry, as the requirements and procedures that the tool needs to support may evolve as LFM regulatory frameworks become more mature and harmonised.

From the **alignment with existing market mechanisms** perspective, the device registry is explicitly intended to support LFM participation, while ancillary services and wholesale markets already have their own procedures and systems. Therefore, this factor is not applicable to device registry.

Regulatory replicability

The factors affecting the regulatory replicability are the dependence on national regulation and the flexibility product definition.

Regarding the **dependence on national regulation**, as the device registry is affected by the absence of a common regulatory framework establishing the requirements and the procedure to register and prequalify assets, the tool is sensitive to national regulations. However, the technical design of the tool makes it adaptable to different contexts and requirements (response time, operational boundaries and prequalification criteria). Therefore, although some adaptations to national regulations would be required, it does not impose a significant barrier to the replicability of the tool.

From the **flexibility product definition**, the specific requirements and characteristics in different countries are yet to be defined. However, the device registry is prepared to be compatible with different product definitions. Therefore, differences in flexibility products are not expected to constitute a major barrier to replicability, although adaptations to the configuration and validation criteria may be required for specific products.

3.3.4 Social dimension assessment

The device registry tool can be used either directly by the FDOs, or by the aggregator representing the FDOs. Therefore, the social dimension is relevant to understand the social barriers that the device registry tool may encounter when scaling and replicating the solution.

Social scalability

The social factors affecting scalability are how the user engagement model facilitates the engagement of new users, the economic attractiveness for end users to participate in these markets, digital skills required and the operational complexity.

From the **user engagement model** perspective, user engagement with the Device Registry depends largely on users' willingness and opportunity to participate in LFMs. The Device Registry itself does not provide a direct value proposition to end users but rather supports the registration and prequalification processes required for market participation. Therefore, adoption of the tool is closely linked to the development and uptake of LFMs and related participation mechanisms.

Regarding the **economic attractiveness**, the device registry does not provide any direct economic benefits as the tool is a prerequisite to participate in LFMs. Therefore, this factor is not considered directly relevant for the tool as its economic attractiveness depends on the economic attractiveness of LFMs.

The **digital skills** are not expected to constitute a significant barrier if the FDO registers their assets through the aggregator, which expected to possess the technical expertise required for the registration process. However, if end users register their assets directly, they may lack the knowledge required to provide the necessary device information and support the initial setup of communication between the Device Registry and the device.

From the **operational complexity** perspective, the onboarding process may require support from technically qualified personnel, as communication between the Device Registry and the device must be configured and asset-specific technical information must be collected. However, the registration process itself is straightforward, and the prequalification process is largely automated.

Social replicability

The social factors identified as relevant for the replicability of the device registry are the social acceptance in different countries, the transferability of engagement strategies and the role of intermediaries.

From the **social acceptance** perspective, the only identified barrier is the reluctance of the users to share their data as they have to share it through a common platform. However, this is not expected to pose major challenges, as users of the device registry are expected to be familiar with data sharing on such type of platform.

The **transferability of engagement strategies** is not applicable to the device registry, since as previously stated, the engagement is not directly related to this tool but to previous tools and third parties.

Finally, for the same reason, the **role of intermediaries** is an important factor due to the dependence on external stakeholders. This would be applicable to any country where the device registry tool is replicated and would also depend on national regulations that might require the use of such a tool.

3.4 sGRID

3.4.1 Overview of the tool

sGRID is the tool that provides DSOs with the mechanisms to monitor their grid and forecast congestions in the LV networks. Based on these forecasts, sGRID connects to the LFM platform to send flexibility requirements for mitigating the congestion. Different instances of sGRID have been deployed in the Slovenian, Spanish and Italian pilot sites. Although the internal logics and models differ across them, the three of them follow the same objectives. The following subsections provide an overview of each implementation, highlighting the characteristics relevant for the SRA of the tool.

3.4.1.1 Slovenian pilot site

sGRID in the Slovenian pilot communicates externally with the **weather forecast service**, which is not pilot-specific as it is an external service that can be used in any pilot, and with **sDATA** to retrieve all the data coming from the data sources (which includes the dynamic data coming from SCADA and the AMI systems of the DSO, as well as the static data such as the grid topology and grid limits). Thus, there is **no direct interaction with the data sources from the pilot**. However, the data models coming from sDATA may affect the replicability of the tool from the software perspective, as well as the communication with sDATA. On the other side, sGRID connects with **sMART to send the flexibility requests,** which will affect the technical replicability when connecting to other LFM platforms, and the regulatory scalability and replicability since it might be dependent on the national regulatory framework.

Internally, sGRID consists of three engines. The first is the **RES and load forecast**. It is pilot-specific, as it depends on the number and typology of RES units and loads connected to the grid. This affects both the scalability and the replicability of the tool. The second consists of the **load flow module and the grid status assessment**, which can be merged into a single **congestion forecasting module**. Its scalability is constrained by grid size, since larger networks increase computational requirements. The third is the **TLS stage calculation**. Although it depends on grid specifications, it does not pose a significant scalability or replicability barrier: the module takes network characteristics and congestion forecast results as inputs, while the underlying algorithm remains independent of the specific network configuration.

As the **end user of this tool is the DSO**, the social dimension will not be a relevant dimension and therefore will not be assessed.

The architecture of the tool is represented in Figure 10.

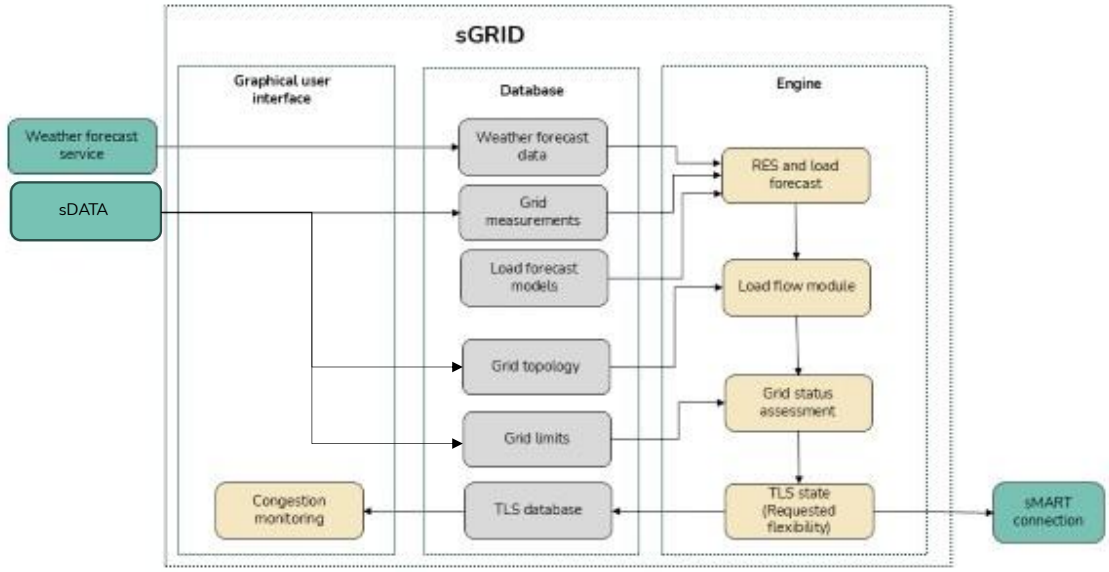


Figure 10: sGRID architecture in the Slovenian pilot site

3.4.1.2 Spanish pilot site

In the Spanish pilot site, sGRID communicates externally with four systems. It connects to the **weather forecast service**, which is an external service independent of the pilot site. It connects to the pilot's **SCADA and AMI systems** to retrieve grid measurements, making this interface pilot specific. This affects scalability, since the size of the grid may increase the number of simultaneous interactions with these systems, and replicability, since it depends on the communication protocols and data models

used. It connects to the pilot's **GIS** to retrieve the grid topology, which can affect replicability because it depends on the data model. Finally, it connects to **sMART** to send the flexibility requirements. This affects technical replicability, depending on the data model and communication protocols, as well as regulatory scalability and replicability, since regulatory frameworks and flexibility products may require adaptations.

Internally, the Spanish sGRID instance is composed of the following modules:

- **The grid monitoring and forecast modules** are pilot specific. They affect the scalability of the tool, since they may increase the volume and frequency of data exchanged with these systems, and the replicability, since this depends on the asset typology.
- **The power flow analysis, congestion detection and forecast, sensitivity analysis, and grid fault management** can be grouped as the **congestion forecast and management module**. This may affect the scalability of the tool, since the size of the grid can affect its computation requirements. Its effect on replicability is reduced, however, because although it depends on the characteristics of the grid, the algorithms remain independent of the network configuration.
- **The market integration module** deals with the preparation and submission of the flexibility requirements, analysed through the connection with sMART.

As the **end user of this tool is the DSO**, the social dimension will not be a relevant dimension and therefore will not be assessed.

The architecture of the tool in the Spanish pilot site is represented in Figure 11.

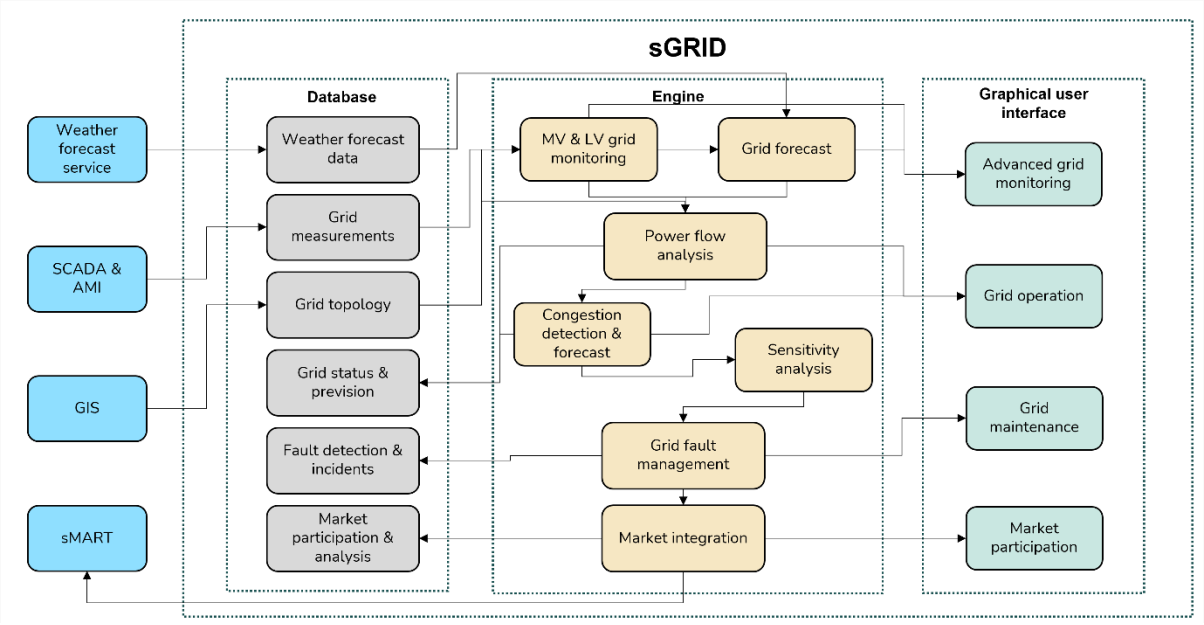


Figure 11: sGRID architecture in the Spanish pilot site

3.4.1.3 Italian pilot site

The external communication of the Italian sGRID instance is similar to the Slovenian pilot, communicating with **sDATA** for retrieving grid measurements and typology and with an **external weather forecast service.** Although sGRID and sMART are interlinked, they do not directly interact as the DSO manually uses sMART to generate the flexibility requirements.

Internally, the modules are: the **grid reconstruction module**, the **prosumer weather-based consumption model** and the **grid condition forecasting module**, which can be grouped under the **grid**

monitoring and forecasting functionality and is pilot specific, as it may affect the scalability of the solution as the size of the grid and the number of consumers may increase the volume and frequency of data exchanged with these systems, and the replicability since it will depend on the grid topology and loads and RES typology. Finally, the **congestion evaluation**, which similarly to the other pilots may affect the scalability due to computation requirements but not the replicability. The architecture of the tool in the Italian pilot site is represented in Figure 12.

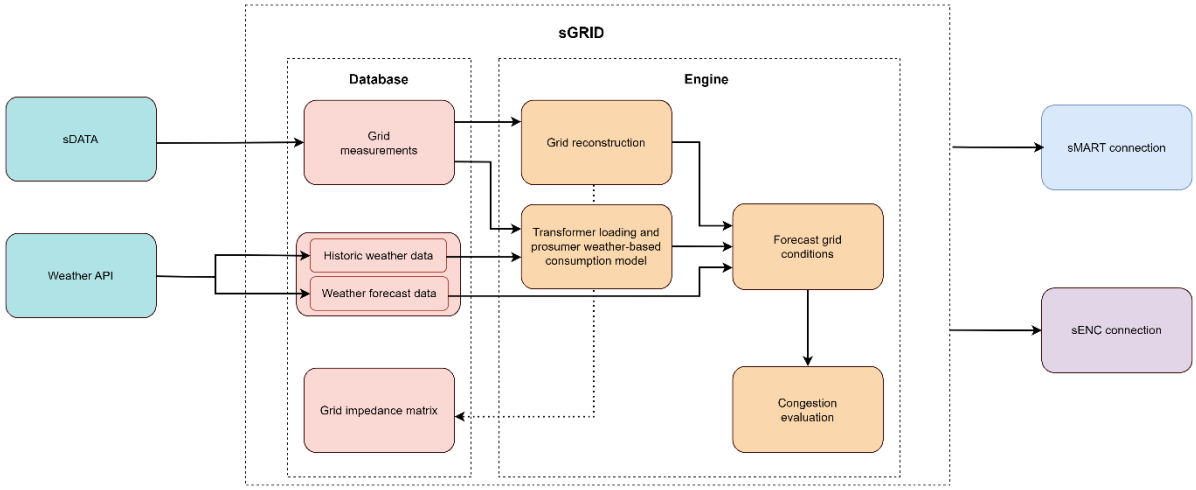


Figure 12: sGRID architecture in the Italian pilot site

3.4.2 Technical dimension assessment

Derived from the previous analysis of the sGRID instances in the three pilot sites, two different data provision approaches should be considered:

- Data provision through sDATA for the Italian and the Slovenian pilots. This data includes measurements and grid topology. Therefore, the communication with sDATA as an external system will be a key factor for the ICT scalability and replicability, while the integration of the data will affect the software scalability and replicability.
- Data provision directly from the pilot for the Spanish pilot through the AMI and SCADA systems for measurement data, pilot GIS data for the grid topology. The communication with these pilot data sources will affect the ICT scalability and replicability, while the integration of the data will affect the software scalability and replicability.

Regarding the interactions with external systems, apart from sDATA in the Slovenian and Italian pilots, in the three pilots sGRID interfaces with sMART to send the flexibility requirements and receive the results of the market sessions. This will affect the ICT and software replicability regarding the communication protocols and data models respectively, while no significant scalability barrier is expected, as the size of the DSO is not expected to significantly affect the communication requirements with the LFM platform.

Finally, the internal layers that can affect the software scalability and replicability are:

- Grid condition forecasting, that encapsulates the generation and consumption forecasts-related functionalities from the three pilots as they include the forecasting of RES generation, load consumption and grid conditions, as its replicability depends on the grid topology and asset typologies supported, while its scalability depends on the size of the grid and the number of assets to be processed.

- Congestion forecasting and management modules from the three pilots, which may affect scalability depending on the number of lines and the associated computational requirements.

In summary, the main technical factors affecting the technical scalability and replicability of sGRID in the three pilots are:

- Software scalability and replicability of the integration of data coming from the pilot AMI and SCADA systems (either directly communicating with the pilot systems or through sDATA).
- Software replicability of the integration of the network topology data.
- Software scalability and replicability of the modules dealing with grid status and congestion forecasting.
- Replicability of the interface with local flexibility market platforms (sMART)
- ICT scalability and replicability of the communication with pilot systems (AMI and SCADA in Spanish pilot), sDATA (Slovenian and Italian pilots) and sMART (the Slovenian and Spanish pilots).

3.4.2.1 ICT scalability and replicability

ICT scalability

From the **technology evolution** perspective, the scalability of sGRID is expected to improve over time as cloud computing capabilities, communication networks and edge computing technologies continue evolving. Since the tool has to process a high volume of data coming from several grid networks, loads, generators and assets, the evolution towards more efficient computing and AI-based forecasting technologies is expected to improve the computational efficiency of the solution.

From the **existing infrastructure** perspective, sGRID does not present significant scalability limitations in general, since, similarly to sENC and sFLEX, the three pilot sites have deployed sGRID in the cloud, allowing computational resources to be increased horizontally according to the size of the distribution grid. Consequently, scaling up the solution mainly requires allocating additional computing, storage and networking resources, with no major architectural changes or modifications expected for the application itself.

From the **interface design** perspective, the sMART interface does not impose significant scalability barriers, as a single interface can support the interaction independently of the size of the DSO or grid. Similarly, increasing the number of assets, loads and lines does not require additional interfaces to access the data sources. In the Spanish pilot, sGRID interfaces with the DSO's SCADA system through a single connection, while AMI data is retrieved through FTP. Therefore, increasing the number of assets or measurements does not require additional interfaces, although it may increase the volume of data exchanged. In the Slovenian and Italian pilots, pilot data is retrieved through sDATA, where a single endpoint provides access to the required data. Consequently, increasing the size of the grid does not require the creation of additional interfaces.

ICT replicability

- Interaction of the tool with DSO systems (Spanish pilot)

In the Spanish pilot the communication with the pilot data sources is, on the one hand connects to the SCADA system through MQTT messaging, and on the other hand, through an FTP server for retrieving consumption and generation measurements. Both are widely used and standardised communication protocols and therefore do not represent significant **standardisation** barriers.

Regarding the **interoperability**, minor developments would be required to connect sGRID to different SCADA systems, as well as the configuration of the file transfer with the corresponding AMI system.

Therefore, although this does not imply a significant barrier, minor ad hoc adaptations may be required to deploy the tool with different DSO systems.

Finally, from the **network configuration** factor, the solutions rely on the availability of smart meters and SCADA systems in the pilot site in order to be able to communicate with the pilot and retrieve the necessary data.

- Interface of the tool with sDATA (Slovenian and Italian pilots)

The communication with sDATA in the Slovenian and Italian pilots is managed through REST APIs, configuring the endpoints to retrieve the necessary data. REST APIs are widely used for communication between services in data-space environments and therefore do not represent a significant **standardisation** barrier from the ICT perspective.

Regarding the **interoperability**, connecting sGRID to a different data space or data source would require adapting the endpoints configuration and/or deploying the dedicated connectors required to establish the connection. Although this would require a dedicated adaptation, this would not impose a significant ICT replicability barrier.

Finally, the **network configuration** factor is not relevant to the ICT replicability.

- Interaction of the tool with sMART (Slovenian and Spanish pilots)

In the Slovenian and Spanish pilot sites, the communication between sGRID and sMART is performed through REST APIs. Similarly to sENC and sFLEX, from the **standardisation** perspective, the use of standard communication protocols facilitates the replication of the communication across different environments, as it reduces dependence on a specific underlying software implementation. However, there is currently no harmonised communication standard for local flexibility market data exchange at European level. Therefore, while the communication protocols themselves do not constitute a significant barrier to replication, adaptations to the specific interfaces and communication requirements of other market platforms may still be required.

Regarding **interoperability**, the use of standard communication protocols facilitates interoperability with market platforms supporting compatible protocols. However, interoperability also depends on the specific interfaces and technical requirements implemented by each market platform. Therefore, the communication can generally be replicated without major ICT barriers, while additional adaptations may be required at the interface/application level.

Finally, the **network configuration** factor is not relevant to the ICT replicability.

3.4.2.2 Software scalability and replicability

Software scalability

From the **modularity** perspective, sGRID architectures are modular by design, with the different components working in parallel and independently. This facilitates the implementation of additional modules and the deployment of the tool in larger distribution grids and limits the increase in computational efforts when scaling-up the solution as not all the modules are affected by the increase in the size of the grid to the same extent.

This modularity also facilitates **software integration,** since new functionalities can be incorporated as independent services without affecting the existing modules. However, as sGRID is designed to be a tool for small- to medium-sized DSOs, it should be noted that the independent modules with higher computational requirements (e.g., forecasting algorithms and power flow calculations) may experience increased computational loads as the grid size grows, potentially increasing processing times and requiring further optimisation or computational resources for larger deployments.

Software replicability

- Integration of data coming from the pilot AMI and SCADA systems

sGRID measurements data rely on SCADA and AMI specific data models from the pilot sites, which do not follow any open standards. The integration of this proprietary data models into a common standard (e.g., CIM) would require the adaptation or the development of a middleware that converts these heterogenous data models into CIM, imposing a significant barrier for replicability in terms of both **standardisation and interoperability**.

Regarding the **network configuration**, the specific configuration of the distribution network does not directly affect the integration of measurements from the SCADA and AMI systems.

- Integration of network topology data (Slovenian and Spanish pilots)

The grid topology data is used in the Slovenian and Spanish pilots, and both follow the CIM standards for grid representation. In the case of the Slovenian pilot, data is directly provided by the DSO in this format through sDATA. In the case of the Spanish pilot, the topology alchemy transformed the structured GIS data provided by the DSO into the CIM format. In the Italian pilot, the topology data was used only for assessing the accuracy of the grid reconstruction module, so the data is not required for the usual operation of the tool once commercialised. The use of the CIM standard facilitates the replicability of the tools in terms of **standardisation**, although the CIM data model is relatively complex and is not yet widely adopted for DSO grid representations. However, the use of the topology alchemy improves the replicability in this sense as it is not required that the original grid model follows the standard.

The connection to sDATA in the Slovenian pilot, and the use topology alchemy in the Spanish pilot, facilitates **interoperability**, as the tools are less sensitive to vendor-specific data models.

Regarding the **network configuration,** even though the CIM format provides detailed data about the configuration of the grid, the experience in the project has demonstrated that producing the final digital model of the grid still requires some simplifications, manual adjustments and manual mapping between measurement data and grid topology.

- Interface with LFM platforms (Slovenian and Spanish pilots)

The same data models heterogeneity across Europe for communication with LFMs affect sGRID. Therefore, the structure of the data exchanged between the sGRID tool of each pilot and their sMART is platform-specific, meaning that adaptations would be required to connect to other market platforms. This implies a barrier to the **standardisation** from the software replicability perspective. Similarly to sENC and sFLEX, the adaptation effort is expected to be limited to implementing adaptations to additional market platforms, without requiring major development effort.

Finally, the **network configuration** is not relevant for the interaction with sMART.

- Grid status and congestion forecasting

Since the grid status and congestion are part of the internal components of the tools, **standardisation** and **interoperability** are not relevant.

Regarding **network configuration**, the forecasting models may be affected by the typology of the loads and RES connected to the grid and the grid topology itself, potentially affecting the replicability of the tools. However, the forecasting approach can be replicated with some adaptations of the models such as training the models with the available historical data and adapting the parametrisation of the model to better adapt to the network topology.

3.4.3 Regulatory dimension assessment

The use, scalability and replicability of sGRID is highly sensitive to the regulatory framework. Although the use of sGRID as a grid monitoring and management tool does not face any regulatory impediment, the interaction of sGRID with LFM platforms should be analysed.

Regulatory scalability

From the **regulatory maturity** perspective, although there are some European (e.g., the proposed Network code on demand response [9] and Directive (EU) 2019/944 [8]) and national (regulatory sandboxes such as Spain and the Energy Act in Slovenia), there is not still a clear definition of the mechanisms of LFMs in Europe. DSOs legal authority to use flexibility is not explicitly stated, nor the framework for procurement conditions.

Furthermore, this lack of clear rules also jeopardizes the **alignment with existing market mechanisms**, as it must be clarified how to coordinate DSOs and TSOs to avoid conflicting signals and activations between the distribution and transmission levels, and double remuneration and commitment.

Regulatory replicability

Regarding **the dependence on national regulation**, the replication of sGRID as a grid monitoring and management tool is not significantly affected, as its core functionalities are not dependent on a specific regulatory framework. However, the integration with LFM platforms may require adaptations depending on the regulatory framework applicable in the target country.

From the **flexibility products definition** perspective, the lack of harmonisation of flexibility products across European countries may require adaptations to the flexibility requirements generated by sGRID. In particular, differences in the definition of products, activation conditions, availability periods, minimum bid sizes and other procurement conditions may affect how sGRID prepares and communicates flexibility requirements to the LFM platform. Therefore, while the core functionality of sGRID can be replicated, adaptations to the configuration of flexibility products and procurement requirements may be required in different national contexts.

3.5 sPLAN

3.5.1 Overview of the tool

sPLAN is a distribution grid planning and analysis tool developed solely for the Slovenian pilot site. Its main purpose is to support the DSO's decision-making in medium to long-term grid development and planning by comparing traditional reinforcement solutions (grid upgrades) with solutions that also consider the impact and potential value of flexibility through power flow simulations.

The tool has only been deployed in Slovenia. Its architecture is represented in Figure 13.

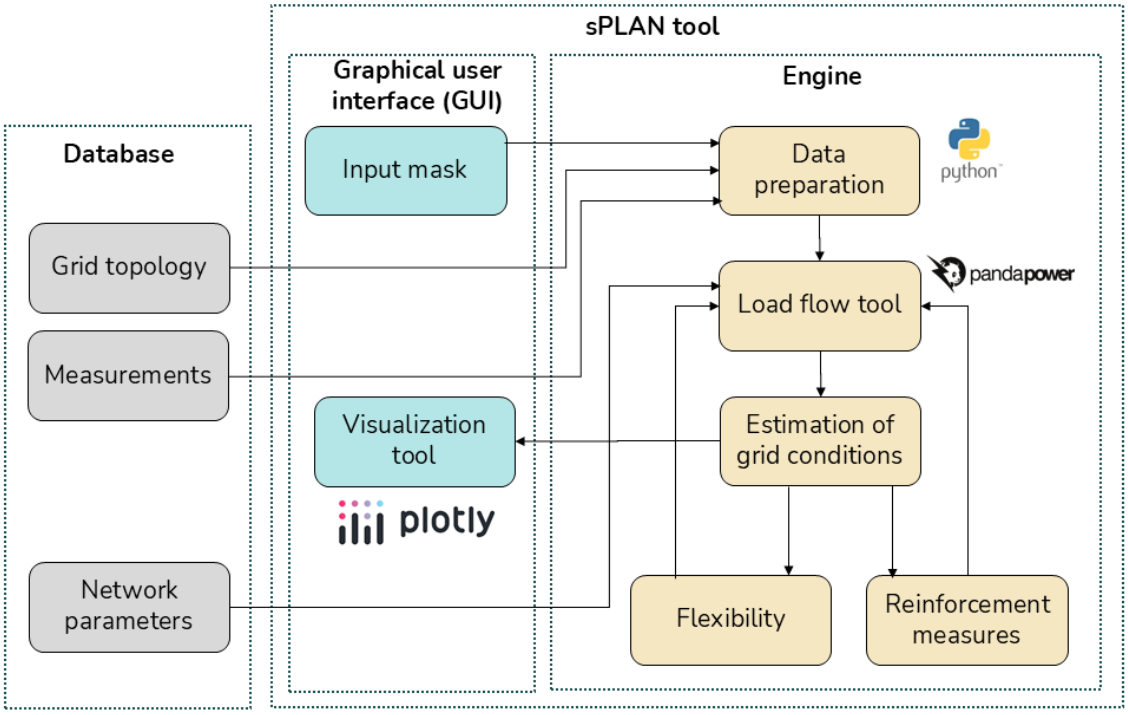


Figure 13: sPLAN architecture in the Slovenian pilot site

From the architecture, it can be derived that there is no interaction with any external tool, since as indicated in [7], sPLAN is a **standalone tool**. Furthermore, historical data from the pilot site is directly provided by the DSO and ingested by the tool, and real-time communication is not required by the tool. Therefore, there is **no interaction with the pilot site systems** (SCADA, AMI or IoT devices). Consequently, the **ICT scalability and replicability is not a relevant factor to be analysed**.

Internally, the tool processes the grid topology and historical data measurements, both provided by the DSO. The internal engines encompass data preparation, load flow and estimation of grid conditions, the flexibility module to estimate the potential benefits of flexibility based on seasonal network profiles and the optimal reinforcement module. From these functionalities, the data preparation engine would depend on the data model of the historical measurements, while the load flow and estimation of grid conditions would be affected by the size of the modelled grid and its topology. The grid reinforcement measures do not depend on the system, while the flexibility module would be dependent on the assets that are part of the grid and their digital model.

In summary, for the technical assessment the following aspects should be analysed:

- Software replicability of the data integrated through the data preparation module, which includes historical data and grid topology.
- Software scalability and replicability of the load flow and estimation of grid conditions.
- Software replicability of the flexibility module.

As the **end user of this tool is the DSO**, the **social dimension will not be a relevant** dimension and therefore will not be assessed.

The tool **does not interact with any LFM platform**, and flexibility is considered as part of the optimization logic, so no regulation affects directly to the tool. Therefore, the **regulatory dimension has not been considered relevan**t for sPLAN and will not be assessed.

3.5.2 Technical dimension assessment

3.5.2.1 Software scalability

Software scalability

From the **modularity** perspective, sPLAN architecture is modular by design, with the different components working in parallel and independently. This facilitates the implementation of additional modules and the deployment of the tool in larger distribution grids and limits the increase in computational efforts when scaling-up the solution as not all the modules are affected by the increase in the size of the grid to the same extent.

Regarding the **software integration**, as the tool is limited to the simulation of one representative week per season, the computation workloads are reduced, thus reducing the impact of grid size on the computational workload. Furthermore, sPLAN relies on PandaPower to calculate the power flows, which uses optimized solvers and optional compilation tools that can reduce computational time for larger networks.

Software replicability

- Integration of data through the data preparation module (historical data and grid topology)

Similarly to sGRID, the network topology data model used in sPLAN is CIM, a recognised standard for the representation of electricity network data. The use of the CIM standard facilitates the replicability of the tools in terms of **standardisation**. However as indicated in sGRID, the CIM data model is relatively complex and is not yet widely adopted for DSO grid representations, implying a potential barrier to replicability. Regarding the historical data, the data provided by the DSO does not follow any standard, which implies that the data integration module would require some adaptations when replicating the solution, imposing a significant barrier for replicability in terms of **standardisation** and **interoperability**.

Finally, regarding the **network configuration**, the same barrier as in sGRID is potentially affecting sPLAN, as the tool would also potentially require manual efforts to understand and integrate the network topology.

- Load flow and estimation of grid conditions modules

As previously indicated, the modules rely on PandaPower for calculating the power flows of the grid. PandaPower relies on established power-system modelling and data-processing libraries and supports the integration of standardised network representations such as CIM. Therefore, once the network data has been appropriately integrated into the tool, these modules are not expected to introduce significant barriers in terms of **standardisation** and **interoperability**.

Furthermore, an appropriate data integration from the previous module would ensure that these modules are not significantly affected by the **network configuration** from a replicability perspective.

- Flexibility module

The flexibility module is an internal logic, so it does not affect the **standardisation** and **interoperability** replicability of the tool.

Regarding the **network configuration**, although the tool is already able to simulate the consumption and generation profiles of several DER technologies (mainly PVs, BESS, HPs and EVs), additional technologies and consumer typologies from different grids might require additional modelling.

3.6 sMART

3.6.1 Overview of the tool

In STREAM, the sMART tool serves as the LFM platform for securing fair and transparent market transactions, enabling DSOs to publish flexibility requests and FSPs to submit flexibility offers. sMART is then responsible for clearing the market and communicating the results to the relevant stakeholders.

Three different sMART instances have been developed in the Slovenian, Spanish and Italian pilot sites.

3.6.1.1 Slovenian pilot site

In the Slovenian pilot site, the sMART tool contemplates two different market mechanisms. The **long-term market** is managed manually through the sMART user interface by the DSO and FSPs, and therefore does not require interaction with external ICT systems. The **short-term market**, in contrast, is integrated with other STREAM tools: it communicates with **sGRID** to receive the TLS state and the resulting flexibility requests, and with **sFLEX** to receive flexibility bids for the auctions opened by the DSO and to communicate the activated bids for the subsequent activation of flexibility assets. Additionally, sMART communicates with the **device registry** to retrieve information on the prequalified assets eligible to participate in the auctions. These interactions are reflected in Figure 14.

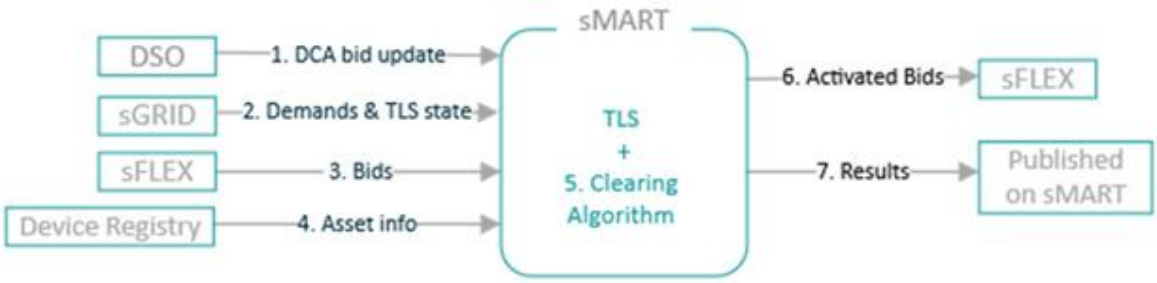


Figure 14: sMART interactions in the Slovenian pilot site

The definition of the products and the timelapses of each market typology are explained in detail in D4.2 [6].

From the technical perspective, the following aspects are relevant for the scalability and replicability assessment:

- Software scalability and replicability of the long-term market functionalities.
- Software scalability and replicability of the short-term market functionalities.
- ICT and software scalability and replicability of the interfaces with external tools.

As the end users of sMART are DSOs and FSPs, and the interaction with the platform is primarily performed through professional users, **no specific social barriers related to the scalability or replicability of the tool are expected**. Therefore, the social dimension is not considered relevant for this assessment.

As sMART is the LFM platform, the regulatory dimension is particularly relevant, as the deployment and replication of the tool are directly dependent on the regulatory framework governing local flexibility markets. The assessment will therefore analyse the regulatory factors that may enable or constrain the scalability and replicability of sMART across different national and market contexts.

3.6.1.2 Spanish pilot site

Similarly to the Slovenian sMART, in Spain the tool has two different market mechanisms: **long-term market** which, as in the Slovenian pilot site, is manually operated both by the DSO for requesting long-

term flexibility availability, and by the FSPs to bid on the open auctions, as well as the **short-term market**, which communicates with **sGRID** to receive the flexibility requirements from the DSO in order to open the LFM sessions, and with **sFLEX** and **sENC** to receive the flexibility bids, both for congestion management and P2P market, and to communicate the market results. Regarding **device registration and prequalification**, these functionalities are integrated into the Spanish sMART instance. FSPs can register their assets either manually through the sMART interface or through an automated service based on REST APIs, allowing multiple registration requests to be processed simultaneously. However, the review and acceptance of asset registrations and prequalification results are performed manually by the MO and the DSO. The connection of sMART with other STREAM tools in the Spanish pilot is presented in Section 3.6.

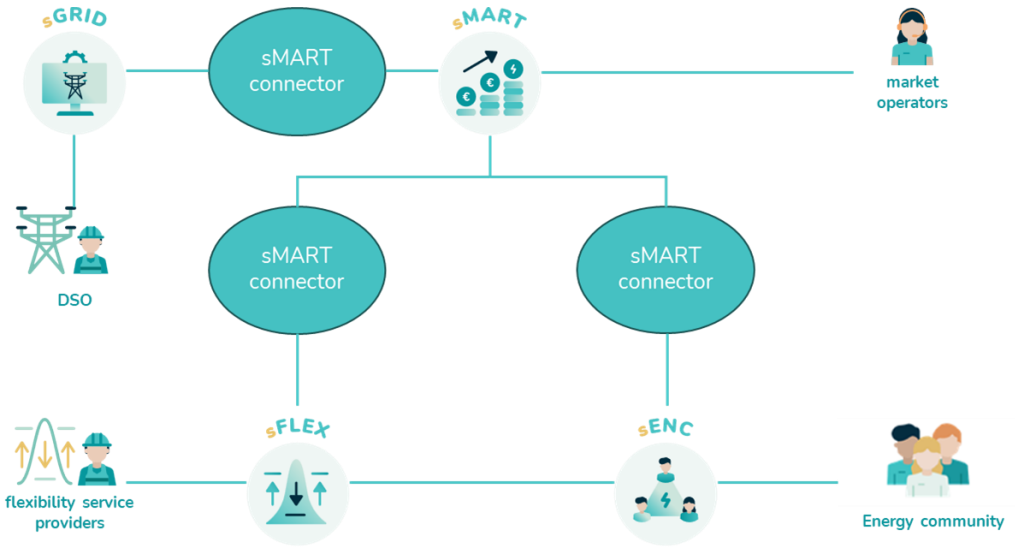


Figure 15: sMART interaction in the Spanish pilot site

From the technical perspective, the following aspects are relevant for the scalability and replicability assessment:

- Registration and prequalification software scalability and replicability
- Long-term market software scalability and replicability
- Short-term market software scalability and replicability
- ICT and software scalability and replicability of the interfaces with external tools

As in the Slovenian pilot site, the end users of sMART are DSOs and FSPs, and no specific social barriers related to the scalability or replicability of the tool are expected. Therefore, **the social dimension is not considered relevant for this assessment**.

Similarly, the **regulatory dimension is particularly relevant** for the Spanish sMART instance, as the deployment and replication of the tool are directly dependent on the regulatory framework governing local flexibility markets. Therefore, the same regulatory considerations described for the Slovenian pilot site apply to the Spanish pilot and will be considered in the assessment.

3.6.1.3 Italian pilot site

In the Italian pilot site, unlike the Slovenian and Spanish pilots, sMART implements only a **short-term market mechanism**. In this configuration, sMART mainly acts as a front-end for the DSO, receiving the congestion calculations from **sGRID** and providing the DSO with the interface to analyse the identified congestion issues and manually define the corresponding flexibility requirements. On the FSP side, flexibility assets are manually registered in sMART, while flexibility offers are manually submitted based on the results provided by sENC. Therefore, unlike the Slovenian and Spanish pilot sites, the

Italian sMART instance does not directly implement automated interactions with FSPs for the submission of flexibility bids.

The following aspects should be analysed as part of the technical assessment:

- Short-term market software scalability and replicability.
- Device registration and flexibility offer management software scalability and replicability.
- Interface with external tools ICT and software scalability and replicability.

As in the Slovenian and Spanish pilot sites, the end users of sMART are DSOs and FSPs, and **no specific social barriers related to the scalability or replicability of the tool are expected**. Therefore, the social dimension is not considered relevant for this assessment.

Similarly, the **regulatory dimension is particularly relevant** for the Italian sMART instance, as the deployment and replication of the tool are directly dependent on the regulatory framework governing local flexibility markets. Therefore, the same type of regulatory factors identified for the Slovenian and Spanish pilots will be considered for the Italian pilot.

3.6.2 Technical dimension assessment

From the previous analysis, it is derived that the technical dimension assessment should mainly considered the following factors that may affect the scalability and replicability of sMART:

- Software scalability and replicability of the adaptability to different market and regulatory requirements, encapsulating the device registration and prequalification, and the long-term and short-term markets.
- ICT and software scalability and replicability of the interfaces with other tools and systems.

3.6.2.1 ICT scalability and replicability

ICT scalability

From the **existing infrastructure** perspective, increasing the number of DSOs, flexibility zones, FSPs and assets would increase the necessary storage and communication capacity, particularly due to the larger static data of the assets, DSOs, market agents, flexibility requests and bids, and market transactions. However, these requirements can be easily managed by increasing the storage and networking resources without changing the architecture of the tool. Therefore, the existing infrastructure is not expected to be a significant barrier.

From the **interface design** perspective, the three pilot implementations are not expected to require additional communication interfaces when scaling the solution to a larger number of assets, users or connected tools. In the Spanish pilot, a single interface allows multiple assets to be registered, while the automated REST API enables multiple registration requests to be handled simultaneously. In the Slovenian pilot, sMART uses interfaces with sGRID, sFLEX and the sDATA, with the same interfaces supporting the exchange of information independently of the number of participating assets or users. In the Italian pilot, sMART mainly acts as a front-end for sGRID, while FSPs register assets and submit bids through the platform. Therefore, increasing the number of DSOs, FSPs or connected systems and tools would increase the number of interactions and transactions handled by the platform, but would not require the configuration of additional interfaces. Therefore, the interface design is not expected to constitute a significant ICT scalability barrier.

ICT replicability

- Interface with external tools

The Spanish pilot uses REST APIs for the device registry and AMQP for bidding, and the SOAP protocol for DSO requirements, while the Slovenian pilot uses REST APIs for communication with sGRID, sFLEX

and the sDATA. In the Italian pilot, sMART exposes secure JSON-based REST APIs over HTTPS for automated data exchange and integration with other tools. Therefore, the use of these commonly used communication protocols facilitates replication from the **standardisation** perspective and reduces the dependence on vendor-specific technologies.

Regarding **interoperability**, the use of these commonly used communication protocols facilitates integration with external systems. However, the specific interfaces and communication requirements of the connected tools may differ between environments, which might require the adaptation of the communication to replicate sMART.

Finally, the **network configuration** is not considered relevant for the ICT replicability of sMART.

3.6.2.2 Software scalability and replicability

Software scalability

From the **software integration** perspective, the main scalability limitation sMART is related to the manual processes involved in asset registration, prequalification and market participation. In the Spanish and Italian pilots, the registration and prequalification of assets require manual interactions from the MO and the DSO. A large-scale deployment involving a significantly higher number of DSOs, FSPs and assets would increase the necessary actions required by the MO and the DSO to review and validate registration and prequalification requests, potentially limiting the scalability of the platform.

Similarly, in the Spanish long-term market, FSPs submit qualification requests manually, while their validation and verification require manual intervention from both the MO and the DSO, which would affect the scalability in a similar way.

Regarding the **market clearing process, which is part of the long-term and short-term market functionalities**, an increase in the number of participating DSOs, FSPs, flexibility bids and flexibility requirements would increase the amount of information processed by the platform. However, the market clearing algorithm does not require meaningful computational resources, as it mainly consists of ordering bids according to their price and identifying the market clearing point. Therefore, although the processing requirements would increase with the number of market participants and transactions, this is not expected to constitute a significant scalability barrier.

Software replicability

- Adaptability to different market and regulatory requirements

The replicability of sMART's device registration and prequalification, long-term market and short-term market functionalities is mainly dependent on the regulatory framework and the specific market arrangements defined in each deployment. These aspects are therefore assessed under the **regulatory dimension**. From the software perspective, however, sMART needs to be flexible to easily adapt the tool to the different regulatory frameworks, which might include adaptations in devices eligibility criteria, required information, validation procedures, flexibility products, market timeframes, bidding requirements, market session structures and clearing rules. These potential differences may require adaptations to the corresponding market logic, configuration and data structures when replicating the tool in a different regulatory environment. However, these adaptations are not expected to constitute a significant software replicability barrier, as the core functionalities of the platform remain applicable.

- Interface with external tools

The three sMART instances use JSON-based data models for exchanging information with external tools. Although the specific information exchanged is different depending on the connected tool and does not follow a common standardised data model, the widespread use and flexibility of JSON facilitate the adaptation of the data exchange when integrating sMART with different systems. The use of JSON does not constitute a major barrier to software replicability in terms of **standardisation**

and interoperability, although adaptations to the specific data structures and information requirements of the target systems may be required.

3.6.3 Regulatory dimension assessment

Regulatory scalability

The regulatory scalability of sMART is mainly related to the **regulatory maturity** of local flexibility market regulations, as well as to their **alignment with existing electricity market mechanisms**. However, the three STREAM implementations present different approaches to regulatory dependency.

In the **Spanish pilot**, sMART implements the local flexibility market platform developed by OMIE, which is intended to be tested within the Spanish regulatory sandbox. This provides a clear pathway towards the scaling of the solution within the Spanish regulatory framework and supports its potential deployment beyond the pilot. However, this implementation is specifically aligned with the Spanish market design and regulatory framework and, therefore, its scalability is intended exclusively for the Spanish regulation.

In contrast, the **Slovenian and Italian sMART implementations are designed with a more flexible approach**, allowing the market configuration to be adapted as national regulatory frameworks for local flexibility markets evolve. In both cases, the DSO acts as the local flexibility market operator, while in the Spanish pilot the market is operated through the national market operator. This difference in market governance may affect the roles, responsibilities and procedures implemented in sMART when scaling the solution to additional DSOs or market areas.

At larger scale, the regulatory framework should also ensure **alignment with existing electricity market mechanisms**, particularly wholesale and ancillary services markets. As the number of local flexibility markets and participating resources increase, clear rules are required to avoid conflicting flexibility requests, double commitments or double remuneration of the same resources.

Regulatory replicability

The regulatory replicability of sMART is highly **dependent on the national regulations** related to local flexibility markets and on the specific market design adopted in each country. The three STREAM implementations follow different approaches to this dependency.

In the **Spanish pilot**, sMART is based on the local flexibility market platform developed and operated by OMIE and is intended to operate within the Spanish regulatory framework. Its replication within Spain is therefore facilitated by the alignment between the platform and the national market operator and regulatory environment. Although the local flexibility market model and its associated processes could be used as a harmonized solution, in some cases it may be necessary to make certain adaptations to ensure compliance with the regulatory requirements of each country.

In the **Slovenian and Italian pilots**, sMART is developed as a more flexible market platform that can be adapted to the regulatory framework and market arrangements established in each country. In these pilots, the **DSO acts as the local flexibility market operator**, which changes the roles and responsibilities of the DSOs compared to the Spanish pilot. The platform therefore needs to accommodate differences in market governance, including the responsibilities of the DSO, FSPs and other market participants.

Regarding **flexibility products definition**, differences in the definition of flexibility products, procurement timeframes, bidding rules, activation conditions and settlement procedures directly affect the operation of the LFM platform. Therefore, replicating sMART in a different regulatory environment may require adaptations to the market rules.

3.7 sDATA

3.7.1 Overview of the tool

In the STREAM project, sDATA is the data exchange platform deployed in the Slovenian, Italian and Finnish pilots, aiming at providing secure, standardized and efficient data access for data providers (pilot users) and consumers (STREAM tools). The objective of the tool is to facilitate interoperability and availability of data for downstream tools. Different versions of the tools have been deployed, one shared by the Slovenian and Italian pilots, and another one in the Finnish pilot.

3.7.1.1 Slovenian and Italian pilot sites

The Slovenian and Italian pilots share the same sDATA implementation. The tool interacts externally on the one hand with multiple **data providers through dedicated connectors and adapters**, including SCADA systems, AMI systems, EV charging stations, other pilot-specific data sources. On the other hand, it interacts with **data consumers (STREAM tools), connected through OpenAPIs for data export**. Internally, the tool is composed of two main components: the **Master Data Management** (MDM) component, in charge of managing metadata, users, permission and grid models, as well as the **Time Series** (TS) Component, which includes data ingestion, queuing, data import, processing and storage. The detailed architecture of the tool is represented in Figure 16.

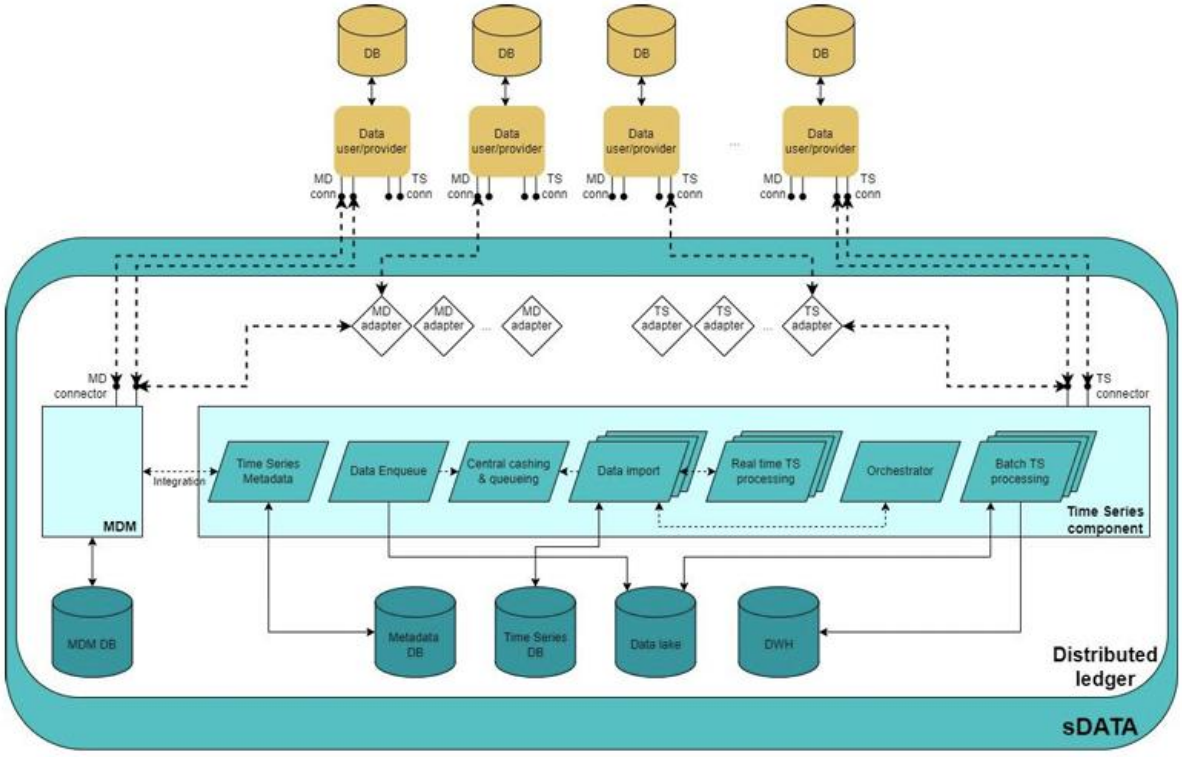


Figure 16: sDATA architecture in the Slovenian and Italian pilots

For the technical assessment, the following aspects must be considered:

- Interactions with pilot data sources.
- Interfaces with downstream analytical tools.
- Scalability and replicability of the internal functionalities (MDM and TS components).

Since sDATA is an infrastructure and data management tool whose end users are mainly technology providers, DSOs, aggregators and analytical applications, the **social dimension is not considered relevant** and will therefore not be assessed. Similarly, as sDATA does not directly implement market

mechanisms or regulatory processes, the **regulatory dimension is also considered out of scope** for the assessment.

3.7.1.2 Finnish pilot site

The Finnish implementation focuses on supporting flexibility services based on residential heating assets and providing a data warehouse for analytical activities. Externally, sDATA interacts with OPT's **control systems and controllers for data collection and storage purposes** and provides data to external consumers such as **sFLEX and other authorized stakeholders** for analytical purposes. Internally, sDATA consists of a relational control database, multiple Timescale time-series databases, a data warehouse, ETL pipelines implemented through Apache NiFi, data processing scripts and Grafana visualization services. These functionalities can be grouped into **data storage, data migration and data analytics support modules**. The detailed architecture of sDATA and its interactions with external systems is represented in Figure 17.

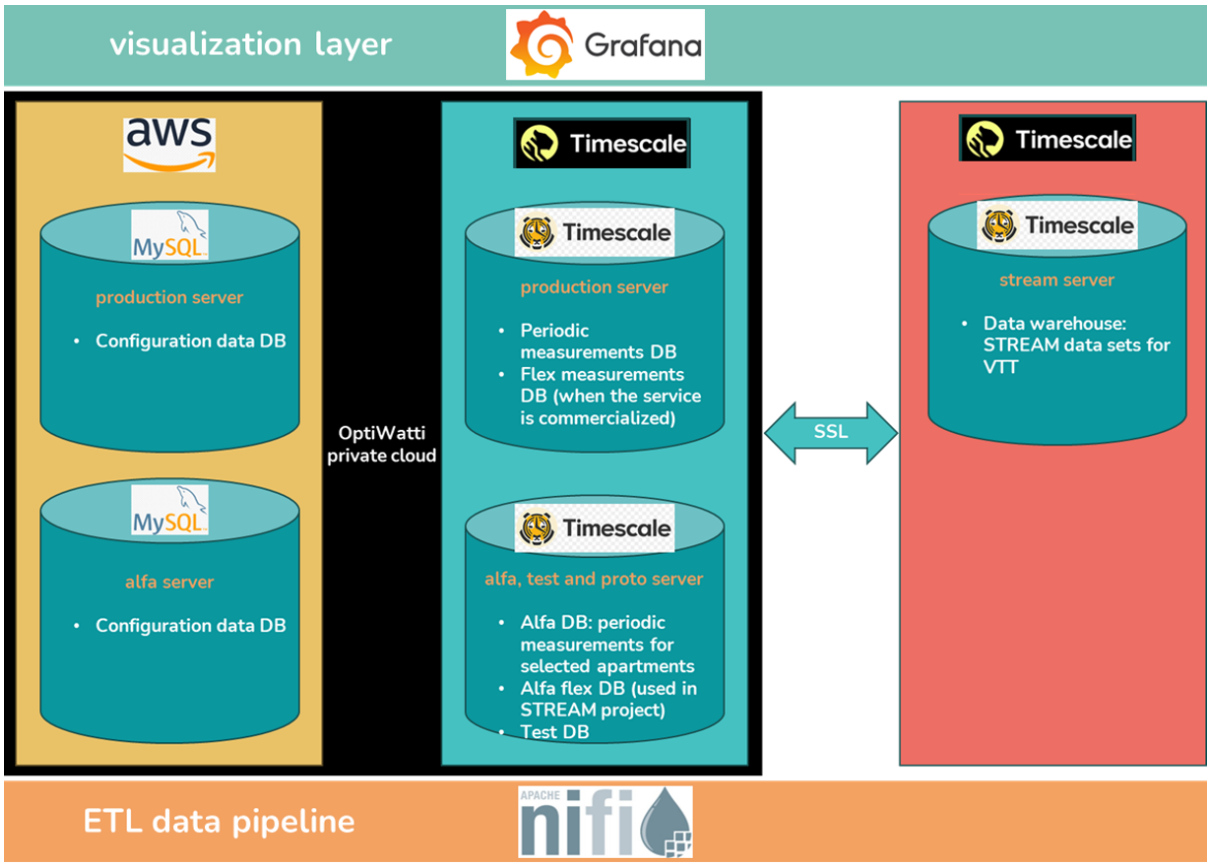


Figure 17: sDATA architecture in the Finnish pilot site

For the technical assessment, the following aspects must be considered:

- Interactions with OPT controllers.
- Interface with sFLEX.
- Internal functionalities scalability and replicability (data storage, data migration and data analytics support modules).

Similarly to the Slovenian and Italian implementation, the **social and regulatory dimensions are not considered relevant** for the assessment.

3.7.2 Technical dimension assessment

From the previous section it is derived that the main technical factors affecting the scalability and replicability of sDATA are:

- Software scalability and replicability of data integration processes.
- Software scalability and replicability of data processing, cleansing and harmonization modules.
- Software replicability of metadata management.
- ICT and software replicability of interfaces with downstream analytical tools.
- ICT scalability and replicability of communication with external data providers and consumers.

3.7.2.1 ICT scalability and replicability

ICT scalability

From the **technology evolution** perspective, the scalability of sDATA is expected to improve as cloud infrastructures, storage technologies and distributed processing frameworks continue evolving. Both implementations rely on technologies specifically designed to handle large data volumes and therefore can benefit directly from advances in cloud computing and database technologies.

From the **existing infrastructure** perspective, no significant ICT scalability barriers are expected. The Finnish implementation deploys the time-series databases in cloud environments, allowing computational and storage resources to be expanded according to data volume growth. Similarly, the Italian and Slovenian implementation relies on dedicated time-series databases, relational databases and distributed processing components that can be scaled by allocating additional infrastructure resources.

From the **interface design** perspective, scalability impacts are limited. Increasing the number of measurement points, users or data sources mainly increases the volume of exchanged data but does not require additional interfaces, as the existing APIs and connectors can accommodate larger data flows.

ICT replicability

- Interface with downstream analytical tools

Both implementations expose standardized APIs for data consumers such as sGRID and sFLEX.

The use of REST-based APIs facilitates replication because the communication approach is independent of the underlying implementation. However, tool-specific data models may require adaptations when integrating with third-party analytical tools beyond STREAM.

- Communication with external data providers and consumers

The communication mechanisms used by sDATA include REST APIs, MQTT, direct database access, file sharing, CSV files and JSON-based data exchange.

The use of standard communication technologies such as REST APIs and MQTT significantly reduces standardisation barriers. However, interoperability may still require dedicated developments because each provider exposes different endpoints, authentication mechanisms and data structures. Consequently, adapting sDATA to new data providers generally requires connector configuration or development, although this does not represent a major ICT barrier.

Network configuration is not a relevant factor for ICT replicability.

3.7.2.2 Software scalability and replicability

Software scalability

From the **modularity** perspective, both sDATA implementations are highly modular. The Italian and Slovenian implementation separates data ingestion, queuing, storage, processing and metadata management into independent components. This architecture facilitates horizontal scaling and the incorporation of additional data providers with limited impact on the existing system. Similarly, the Finnish implementation separates control databases, time-series storage, ETL pipelines, data warehouses and visualization layers, reducing scalability bottlenecks.

The principal scalability challenge is associated with the increasing volume of measurement data and metadata from the **software integration** perspective. As the number of connected assets, users and measurement points grows, additional computational resources may be required, particularly for data cleansing, aggregation and long-term retention functions.

Software replicability

- Data integration processes

sDATA integrates data originating from multiple providers that use heterogeneous data models such as JSON, CSV, SQL databases and API-based services.

The absence of a single harmonized data model for all exchanged measurements creates a moderate replicability barrier. New deployments require mapping local data structures into the internal sDATA information model and, in some cases, implementing additional adapters and ETL processes.

However, the use of generic internal data models greatly reduces this barrier compared to tightly coupled architectures.

- Data processing, cleansing and harmonisation modules

Data cleansing, normalization and aggregation are core functionalities of sDATA.

Standardisation and **interoperability** are not direct barriers because these processes occur internally within the platform. However, replicability may be affected by the characteristics of incoming datasets, including sampling frequencies, missing data patterns, data quality issues and available metadata. Although specific processing rules may require adaptation in new deployments, the general processing framework can be replicated with limited effort.

- Metadata management

The MDM component is built on generic data structures capable of storing multiple categories of metadata. Since metadata schemas can be extended without modifying the core architecture, **network configuration** has a limited impact on replicability. This functionality therefore presents low replicability barriers.

- Interface with downstream analytical tools

The APIs used by sGRID and sFLEX depend on predefined data structures and metadata definitions. Consequently, software replicability may require adaptations when integrating with analytical tools that use different information models. Nevertheless, the use of OpenAPIs and standardized formats considerably reduces the effort required for replication in terms of **standardisation** and **interoperability**.

4 SYNTHESIS OF THE MAIN FINDINGS ACROSS STREAM PILOTS AND TOOLS

From the assessments above, it can be concluded that, although each pilot site has implemented its own tools, in terms of scalability and replicability they are supported by common opportunities and affected by common barriers. This section provides a synthesis of these common opportunities and barriers, together with a summary of the key differences across pilots and tools.

4.1 COMMON OPPORTUNITIES

The common technical opportunities identified in the four pilot sites are:

- **Software modularity and cloud deployment:** the modular architecture of the STREAM tools and the cloud deployment are key scalability enablers, as these features allow for a larger-scale implementation without reducing performance or requiring adaptations to all the independent modules. Furthermore, cloud deployment facilitates allocation of computational resources according to deployment scale, minimizing investments in additional hardware infrastructure.
- **Efficient interface design:** The interfaces deployed in the pilot sites have been designed so that increasing the number of assets or the size of the modelled grids does not require the configuration of additional communications at the same scale. This enables efficient communication and supports the scalability of the tools without requiring a proportional increase in resources or reducing the overall performance of the communication layers.
- **Interoperability and standards:** The tools developed in the pilot sites are able to ingest a wide range of data formats and to communicate using several standard communication protocols. Although the data format heterogeneity is a barrier in itself (as will be identified in the following section) and some adaptations are unavoidable, the use of formats such as JSON, GeoJSON and protocols such as AMQP, MQTT and OCPP can minimise the adaptation efforts.
- **Data availability through smart meters and SCADA:** The widespread deployment of smart meters in DSO grids and the use of SCADA systems represent a crucial opportunity to deploy the STREAM tools in real-world environments.
- **Reusability of forecasting models:** The forecasting models developed in the pilot sites can be reused in other contexts and countries. Although adaptations may be required for different consumer typologies or DER technologies (see next section), the already developed models establish a strong foundation for reducing development effort and facilitating replication.
- **Use of sDATA as** a **data exchange enabler:** The use of a data space-based platform can streamline standardisation, data quality and data governance. The use of the same sDATA implementation in both the Slovenian and Italian pilot sites has demonstrated that the tool can act as an enabler for secure and interoperable data exchange across different deployment contexts.

The following common regulatory opportunities have been identified:

- **Increasing regulatory support for the establishment of LFMs in Europe:** the upcoming network code on demand response [9], European regulations such as the Directive 2019/944 [8], Directive 2024/1711 [12] and national regulations such as Ley 24/2013 [13] and Circular 8/2025 [14] in Spain, and the Slovenian Energy Act (Državni zbor Republike Slovenije (ZOEE))

promotes the establishment of LFMs, allowing DSOs to acquire flexibility services. Although further efforts are required to finalize a widespread establishment of LFMs, these regulations are expected to support the development of frameworks for LFMs and enable DSOs to procure flexibility services.

- **Emerging EnCs and the role of aggregators:** Energy communities are already an emerging and increasingly established actor in the European energy systems. Together with aggregators, which are now also regulated actors, these entities enable the participation of small consumers in LFMs.

Finally, the following common social opportunities have been identified:

- **Energy communities and aggregators as engagement enablers:** Energy communities, aggregators and other intermediary organisations can facilitate the engagement of residential customers and small-scale DER owners in flexibility markets. Their existing relationships with users can support communication, trust-building and participation, reducing the effort required to reach and mobilise a large number of individual users.
- **Trust in energy communities and aggregators to act as representatives of end users:** As it explained in Section 3.1, sENC is a tool intended for EnC managers to participate in LFMs on behalf of EnC members. This indirect participation of end users can overcome the potential technical and knowledge-related complexity of LFM participation, positioning EnCs as a pivotal actor in LFMs to overcome potential social barriers.

4.2 COMMON BARRIERS

The technical barriers identified across the four pilot sites are:

- **Heterogeneity of data formats and communication interfaces:** Data heterogeneity has been observed as a common factor hindering replicability in terms of standardisation and interoperability. Although all the tools and pilots, in general, use standard data formats (JSON, XML, GeoJSON) and protocols (AMQP, OCPP, MQTT, OpenAPI, etc.), the communication across the tools and with the LFM platforms follow different logics and data models. This reflects that adaptations would be required to deploy the tools in different contexts and frameworks, particularly at the interfaces with external systems.
- **Differences in data availability and granularity:** the different tools require different type of data at different spatial and temporal granularities: from previous day smart meters hourly or 15-minute measurements to real-time data coming from IoT devices, availability of SCADA data, GIS topology data, etc. The unavailability of any of these data sources can affect the configuration and the performance of the tools, requiring the adaptation of data ingestion and processing, and potentially requiring the use of alternative data sources or data preprocessing.
- **Integration with and access to legacy DSO systems and data (SCADA, AMI, GIS):** Access to existing DSO systems and data is highly dependent on the technical infrastructure and interfaces available in each country and organisation. Differences in system architectures, access mechanisms and data models can increase the effort required to integrate the STREAM tools.

- **Scalability of data ingestion and processing:** The volume, frequency and heterogeneity of data increase significantly when moving from pilot-scale deployments to larger portfolios of assets, customers or grid elements. For example, the Finnish pilot site has tested the tools with a limited number of users, while a real deployment would require a larger number of users. Similarly, modelling larger distribution networks would certainly imply a larger volume of data and communications. Ensuring that data ingestion, storage, processing and analytics can handle these larger volumes without affecting performance may therefore require additional optimisation and infrastructure adaptations.
- **Differences in forecasting and optimisation algorithms:** The algorithms for forecasting and optimising the behaviour of the energy communities and DERs are dependent on their typology (industrial or residential assets, PV, wind, EVs, etc.). The models that have been developed for the DERs and type of users of the pilots might require adaptations (retraining, recalibration, etc.) in other implementations. The availability of historical data and different data granularities may affect also the use of the preconfigured models.

In terms of regulatory barriers, as assessed in this deliverable and reflected in the Policy recommendations document, the following barriers prevent the scalability and replicability of the tools:

- **Unclear roles and responsibilities of the market participants (DSO, FSPs, MO, etc.):** this barrier is reflected in the different approaches followed by the pilot sites. While in the Spanish pilot site the MO (OMIE) was responsible for the operationalisation of the LFM, including market participant and device registration, and administrative prequalification and qualification, being the DSO the responsible for the technical prequalification, in the Slovenian pilot site the device registry was externalized to a third-party, communicating the results of the prequalification to the DSO and the MO through sMART. On the other hand, responsibilities of the FSPs are yet to be defined, such as the penalties for non-compliance. These differences in the allocation of responsibilities may require changes in the workflows and interfaces between the STREAM tools and the different market actors when replicating them in other countries.
- **Different flexibility products and market rules:** The flexibility products, procurement mechanisms, activation procedures and settlement rules considered by the pilots differ depending on the national regulatory and market framework. These differences affect how flexibility is defined, bid, procured, activated and settled, requiring adaptations to the configuration and workflows of tools interacting with local flexibility markets.
- **Country-specific device registry and prequalification requirements:** The requirements and processes for device registry, prequalification and qualification vary across countries. Differences in the information required, responsible entities, verification tests, technical requirements and communication procedures may require adaptations to the registration and prequalification workflows and to the interfaces between FSPs, DSOs, market operators and STREAM tools.

Finally, in terms of social barriers, the following has been identified:

- **Stakeholder acceptance and willingness to adopt new tools and processes:** The deployment of new flexibility-management and decision-support tools requires changes in existing

operational processes and interactions between market participants. Differences in stakeholder expectations, trust in automated decision-support functionalities and willingness to modify established workflows may therefore influence the adoption and replication of the tools.

- **Training and organisational adaptation:** Even where the technical and regulatory conditions for replication are met, the deployment of the tools may require users and operators to acquire new skills and adapt existing procedures. The effort required for training and organisational change may vary depending on the maturity and experience of the target organisation.
- **Dependence on intermediaries to reach and engage users:** Although EnCs have been identified as an opportunity to engage residential customers in LFMs, as pinpointed in the previous section, EnCs play a pivotal role on end user engagement and social enablers. The dependence on this type of intermediary can be a barrier to scaling up and replicating the tools. LFMs in distribution grids that are mostly composed of residential users require a large number of end users to aggregate sufficient flexibility to provide services. This implies that an entity such as an EnC can be important for ensuring broader outreach and continuous user engagement.

4.3 KEY TECHNICAL, REGULATORY AND SOCIAL DIFFERENCES

Although common opportunities and barriers exist across the different tools and pilot sites, some key differences have also been identified. These differences reflect the diversity of the contexts in which the STREAM ecosystem can be deployed and demonstrate that their core concepts can be applied beyond the specific pilot configurations. At the same time, these differences may require technical, regulatory or organisational adaptations depending on the target context. Table 1 provides a summary of the key differences, what they demonstrate as a strength of the STREAM ecosystem and their implication for replication.

Table 1: Key technical, regulatory and social differences across pilot sites

Dimension	Key differences across pilots	What these differences demonstrate	Implication for replication
Technical	Different data sources and granularity; different DSO ICT infrastructures; different data formats and communication interfaces	Adaptability of the STREAM ecosystem to heterogeneous data, ICT infrastructures and communication environments	Interface, data-ingestion and configuration adaptations may be required
Regulatory	Different LFM maturity, market rules, participant roles and prequalification processes	Adaptability of the STREAM ecosystem to different market and regulatory configurations	Country-specific market and workflow adaptations may be required
Social	Different roles of EnCs/aggregators, stakeholder involvement and operational practices	Adaptability of the STREAM ecosystem to different organisational models and stakeholder arrangements	Different engagement, training and organisational adaptations may be required

5 SCALABILITY AND REPLICABILITY ROADMAP

The last stage of the SRA consists in gathering the results obtained through the previous process and defining the next steps required to ensure that the solutions are scalable and replicable beyond the STREAM pilots. The roadmap focuses on the technical, regulatory and organisational conditions required to move from pilot-scale implementations towards wider deployment in different national and market contexts.

5.1 TECHNICAL SCALABILITY AND REPLICABILITY ROADMAP

This section will define the required development and testing steps that should be undertaken during the go-to-market phase to ensure that the tools are technically scalable and replicable.

5.1.1 Step 1: Ensure the scalability of the deployments

Prior to ensuring replicability, it is essential to make sure that the tools are scalable in order to use the tools in larger-scale real-world conditions. To do so, the following activities must be undertaken:

- Validate the performance of the tools when increasing the number of users, size of the grid and assets. As previously assessed, modularity and the use of cloud infrastructure decouple the performance of the different modules, but an intensive testing must be undertaken to ensure the correct performance of the modules.
- Optimise the data ingestion, storage, processing and simultaneous communications. In this sense, sDATA should evolve from a centralized data platform to a federated data space, establishing the connectors for the tools to access pilot data without storing it while preserving its main bloc.
- Dimension the cloud and computing infrastructure to ensure the scalability for the target market of the tools.

5.1.2 Step 2: Decouple country- and asset-specific functionalities

One of the main factors hindering replication was the adaptation of the algorithms for forecasting and optimizing DERs and prosumers behaviour, and the dependence on the specific requirements of the connection to and participation on regional and national LFM and ancillary services platforms. The following procedures can be followed to lower this barrier:

- Training and integration of pretrained models for different DER technologies and consumers typologies to expand the catalogue of “compatible” assets.
- Where possible, 15-minute granularity should be supported as a common baseline, allowing higher-frequency requirements to be addressed where required by the target application. When hourly measurements are required, it would be a matter of aggregating 15-minutes measurements.
- Flexibilization of the market integration and participation modules, enabling the adaptation of market-specific rules, processes and requirements through configuration rather than redevelopment, reducing the effort required to integrate the STREAM ecosystem with different flexibility markets.
- Definition of reusable APIs and integration interfaces.

5.1.3 Step 3: Standardisation strategy to facilitate interoperability

Although plug-and-play interoperability partly depends on the devices, assets and infrastructure connected to the tools, the replication effort can be significantly reduced by standardising the interfaces and data models used to integrate them with the STREAM ecosystem. The following actions should be considered.

- Identify the relevant standards in the target replication context and assess their compatibility with the standards and interfaces already used by the STREAM tools. The assessment should identify which existing STREAM interfaces can be reused, which require adaptation and where new adapters or connectors may be needed to integrate the target context.
- Prioritise standardised interfaces and semantic models at the boundaries of the STREAM ecosystem. This includes the incorporation of OpenADR 3.0 for demand response and LFM-related communications, CIM for smart-grid-related data and SAREF for semantic interoperability at device level, together with the MQTT, OCPP, AMQP and open APIs already used across the tools.
- Develop reusable adapters/connectors for heterogeneous devices and external systems. The STREAM pilots have shown that deployment of the tools involve different DSO systems, smart-metering infrastructures, SCADA/GIS systems, flexibility platforms and distributed energy resources, which rely on different communication protocols, data formats and interfaces. Developing reusable adapters for these integration requirements would reduce the effort required to replicate the tools in new contexts, while avoiding modifications to their core functionalities.
- Consider relevant gateway-based standardisation approaches in target replication contexts. For example, the German Redispatch 2.0 [15] framework provides an example of how interoperability can be addressed without requiring homogeneous underlying devices. Site-level assets may use different proprietary or field-level protocols, while gateway or site-controller architectures provide a standardised and secure interface towards grid operators. This approach, in which device-specific communication is abstracted behind a standardised integration layer, could be considered when replicating the STREAM ecosystem in contexts with similar requirements for secure and interoperable access to flexibility assets.
- Follow the results of the ECLIPSE project [16] and the INSIEME project [17]. The ECLIPSE project is implementing the Common European Reference Framework (CERF) for energy applications, providing a reference architecture, communication protocols and data models to support the interoperability of smart-grid and demand-response-related tools. In parallel, the INSIEME project is implementing the Common European Energy Data Space and developing reference models and data-exchange procedures for a wide range of energy-system use cases, including flexibility management and provision. The STREAM tools should follow the proposed architectures, standards and data flows, as well as the recommendations and outcomes of the Data for Energy (D4E) subgroup of the Smart Energy Expert Group, to ensure alignment with the emerging European approach to energy data interoperability and facilitate the integration and replication of the STREAM ecosystem in future deployment contexts.
- Similarly to the topology alchemy used in the Spanish pilot, develop AI-based models able to map proprietary data formats into standards. As it has been already explained through this

document, the use of standards does not ensure interoperability as devices commonly use proprietary formats. AI-assisted mapping could therefore reduce the effort required to integrate heterogeneous data sources and facilitate more seamless connectivity.

5.1.4 Step 4: Validate replication in additional contexts

Once scalability has been ensured and replication measures have been undertaken, the final step is to validate that the tools are actually replicable in additional and controlled contexts. To do so, the following recommendations are provided:

- Select additional deployment contexts, covering different assets and consumers typologies and diverse grid infrastructures. These additional contexts can be derived from the other pilot sites of the STREAM project.
- Perform a gap analysis to identify differences in the selected context. This will help verify that the previous replicability steps have facilitated the replication.
- Identify, if existing, the required adaptations to ensure the correct performance of the tools.
- Validate that data is integrated correctly, the functionalities are running with the expected performance and communication with external systems is working.
- Replicate the assessment methodology with additional contexts.

5.2 REGULATORY SCALABILITY AND REPLICABILITY ROADMAP

The regulatory roadmap for the STREAM ecosystem ultimately depends on the establishment of clear and harmonised regulatory frameworks across member states regarding LFMs. Recommendations have been provided in the Policy Recommendations document to foster the replicability of LFM related tools. From the STREAM ecosystem side, the focus is therefore placed on ensuring that the tools and their individual modules are sufficiently flexible to accommodate different regulatory frameworks and market configurations, instead of anticipating or defining country-specific regulatory developments. All in all, regulatory framework is considered an external enabling condition for replication, while regulatory adaptability is addressed as a technical roadmap, as analysed in Section 5.1.

5.3 SOCIAL SCALABILITY AND REPLICABILITY ROADMAP

Finally, the social scalability and replicability roadmap is presented to ensure end user engagement, acceptance and usage of the STREAM ecosystem.

5.3.1 Step 1: Ensure that the tools are user friendly by identifying the base knowledge of the potential end user, limiting complexity and required skills

Although the tools in general have followed different mechanisms to ensure that the operational complexity and the digital skills required are low, different social contexts might imply the reduction of end users' expertise and knowledge. The following procedures are recommended to ensure end user acceptance of the tools in this sense:

- Analyse the complexity of the tools and the number of interactions that must be done to operate them.
- Assess the knowledge required to properly take the necessary decisions without compromising the correct development of the related operations.
- Validate the tool with non-expert users that are not familiar with its functionalities.

5.3.2 Step 2: Establish an adequate engagement model and mechanisms

The STREAM project provides examples of different end-user engagement models. In Spain and Italy, end users have been engaged through their EnCs, which facilitates the participation of non-expert users as they trust the EnC manager as an intermediary. In Slovenia, industrial partners are engaged through their aggregator, while small consumers in Finland are more familiar with explicit flexibility measures through the automatic actuation of their assets, facilitating their engagement in LFMs and the provision of ancillary services. Therefore, the replication of the STREAM ecosystem should consider the characteristics of the target context to identify the most appropriate actors and engagement mechanisms for involving end users. The following aspects should therefore be considered:

- Identify the relevant intermediaries or organisations that can facilitate end-user engagement, such as EnCs, aggregators or other trusted entities.
- Assess the level of familiarity of potential end users with flexibility services and automated energy-management mechanisms.
- Define the most appropriate engagement mechanisms according to the target user profile and organisational context.

5.3.3 Step 3: Provide training and ensure continuous end user support

Although reducing operational complexity and the digital skills required to run the tools reduces the burden of properly using them, training and continuous user support are key activities to explain the benefits of using the tools and facilitate their adoption. The following activities should be considered:

- Provide training adapted to the knowledge and digital skills of the target users, focusing on the functionalities and decisions relevant to their role.
- Develop user documentation and support materials that facilitate the correct use of the tools and reduce dependence on technical assistance.
- Establish continuous support mechanisms during the initial deployment and operation of the tools to address user difficulties and facilitate adoption.
- Monitor recurring user issues and use them to identify improvements in the interfaces, workflows and functionalities.

5.3.4 Step 4: Collect end user feedback for validation from different contexts

End-user validation should not be limited to the original pilot contexts, as user expectations, digital skills, operational practices and engagement mechanisms may differ significantly across countries and user profiles. Collecting feedback from different contexts can therefore help to ensure that the tools remain usable and acceptable when replicated. The following activities should be considered:

- Validate the tools with different user profiles, including expert and non-expert users and different types of intermediaries.
- Collect feedback on usability, perceived complexity, usefulness, trust and the clarity of the information provided by the tools.
- Identify context-specific barriers affecting user acceptance, engagement and continued use.
- Incorporate the feedback into iterative improvements of the user interfaces, workflows, training materials and engagement mechanisms.
- Document the validated user requirements and engagement mechanisms to support their reuse in subsequent replications.

6 CONCLUSIONS

This document has provided the scalability and replicability analysis of the STREAM ecosystem. Overall, the solutions developed have significant scalability and replicability potential, although adaptations may be required to deploy them in different contexts and countries. This is mainly due to the absence of a common European framework for Local Flexibility Markets (LFMs), which contributes to differences in market rules, communication requirements and data models across countries.

Following this analysis, a roadmap to facilitate the scalability and replicability of the STREAM ecosystem has been provided, aiming to overcome the barriers and exploit the opportunities identified throughout the document. The technical roadmap focuses on ensuring the scalability of the solutions by providing the necessary cloud and infrastructure resources, and facilitating their replicability through the adoption of relevant standards and by following initiatives establishing common procedures and data models. The regulatory roadmap is supported by the policy recommendations provided by the STREAM consortium, as the establishment of clear regulatory frameworks for LFMs falls beyond the direct scope of the consortium. Finally, the social roadmap focuses on collaboration with relevant intermediaries to facilitate end-user engagement, while reducing the technical complexity and skills required for non-expert users.

Overall, the analysis demonstrates that the STREAM ecosystem provides a flexible basis for moving from pilot-specific implementations towards wider deployment, by combining reusable core functionalities with the adaptability required to address different technical, regulatory and social contexts.

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7.2 ACRONYMS

Acronyms list	
AMI	Advanced Metering Infrastructure
AMQP	Advanced Message Queuing Protocol
BESS	Battery Energy Storage System
CEEDS	Common European Energy Data Space
CERF	Common European Reference Framework
CIM	Common Information Model
D	Deliverable
DER	Distributed Energy Resource
DSO	Distribution System Operator
EU	European Union
EV	Electric Vehicle
FSP	Flexibility Service Provider
KPI	Key Performance Indicator
LFM	Local Flexibility Market
MO	Market Operator

MQTT	Message Queuing Telemetry Transport
OCPP	Open Charge Point Protocol
SCADA	Supervisory Control And Data Acquisition
SRA	Scalability and Replicability Analysis
T	Task
TSO	Transmission System Operator
WP	Work Package