interconnect

interoperable solutions connecting smart homes, buildings and grids

WP5 – Digital Platforms and Marketplace

D5.5

Interoperable marketplace toolbox v2.0

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant agreement No 857237

DOCUMENT INFORMATION

DOCUMENT	D5.5 – Interoperable marketplace toolbox v2.0
TYPE	O
DISTRIBUTION LEVEL	PU
DUE DELIVERY DATE	30/09/2022
DATE OF DELIVERY	30/09/2022
VERSION	V1.0
DELIVERABLE RESPONSIBLE	INESCTEC
AUTHOR (S)	Fábio Coelho (INESC), Milenko Tosic (VLF)
OFFICIAL REVIEWER/s	INESC, VLF, TNO

DOCUMENT HISTORY

VERSION	AUTHORS	DATE	CONTENT AND CHANGES
0.1	Fábio Coelho (INESC)	10/07/2022	Document Structuring
0.2	Milenko Tosic (VLF)	10/08/2022	Document draft 1
0.3	Fábio Coelho (INESC), Milenko Tosic (VLF)	15/09/2022	Document draft 2.
0.4	Fábio Coelho (INESC), Milenko Tosic (VLF)	20/09/2022	Final version for QA review.
1.0	Fábio Coelho (INESC), Milenko Tosic (VLF), David Rua (INESC)	30/09/2022	Version for submission.

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

One of the key exploitable results of the InterConnect project is the **Semantic Interoperability Framework (SIF).** The SIF is realized as a **set of tools, software components and validated methodologies that allow stakeholders to interconnect their semantically interoperable solutions into interoperable ecosystems.** These interoperable ecosystems (InterConnect project pilots are example of such systems) are the basis for developing innovative services, use cases and business models capitalizing on the semantic interoperability, knowledge dissemination and control. The semantically interoperable ecosystems are also the basis for building single and cross-domain data spaces.

This document provides overview of the SIF software components and methodologies developed and defined within WP5.

A top-down and bottom-up approach were conducted for deriving requirements and identifying the best practices for the SIF. The top-down approach included analysis of reference architectures and best practices from other initiatives and previous projects. Projects like Platoon, Platone, OneNet, European IoT Platform Initiative projects (most notably Vicinity, symbIoTe and InterIoT) and initiatives like BRIDGE, FI-WARE, OpenDEI were carefully assessed, especially their approaches for handling intra/inter domain interoperability on syntactic and semantic levels. The bottom-up approach started with creation of InterConnect catalogue of digital platform brought to the project pilots by the project's participants. Their capabilities and requirements for syntactic and semantic interoperability, knowledge sharing and semantic based control limitations and potential and security and data protection mechanisms are assessed and used as guiding requirements for SIF specification. This was necessary in order to ensure acceptance and validation at scale, first by consortium members and then by 3rd party integrators.

Based on collected requirements and identified best practices, the WP5 proceeded to specify and implement the SIF as a collection of software enablers and tools namely the Semantic Interoperability Layer, the Service Store, the Generic Adapter and the P2P marketplace enablers. A set of supporting tools is also available which ease the process of achieving semantic interoperability and becoming part of InterConnect semantically interoperable ecosystems.

Document D5.4 "First Prototype of Interoperable Marketplace Toolbox" described the interoperability role of each one of the developed SIF core components and identified each one of repositories containing source code and technical documentation needed for 3rd party integrators to make use of the SIF. The D5.4 also provided an overview of the required steps for onboarding a new interoperable service into the IF, providing a step-by-step methodology.

Now, the D5.5 (this document) provides final updates to the development and integration results of the core SIF components. This document should be used as a reference point towards specific details of each one of the developed software components. All information

will be maintained and updated in the projects' public Wiki page[1] to allow adopters of the SIF to follow the latest developments, which will be particularly relevant in the open calls that will provide support to entities towards the development, implementation and of interoperable features into their existing (or to be created) solutions and services. This document revisits the step-by-step instructions for achieving semantic interoperability for existing services. Digital systems and their interfaces and building semantically interoperable ecosystems between multiple stakeholders from different domains covered by the project. The future release plan for the SIF towards the end of the project and beyond was outlined, positioning of the SIF in the extensive landscape of various relevant initiatives on the EU level and towards post-project exploitation.

[1] https://gitlab.inesctec.pt/groups/interconnect-public/-/wikis/home

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ABBREVIATIONS AND ACRONYMS

API	Application Programming Interface
DSO	Distribution System Operator
GA	Generic Adapter
IC	InterConnect
SIF	Semantic Interoperability Framework
IoT	Internet of Things
KE	Knowledge Engine
P2P	Peer-to-Peer
RDF/OWL	Resource Description Framework / Ontology Web Language
REST	Representational State Transfer
SAREF	The Smart Applications REFerence
SHBERA	Smart Energy Refence Architecture
SSA	Service Specific Adapter

1. INTRODUCTION

Important note – the original concept of **Interoperable Marketplace Toolbox** was renamed to **InterConnect Semantic Interoperability Framework (SIF)** at the beginning of WP2 and WP5 activities to better reflect on the role of the developed technology in enabling integrators to achieve semantic interoperability.

1.1 WP5 OBJECTIVES

Within the InterConnect project, WP5 "Digital Platforms and Marketplace" oversees the following activities and objectives:

- Establish semantic interoperability between project stakeholders (platforms, services, IoT devices) by leveraging the ontologies, standards and designed specifications (T5.1);
- Demonstrate via the Interoperability Framework how several technologies can create a pluggable and transparent approach while focusing on interfacing functionality-by-design (T5.2);
- Provide security-enabled and a privacy-by-design architecture by considering a mix of cloud-enabled services and legacy systems (T5.3);
- Leverage on the interoperability toolbox to provide P2P marketplace enablers between stakeholders (T5.4);
- Provide continuous support to the project pilots and integrators of the interoperability enablers (T5.5).

This WP is responsible for delivering InterConnect Semantic Interoperability Framework as a set of software tools and enablers for facilitating semantic interoperability between digital platforms, services and devices comprising the project pilots.

1.2 RELATION TO OTHER WPS

As shown in Figure 1, the work carried out in WP5 is based on the work carried out in other technical WPs, while at the same time providing key enablers for the same WPs, namely:

- From WP1, this WP utilizes the use case requirements to infer the architectural requirements the IC Interoperability Framework needs to consider.
- From WP2, WP5 utilizes and develops the concepts and functions (data models, interfaces, protocols, security, and privacy requirements) introduced by the project's Secure Interoperable IoT Smart Home/Building and Smart Energy Reference Architecture (SHBERA). All ontology and semantic interoperability specifications and requirements for the IC Interoperability Framework are provided by WP2.
- WP3 provides interoperable/adapted energy and non-energy services while WP5 provides to WP3 the service store specification and generic adapter for achieving semantic interoperability of the services.

- WP4 provides specification of the DSO interface while WP5 provides integration of the service behind this interface with the Interoperability Framework and interoperable ecosystems established within the pilots.
- WP5 will provide WP7 pilots with the Interoperability Framework toolset as key input for realizing the project use cases leveraging established semantically interoperable ecosystems. The WP7 pilots will provide continuous feedback leading to further updates of the Interoperability Framework.
- WP5 will provide cascade funding projects/partners (WP8) with the toolbox necessary for making their platforms and services interoperable with the Interoperability Framework and established pilots.

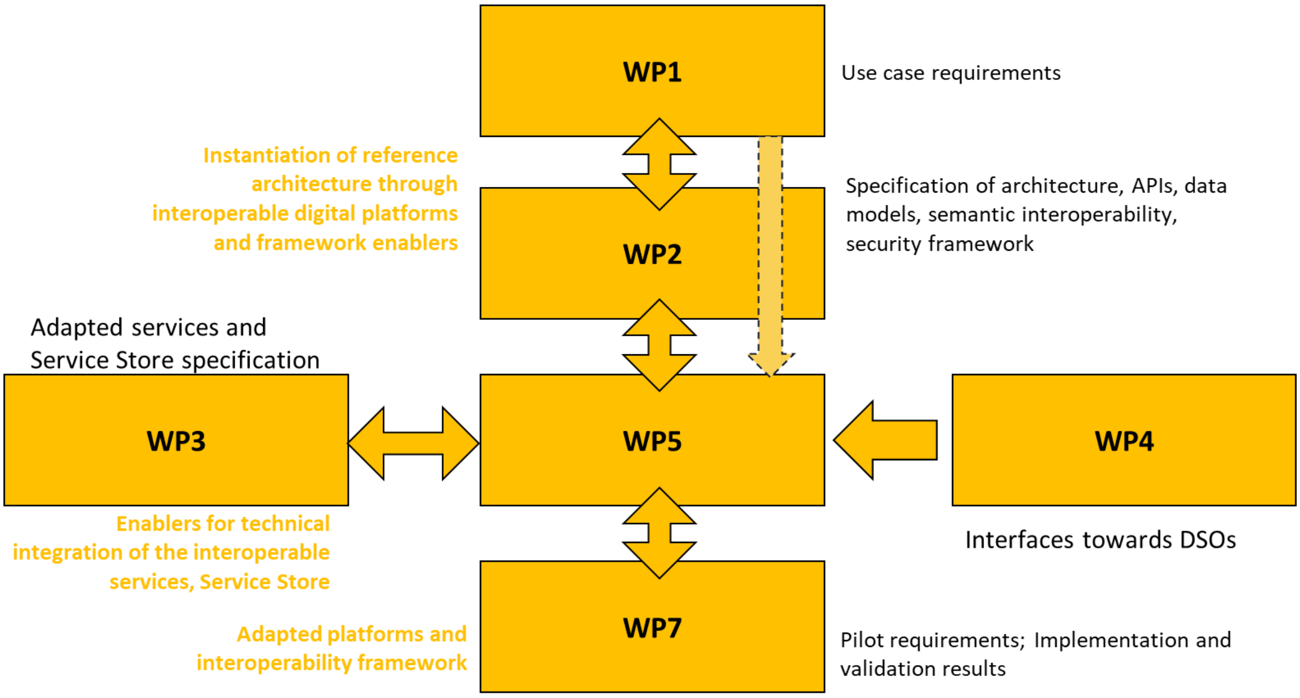

FIGURE 1 - RELATION OF WP5 TO OTHER WPS (ORANGE FONT ARE INPUTS FROM WP5).

1.3 D5.5 OBJECTIVES AND APPROACH

This deliverable is part of the result of the work carried out in *T5.5 – Continuous support and development of the interoperability framework*. This task is responsible to provide support to all integrators of the SIF and especially to the teams behind project's large-scale pilots and open call selected participants. T5.5 also provides regular updates of the SIF developments, introduce new features, software tools and methodologies into the overall framework and defines best practices, based on the feedback received from the project pilots and other SIF integrators and users. Also, the SIF is aligned with the main results and progress across key initiatives and standards that the framework follows. This ensures continuous evolution of the SIF, making it more competitive and thus attractive for 3rd party integrators to adopt.

Similar to the D5.4, this deliverable (D5.5) document the developed software components as part of the SIF, identifying what is the key interoperability role they play, along with the identification of the software repositories and respective documentation resources. The technical documentation (instruction, examples, FAQs and API documentation) for each Interoperability Framework component is regularly maintained in the corresponding GitLab project. All the documentation and open-source software components are then linked in one page – the project public Wiki page.

Finally, this document takes a step further from D5.4 by providing details on the plan for maintaining and updating the SIF until the end of the project and overall strategy for exploitation during and after the project.

This document is not a user guide on how to utilize the SIF!

It serves as a supporting element with the identification of relevant developments made in the scope of WP5 with relevant information and links to key resources concerning each one of the software systems developed. Detailed information and user guide references can be found in the documentation of each one of the components in the project public wiki. The content published there will be regularly updated according to the improvements and additional development s carried out. Therefore, the project public Wiki page is the main source of technology/technical truth since it will be maintained as the SIF is continuously updated based on the feedback and validation results received from the project pilots and open call partners.

1.4 DOCUMENT STRUCTURE

This introduction is part of **Chapter 1**. The overall organization of the chapters follows the WP5 methodology and the Semantic Interoperability Framework specification.

Chapter 2 – Semantic Interoperability Framework describes the framework for the readers' reference and positioning towards the described developments.

Chapter 3 – Semantic Interoperability Layer identifies of all resources concerning the Knowledge Engine software system, including references to the source code and the respective documentation.

Chapter 4 – Service Store distinguishes all resources concerning the Service Store software system, including references to the source code and the respective documentation.

Chapter 5 – Generic Adapter characterizes all resources concerning the Generic Adapter software system, including references to the source code and the respective documentation.

Chapter 6 – P2P Marketplace Enablers identifies all resources concerning the Blockchain P2P Marketplace Enablers and their configurations for the three project pilots, including references to the source code and the respective documentation.

Chapter 7 – Supporting Tools for Integrators overviews the main support tools that are part of the SIF and are used to streamline the process of achieving semantic interoperability and establishment of interoperable ecosystems.

Chapter 8 – Integration Workflow describes, step-by-step, the process required for a service provider in order to make corresponding service interoperable and onboard it into the InterConnect semantically interoperable ecosystem(s).

Chapter 9 – SIF Continuous Support Plan presents the main actions that the InterConnect consortium (especially WP5) will undertake to ensure that all integrators are provided with proper support in instantiating the SIF and all received feedback and large-scale pilot validation results are properly translated into the incremental updates.

Chapter 10 – SIF as Key Exploitable Result overviews the alignment of the SIF exploitation with the relevant European initiatives and touches on the project's plans for SIF exploitation (in detail covered in WP10 deliverables).

2. SEMANTIC INTEROPERABILITY FRAMEWORK

The InterConnect Semantic Interoperability Framework (SIF) provides a set of tools, enabling the provisioning of SAREF-centric semantic interoperability for digital platforms, services, and digital assets such as connected devices.

This deliverable identifies the **key components of the interoperability framework** and the respective software artifacts and documentation.

The overall process of specifying the requirements and functional components of the SIF is presented in the deliverable document D5.1 [2]. In this document we will present the main requirements that led us towards specification and implementation of the SIF. We started by confirming the main challenges for cross domain semantic interoperability and, in general, the main obstacles for wider adoption of semantic web technologies in the domains covered by the project:

- **Steep technology learning curve** - It is a disruptive paradigm based on information dissemination, rather than a one-to-one data exchange approach used today by digital systems.
- Agreeing **business level interoperability** between industrial leaders requires that the process is cost effective and risk free.

Most solution deployed, in practice, call for centralized interoperability facilitator, but that comes with a set of challenges:

- Dependability on centrally hosted facilitators both technically- and business-wise;
- Data needs to be processed by a 3rd party which opens new data and privacy protection risks;
- Performance is dictated by capacity of the facilitating platform;
- Accepting new technologies and standards depends on the facilitating platform operator;
- End-to-end cybersecurity is limited by the security measures employed by the facilitating platform.

The SIF addresses these challenges and requirements in the following way (see Figure 2):

- The project enables cross-domain semantic interoperability to be established in **distributed manner among already existing digital platforms** – no need for centrally hosted facilitating platform.
- **Interoperability originates at stakeholder's end,** and it does not disrupt existing practices – this is achieved with the Service Adapters.
- Semantic interoperability within the project is based on **SAREF** ontology. However, the developed enablers are **ontology agnostic**.
- The achieved semantic interoperability **enhances security and privacy protection** measures by securing communication interfaces and providing integrators with means to enforce their security related best practices as well as to customize knowledge flows through selecting

- The enablers of the project can be deployed on **all system levels** from devices over the edge to the cloud.
- Finally, semantically interoperable ecosystems provide federate knowledge spaces capable of providing answers to complex queries issued by stakeholders. This is also basis for establishing intra and inter-domain data spaces.

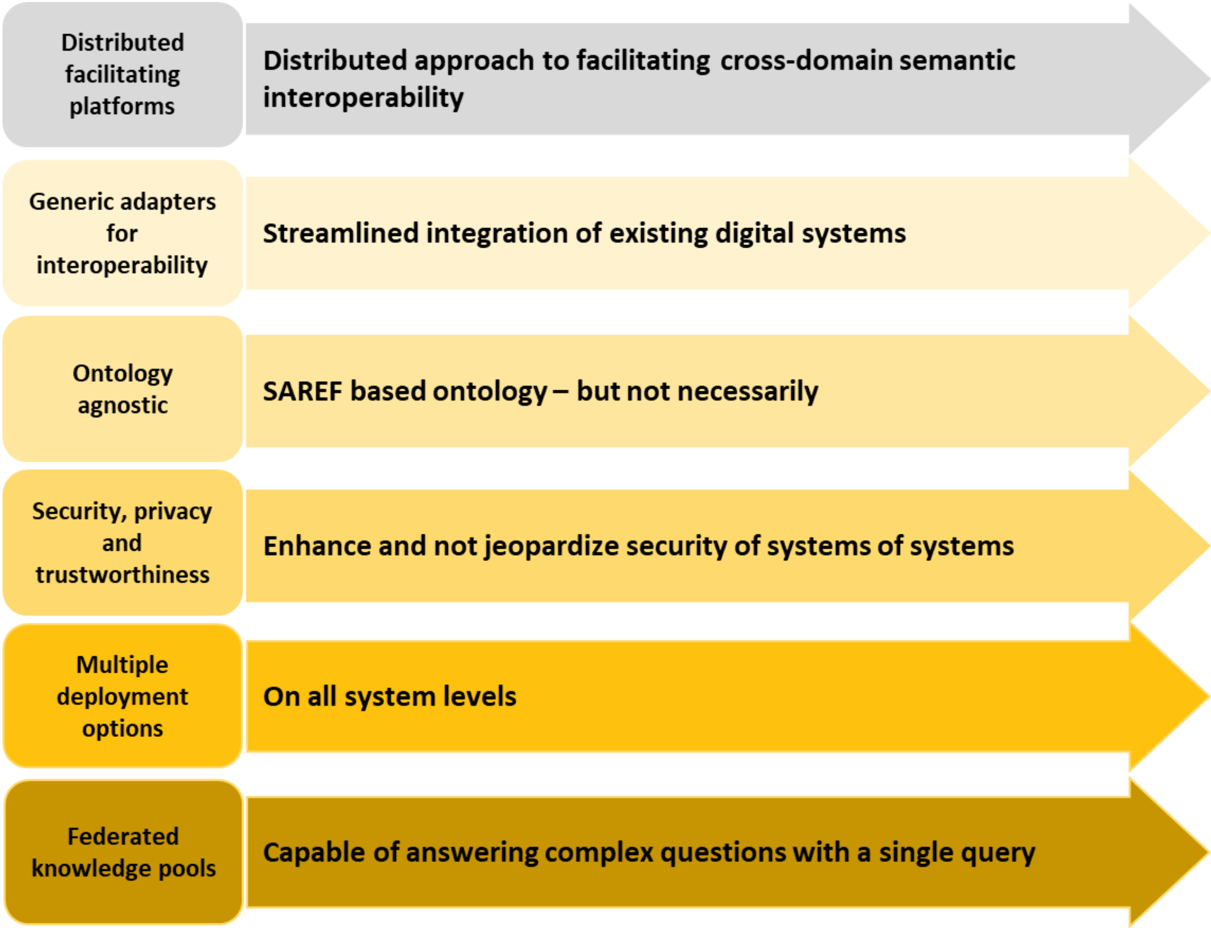

FIGURE 2 - SIF APPROACH FOR ADDRESSING CHALLENGES FOR SEMANTIC INTEROPERABILITY.

The described features of the InterConnect SIF are provided by the functional modules presented in the Figure 3.

The SIF includes the following components:

- Semantic Interoperability Layer;
- Service Store;
- Generic Adapter;
- P2P Marketplace enablers;
- Each component provides it set of data in transit and data at rest protection measures which are documented in the D5.3 [3].
- Set of supporting tools for integrators (SSA Test Tool, Graph pattern visualiser).

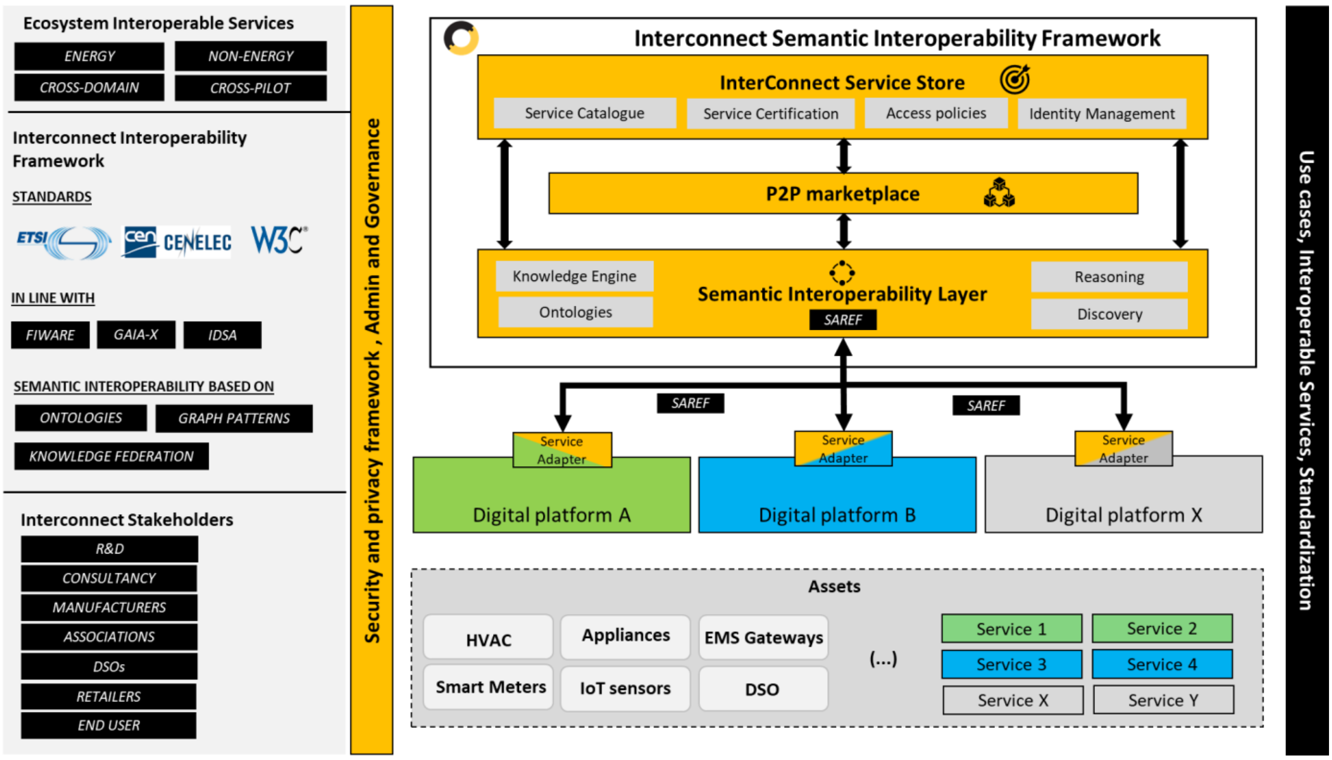

FIGURE 3 - HIGH LEVEL FUNCTIONAL ARCHITECTURE OF THE SEMANTIC INTEROPERABILITY FRAMEWORK.

Each component is characterized in the following sections. More details on each components' role and specification can be found in D5.1 [2] and on the project's public Wiki page [4]. There is also an introductory video prepared to present the SIF[2].

Figure 4 depicts the layers of interoperability provided by the SIF. The framework covers syntactic interoperability primarily with the Generic Adapter but also the Knowledge Engine REST APIs. The semantic interoperability is ensured with the SAREF-based ontology and Knowledge Engine features for knowledge interactions, discovery and reasoning. The service Specific Adapters (SSA) are responsible for facilitating semantic interoperability of legacy interfaces and semantic sets of the integrators' services. The business level interoperability is the topic covered by the project pilots and use cases.
The SIF supports semantically interoperable services from the grid and IoT/smart building domains as well as cross-domain services developed and provided by the consortium partners.
The SIF components can be deployed on any system level (depending on the hardware/system capabilities). Therefore, the interoperability can originate anywhere from devices/edge to the private/public cloud.

[2] https://www.youtube.com/watch?v=sSXDMCeIw2o

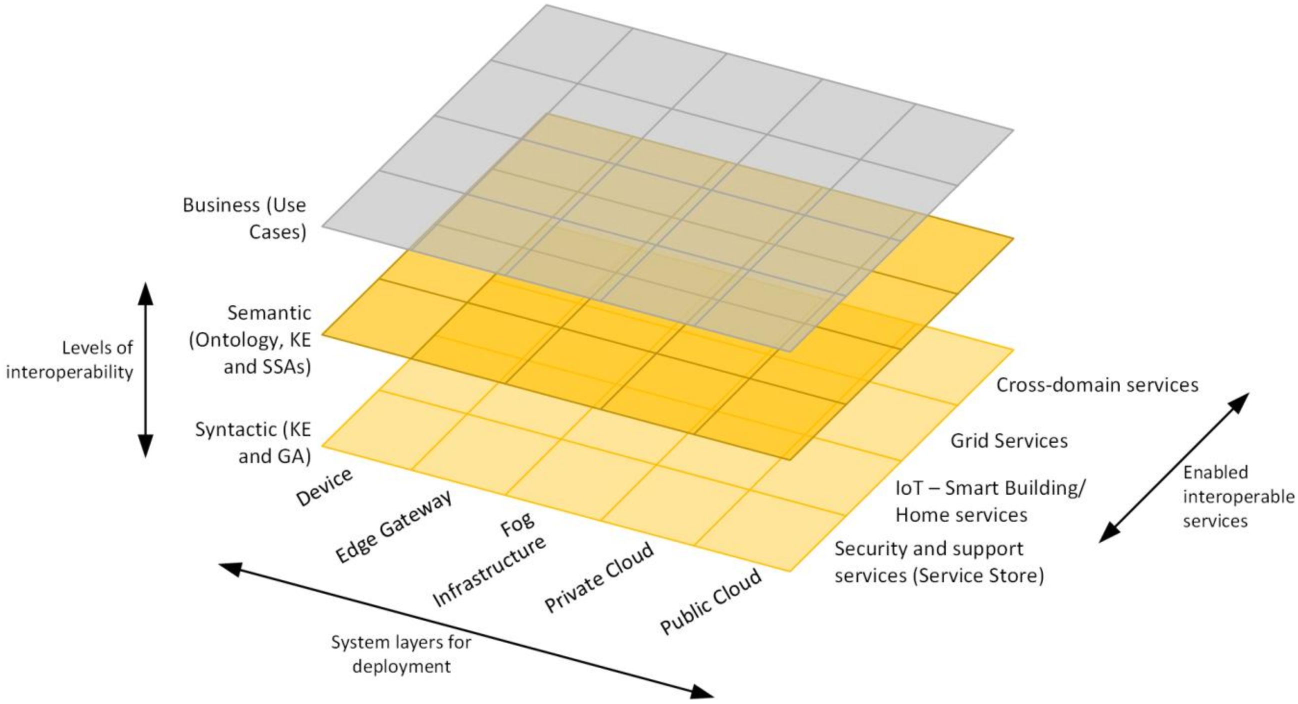

FIGURE 4 - SIF - LEVELS OF INTEROPERABILITY.

3. SEMANTIC INTEROPERABILITY LAYER

3.1 INTEROPERABILITY ROLE

The InterConnect's Semantic Interoperability Layer is based on the Knowledge Engine technology supplied by TNO and developed for the InterConnect use in the scope of the WP2 and WP5. The Knowledge Engine is a technology aimed at providing semantic interoperability by means of two features: *translation* and *discovery*. Both features require a common ontology. The ontology of choice for the InterConnect Interoperability Framework is SAREF together with several extensions that complete the InterConnect ontology. It is important to state that the Knowledge Engine is ontology agnostic and, in principle, able to work with any ontology if it is expressed in the RDF/OWL format.

3.2 SOFTWARE ARTIFACTS AND REPOSITORY

The Knowledge Engine software artifacts are hosted on the TNO's GitHub account and are publicly available[3]. The current active release is 1.1.3 (as of 30th of September 2022). The table below lists key software artifacts of the Knowledge Engine.

TABLE 1 - KNOWLEDGE ENGINE SOFTWARE ARTIFACTS.

KNOWLEDGE ENGINE – RELEASE 1.1.3		
SUB-COMPONENT	DESCRIPTION	URL
Smart-connector	Knowledge Engine connector to interact with the semantic exchange API	https://github.com/TNO/knowledge-engine/tree/master/smart-connector
Smart-connector-api	Knowledge Engine Smart Connector API	https://github.com/TNO/knowledge-engine/tree/master/smart-connector-api
Smart-connector-rest-server	Knowledge Engine Rest Server – Non-Distributed version	https://github.com/TNO/knowledge-engine/tree/master/smart-connector-rest-server
Smart-connector-rest-dist	Distributed Knowledge Engine Runtime Server	https://github.com/TNO/knowledge-engine/tree/master/smart-connector-rest-dist
Admin-ui	Command-line administer	https://github.com/TNO/knowledge-engine/tree/master/admin-ui
Knowledge-directory	Knowledge Engine distributed instance locator and directory if all registered smart connectors and their knowledge interactions	https://github.com/TNO/knowledge-engine/tree/master/knowledge-directory

[3] https://github.com/TNO/knowledge-engine

3.3 DOCUMENTATION

The documentation is available in the project's public Wiki page.

TABLE 2 - KNOWLEDGE ENGINE DOCUMENTATION.

KNOWLEDGE ENGINE – RELEASE 1.0.3		
SUB-COMPONENT	DESCRIPTION	URL
Documentation	Knowledge Engine documentation	https://gitlab.inesctec.pt/interconnect-public/knowledge-engine/-/tree/main/docs
REST API documentation	OpenAPI specification of the Knowledge Engine REST developer API	https://gitlab.inesctec.pt/interconnect-public/knowledge-engine/-/blob/main/openapi-sc.yaml

3.4 RUNNING TEST INSTANCE

A test running instance of the Knowledge Engine is available in the URL detailed in Table 3. API requests can be directed at this endpoint for testing purposes. This instance is primarily used for testing proof of concept integrations between services. SIF early adopters from the consortium used this instance to test their developments and integration efforts. The centralized test instance allows the core development team to perform necessary debug operations and asses overall performance. After successful validation on the test instance, the integrators proceed to deploy and configure their own Knowledge engine instances which can be shared with other stakeholders that participate in building an interoperable ecosystem. Pilots may deploy several instances within and across pilot setups. The distributed nature of the knowledge engine allows this to occur by design, establishing a federated network of Knowledge Engine instances.

TABLE 3 - KNOWLEDGE ENGINE RUNNING TEST INSTANCE.

KNOWLEDGE ENGINE – RELEASE 1.0.3		
SUB-COMPONENT	DESCRIPTION	URL
Smart-connector-rest-server	Knowledge Engine instance	https://ke.interconnectproject.eu/rest

4. SERVICE STORE

4.1 INTEROPERABILITY ROLE

InterConnect Service Store is the "frontend" of the whole interoperable ecosystem built with the SIF. The service store is conceptualized as a web service with its front-end and back-end modules and processes. The main objective is to enable building of the InterConnect ecosystem of service providers and adopters by allowing them to register new interoperable services and browse existing ones to identify services best suited for the challenge at hand and get all necessary information for accessing and properly utilizing selected services. The service store is the main identity provider for the project, and it is responsible for providing trustworthiness towards integrators that the services listed I nits catalogue are indeed interoperable and can be trusted for integration into semantically interoperable ecosystems. The Service Store also provides Knowledge Explorer functionality which enables visualization of the semantically interoperable ecosystems established by stakeholders. It also provides feature for tracking KPIs of the project's large-scale pilots. The Service Store is also available for independent hosting by integrators if necessary.

4.2 SOFTWARE ARTIFACTS AND REPOSITORY

The Service Store component is built from two sub-components as depicted in Table 4. All sub-components correspond to the latest public version available – Release 1.2.

TABLE 4 - SERVICE STORE SOFTWARE ARTIFACTS.

SERVICE STORE – RELEASE 1.2		
SUB-COMPONENT	DESCRIPTION	URL
Service Store – Backend	Service Store Backend System	https://gitlab.inesctec.pt/interconnect-public/service-store-backend
Service Store – Frontend	Service Store Frontend System	https://gitlab.inesctec.pt/interconnect-public/service-store-frontend

4.3 DOCUMENTATION

The documentation for the Service Store is available in the public Wiki page of the project.

TABLE 5 - SERVICE STORE DOCUMENTATION.

SERVICE STORE – RELEASE 1.2		
SUB-COMPONENT	DESCRIPTION	URL
Service Store – documentation	Service Store documentation and user guide	https://gitlab.inesctec.pt/interconnect-public/service-store-frontend/-/wikis/home
REST API docs	Service Store REST API documentation (needs Service Store Account)	https://store.interconnectproject.eu/backend/swagger-ui.html#/

4.4 RUNNING TEST INSTANCE

A test running instance of the Service Store is available in the URL detailed in Table 6. API requests can be directed at this endpoint for testing purposes.

TABLE 6 – SERVICE STORE RUNNING TEST INSTANCE.

SERVICE STORE – RELEASE 1.1		
SUB-COMPONENT	DESCRIPTION	URL
Service Store – Backend	Service Store Backend System	https://store.interconnectproject.eu/backend
Service Store – Frontend	Service Store Frontend System – used by integrators to onboard their services and browse existing ones.	https://store.interconnectproject.eu/ServiceStore

5. GENERIC ADAPTER

5.1 INTEROPERABILITY ROLE

The Generic Adapter is a software gateway for secure and trusted communication between a service and a wider Interoperability Framework instance (including Service Store and the Knowledge Engine). The project introduced three adapter concepts (see Figure 5). First, we have Service Specific Adapter (SSA) that was the main focus of the WP3 work. This is where legacy interfaces and data models of the partner's services are mapped onto the SIF interfacing logic and project's SAREF-based ontology. Next, we have the Generic Adapter (GA). The GA provides unified REST API towards Service Specific Adapter. This GA REST API ensures communication with the Service Store for authentication and authorization of the service and the GA itself with the central identity provider. The GA REST API also facilitates interactions with the semantic interoperability layer (Knowledge Engine instance) by providing methods for Knowledge Base and Knowledge Interaction registration and also methods for executing corresponding knowledge exchanges. The SSA and GA combine into InterConnect Service Adapter which represent a complete semantic interoperability enabler which on the "south side" integrates with the legacy interfaces and service logic and on the "north side" exposes unified interface that all participants in the semantically interoperable ecosystem understand.

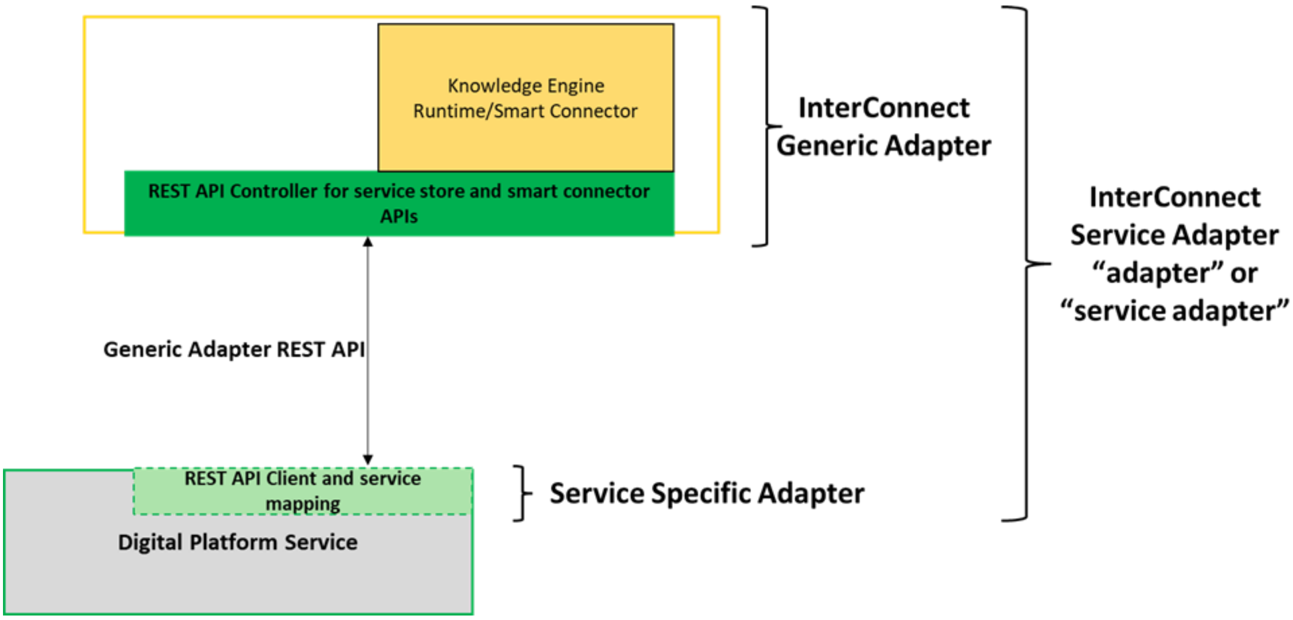

FIGURE 5 - INTERCONNECT ADAPTERS.

The GA component will continue to be updated throughout the project in order to integrate the repetitive/common steps for various types of interoperable services. The plan is to elevate parts of SSA logic into different GA pre-configurations. This will be based on the experience and best practices supplied by the projects partners who are early adopters of the SIF and need as such to go through the extensive process of adapting their services and interfaces to the new way of interoperating. Future integrators will capitalize on the experience of the partners of the project and they will be able to choose GA configurations which fit best to their specific services and interfacing logic and with minimal developments reach the semantic interoperability. This new approach will be documented in the project's public Wiki page when ready.

5.2 SOFTWARE ARTIFACTS AND REPOSITORY

The Generic Adapter software components are listed in Table 7 – latest public Release 2.0 (30th of September 2022).

TABLE 7 - GENERIC ADAPTER SOFTWARE ARTIFACTS.

GENERIC ADAPTER – RELEASE 2.0		
SUB-COMPONENT	DESCRIPTION	URL
Generic Adapter	Generic Adapter source code	https://gitlab.inesctec.pt/interconnect-public/generic-adapter
Generic Adapter - docker	Generic Adapter – Docker versions	https://gitlab.inesctec.pt/interconnect-public/generic-adapter/container_registry/313

5.3 DOCUMENTATION

The documentation is available on the public wiki page of the project.

TABLE 8 -GENERIC ADAPTER DOCUMENTATION.

GENERIC ADAPTER – RELEASE 2.0		
SUB-COMPONENT	DESCRIPTION	URL
Generic Adapter – documentation	Generic Adapter documentation and user guide.	https://gitlab.inesctec.pt/interconnect-public/generic-adapter/-/tree/master/docs
Generic Adapter REST API documentation	OpenAPI specification of the GA REST API.	https://gitlab.inesctec.pt/interconnect-public/generic-adapter/-/blob/master/generic-adapter-rest-OpenAPI.yaml
Generic Adapter postman collection	Postman Collection for testing GA REST API integration.	https://gitlab.inesctec.pt/interconnect-public/generic-adapter/-/blob/master/InterConnect%20GenericAdapter%20Postman%20Collection.json

6. P2P MARKETPLACE ENABLERS

6.1 INTEROPERABILITY ROLE

There are no updates to the P2P marketplace enablers since the deliverable report D5.4.

The Interoperability Framework provides P2P marketplace enablers as part of its toolbox. The enablers are provided as deployable containers that allow pilot owners and integrators to deploy and fully manage P2P marketplace instances. The established P2P marketplaces are in full control and under jurisdiction (regulatory, market wise, data privacy protection) of the integrators. The goal was to develop enablers which would allow establishment of blockchain ledgers shared between community members and supporting community specific services for data exchange in the project pilots. The P2P marketplace enablers include:

- Hyperledger Fabric blockchain configurations.
- Smart contract templates for generating reports and audits about status of the marketplace and executed transactions, for registering and identifying key actors and resources constituting P2P marketplaces and for integration of interoperable services which write data to or read data from the Hyperledger Fabric.
- Configurable order matching engine.
- White-labelled web application for providing interface through which end users place orders.

The P2P marketplace can be an energy marketplace or a marketplace for data transactions required for the realization of the community-based use cases. In the scope of the Task 5.4 the following P2P marketplace configurations are implemented and made available for the pilots and 3rd party integrators:

- Generic data marketplace configuration that can be easily adapted to specific use cases in energy and IoT domains. This implementation also features a web application for demonstration purposes.
- Specialized configurations based on participating pilots (each having specific set of requirements for integration of P2P marketplaces into instances of the Interoperability Framework):
    - Dutch pilot - IoT data exchange with loyalty tokens realized through P2P marketplace.
    - Portuguese pilot - flexibility and energy profile trading/aggregation in communities through P2P marketplace instance.
    - Belgium pilot from Think E! and VUB - P2P energy trading within and between energy communities through instantiated P2P marketplace.

6.2 SOFTWARE ARTIFACTS AND REPOSITORY

The P2P marketplace configurations are listed in Table 9. All the P2P marketplace configurations are supplied to the corresponding pilots for integration with their instances of the Interoperability Framework.

TABLE 9 - P2P MARKETPLACE ENABLERS SOFTWARE ARTIFACTS.

P2P MARKETPLACE ENABLERS version 1.0		
SUB-COMPONENT	DESCRIPTION	URL
Portuguese pilot configuration	P2P marketplace configuration for the Portuguese pilot use case focusing on flexibility and energy profile trading/aggregation in communities	https://gitlab.inesctec.pt/interconnect-public/p2p-marketplace/-/tree/p2p-flex-sharing
Belgian pilot configuration	P2P marketplace configuration for the Belgian sub-pilots with focus on energy trading within and between communities.	https://gitlab.inesctec.pt/interconnect-public/p2p-marketplace/-/tree/p2p-energy-trading
Dutch pilot configuration	P2P marketplace configuration for the Dutch pilot and its use case on IoT data exchange with loyalty tokens.	https://gitlab.inesctec.pt/interconnect-public/p2p-marketplace/-/tree/p2p-data-mp-activities-mg
Generic energy P2P marketplace configuration	P2P marketplace configuration that can be used as basis for building new P2P marketplaces in other pilots and for cascade funding. Also contains a PoC web application for texting and demonstrating purposes.	https://gitlab.inesctec.pt/interconnect-public/p2p-marketplace/-/tree/p2p-sample-marketplace

6.3 DOCUMENTATION

The documentation is available in the project public wiki page.

TABLE 10 - MARKETPLACE ENABLERS DOCUMENTATION.

P2P MARKETPLACE ENABLERS		
SUB-COMPONENT	DESCRIPTION	URL
P2P Marketplace Enablers – documentation	P2P Marketplace Enablers documentation - root for all branches	https://gitlab.inesctec.pt/interconnect-public/p2p-marketplace
Portuguese pilot P2P marketplace documentation	Documentation with diagrams, instructions, and link for tutorial video	https://gitlab.inesctec.pt/interconnect-public/p2p-marketplace/-/tree/p2p-flex-sharing
Belgian pilot P2P marketplace documentation	Documentation with diagrams, instructions, and link for tutorial video	https://gitlab.inesctec.pt/interconnect-public/p2p-marketplace/-/tree/p2p-energy-trading
Dutch pilot P2P marketplace documentation	Documentation with diagrams, instructions, and link for tutorial video	https://gitlab.inesctec.pt/interconnect-public/p2p-marketplace/-/tree/p2p-data-mp-activities-mg
Generic energy P2P marketplace documentation	Documentation with diagrams, instructions, and link for tutorial videos	https://gitlab.inesctec.pt/interconnect-public/p2p-marketplace/-/tree/p2p-sample-marketplace

In P2P marketplace enablers and their use case specific configurations, the smart contracts expose REST APIs. Documentation of REST API methods is prepared with the help of Postman collections. Through these REST APIs, the P2P marketplaces can be integrated with other interoperable services and support deployment of custom UIs for engaging end users. Instructions

1. Download Postman from this link: https://www.postman.com/downloads/
2. Open the Postman application and import all files from the folder 'postman'. 1 collection and 4 environments should appear.
3. Test if the REST APIs are responding properly by issuing the 'Register EndUser' API from Postman. The response should return a success message & token.

TABLE 11 - P2P API SPECIFICATION – POSTMAN COLLECTIONS.

P2P MARKETPLACE ENABLERS	
SUB-COMPONENT	**DESCRIPTION**
Portuguese P2P marketplace configuration	https://gitlab.inesctec.pt/interconnect-public/p2p-marketplace/-/tree/p2p-flex-sharing/postman
Belgian P2P marketplace configuration	https://gitlab.inesctec.pt/interconnect-public/p2p-marketplace/-/tree/p2p-energy-trading/postman
Dutch P2P marketplace configuration	https://gitlab.inesctec.pt/interconnect-public/p2p-marketplace/-/tree/p2p-data-mp-activities-mg/postman
Generic P2P marketplace configuration	https://gitlab.inesctec.pt/interconnect-public/p2p-marketplace/-/tree/p2p-sample-marketplace

7. SIF SUPPORT TOOLS FOR INTEGRATORS

7.1 INTEROPERABILITY ROLE

The SIF provides a set of software tools that improve “quality of life” for integrators. These tools were defined based on the feedback received from the SIF early adopters from the project consortium. Based on the reported issues, recuring questions and dilemmas in the SAREFization process and general SIF integration, the WP5 team defined a set of tools which will streamline with processes behind semantic interoperability enablement. The support tools include:

- SSA test tool – This tool allows the integrator to test the behaviour and completeness of the semantic interactions sent via the Generic Adapter. Namely, it allows to test and verify the validity of graph patterns, its binding sets and prefixes. The SSA Test tool I part of the Generic Adapter Control Panel interface.
- Graph Pattern visualization tool – This tool allows to visualize a graph pattern, decomposing it into the nodes and links established.

7.2 SOFTWARE ARTIFACTS AND REPOSITORY

Table 12 lists the support tools and location of their software artifacts.

TABLE 12 – SOFTWARE ARTIFACTS FOR THE SUPPORT TOOLS FOR INTEGRATORS

SUPPORT TOOLS FOR INTEGRATORS		
SUB-COMPONENT	DESCRIPTION	URL
SSA test tool	Service Specific Adapter Test Tool that allows pre-testing and assessment of graph pattern construction	Available through the Generic Adapter local address.(e.g., http://<ga_localaddress>:<ga_localport>
Graph pattern visualization tool	Tool allowing to build a graphic representation of the graph pattern.	https://interconnect-dev.inesctec.pt/graph/

7.3 DOCUMENTATION

Documentation for the support tools is listed in the table below.

TABLE 13 - DOCUMENTATION FOR THE SUPPORT TOOLS FOR INTEGRATORS.

SUPPORT TOOLS FOR INTEGRATORS		
SUB-COMPONENT	**DESCRIPTION**	**URL**
SSA test tool	Documentation for the SSA test tool which is part of the GA.	https://gitlab.inesctec.pt/interconnect-public/generic-adapter/-/blob/master/docs/09_SSA-Test-Tool.md
Graph pattern visualization tool	Documentation for the graph pattern visualization tool which is part of the GA.	https://interconnect-dev.inesctec.pt/graph/

8. INTEGRATION WORKFLOW

Figure 6 depicts the concept of *knowledge base*, where all the knowledge exchanged to a from a digital service will reside. This conceptual representation is built from several software components, namely: the digital service that will become interoperable, the service specific adapter (SSA) and the generic adapter (GA).

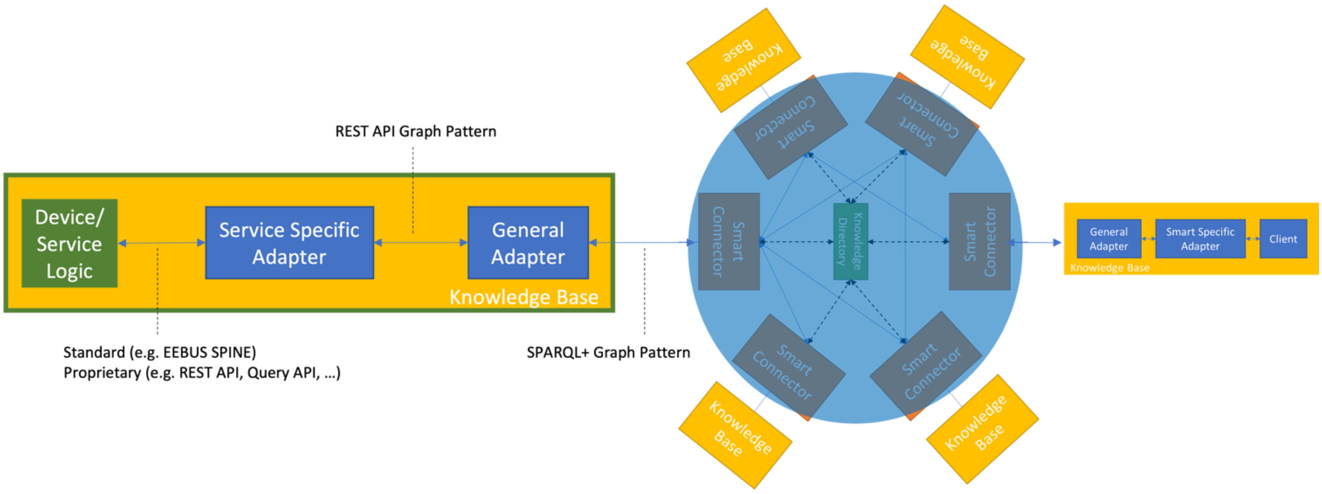

FIGURE 6 - KNOWLEGE BASE AND GENERIC ADAPTER CONCEPT.

The Service Specific Adapter (SSA) defines the client code that the digital service uses to integrate with the API from the Generic Adapter. It holds all the knowledge descriptions and will be used to feed data into the ecosystem. The Generic Adapter (GA) establishes the gateway towards the wider interoperable ecosystem.

Figure 7 depicts the key messages and data exchanges between two interoperable services. The complete chain comprising Service Legacy Interface, SSA, GA, Knowledge Engine Smart Connector on both sides of the communication path are depicted. Also, the messages exchanged with the SIF core components like Service Store and Knowledge Engine Knowledge Directory are presented. In the figure below the KB is a Knowledge Base (service with its SSA and GA) and KI is knowledge interaction. More details about these concepts can be found in the Knowledge Engine documentation on the public Wiki page[4]. The concept of semantic reasoning is also presented in this documentation. The diagram is divided into three phases. The first step - services need to be onboarded to the Service Store and then registered as interoperable Knowledge Bases within a SIF instance. The second step – services/Knowledge Bases register their capabilities as Knowledge interactions and Graph Patterns. This way services present to the interoperable ecosystems what are their capabilities and roles and what types of knowledge they provide and expect to receive. After these two steps finalize, the third step can be realized and it includes actual data/knowledge exchange between the interoperable services. We have also added an auxiliary message exchange happening between the Service Store and an instance of the Knowledge Directory for the purpose of supplying metadata needed by the Knowledge Explorer functionality of the Service Store.

[4] https://gitlab.inesctec.pt/interconnect-public/knowledge-engine/-/tree/main/docs

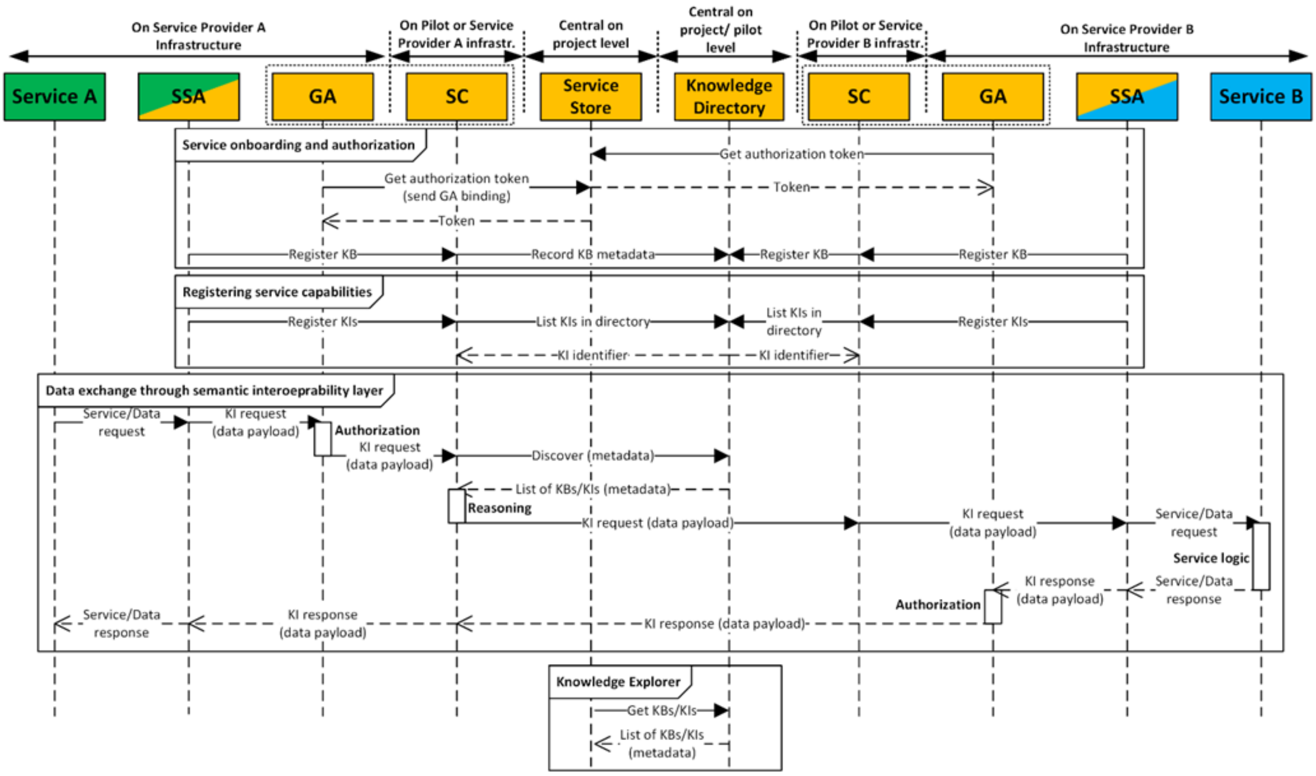

FIGURE 7 – MESSAGE FLOW DIAGRAM FOR MESSAGE EXCHANGES BETWEEN TWO INTEROPERABLE SERVICES.

8.1 PROCESS TO INTEGRATE A SERVICE

In this section the main steps in integrating a service into the SIF are listed. This flow was already presented in the D5.4 [5]. A video tutorial[5] is also available covering all these steps.

Based on the previous concepts, a digital service requires to undergo as series of steps. This section is not exhaustive. A URL is provided with specific instructions for each step.

1. Create an account and register a service using Interconnect's Service Store. This step establishes the first step into the Interoperability framework, creating the registry for each interoperable service.

#	Where	Action	Documentation for Action
1.1	Service Store	Create and validate Account	https://gitlab.inesctec.pt/interconnect-public/service-store-frontend/-/wikis/1.1-User-Guide-:-Register-User-Account
1.2	Service Store	Register Service	https://gitlab.inesctec.pt/interconnect-public/service-store-frontend/-/wikis/1.3-User-Guide-:-Register-Service

[5] https://www.youtube.com/watch?v=-GCfEj-FAkU

2. Download and instantiate a Generic Adapter instance for your service. Acquiring the Generic Adapter will allow services to start the integration by instantiating the gateway to the Interoperability framework in setting the privacy choices for each service.

#	Where	Action	Documentation for Action
2.1	Interconnect Repository	Download Generic Adapter	https://gitlab.inesctec.pt/interconnect-public/generic-ada
2.2	Local instance	Start the Generic Adapter	https://gitlab.inesctec.pt/interconnect-public/generic-ada /blob/master/docs/01_preparations.md

3. Register the Generic Adapter instance for your service. By registering the generic adapter, a binding will be established between a generic adapter instantiation and a service record in the Service Store.

#	Where	Action	Documentation for Action
3.1	Generic Adapter	Register the Generic Adapter by including the service reference.	https://gitlab.inesctec.pt/interconnect-public/generic-adapter/-/blob/master/docs/02_service_store.md

4. Instantiation of the KE or KER and KD. Instantiating a privately hosted instance of the KE will allow (e.g.,) an instance per pilot or per building. Moreover, the KE can leverage from its distributed design when using the KER, composed of a series of federated KE instances. The latter requires a KD deployment, acting as a discovery point to all available KER instances.

#	Where	Action	Documentation for Action
3.1	Knowledge Engine	Instantiation of the KE or KER + KD	https://github.com/TNO/knowledge-engine

5. Build the Service Specific Adapter for your service. The creation of the SSA will establish the kind of knowledge interactions, that is, the knowledge a service is able to *serve* and how it will relate with other services in the interoperable ecosystem. This is achieved through the ontological graph pattern descriptions, based on SAREF.

#	Where	Action	Documentation for Action
5.1	Interconnect Repository	Refer to the Interconnect ontology repository.	https://gitlab.inesctec.pt/interconnect-public/ontology
5.2	Interconnect Repository	Get acquainted with the ASK, ANSWER, POST, REACT knowledge interactions.	https://gitlab.inesctec.pt/interconnect-public/knowledge-engine/-/blob/main/docs/01_concept.md
5.3	Interconnect Repository	Follow the process to build the SSA.	https://gitlab.inesctec.pt/groups/interconnect-public/-/wikis/home#service-specific-adapters
5.4	InterConnect Wiki page	Video tutorials for SAREFization process and SSA creation	Graph pattern creation part 1: https://www.youtube.com/watch?v=FM30JOFQDLo Graph pattern creation part 2:

			https://www.youtube.com/watch?v=I_QI7zoTazQ SSA creation part 1: https://www.youtube.com/watch?v=GOUCN0KKpuo SSA creation part 2: https://www.youtube.com/watch?v=W7ywyJSNEGs

6. Test the SSA integration with the Generic Adapter instance. The test stage allows requests to be proxied by the generic adapter and to collect the feedback from the knowledge sent and exchange via the SIL, particularly via the KE. It also takes part in the certification flow of services, allowing other services to acknowledge what is the development stage of a given service.

#	Where	Action	Documentation for Action
6.1	Generic Adapter	Test the SSA integration with the GA by checking logs.	https://gitlab.inesctec.pt/interconnect-public/generic-adapter/-/blob/master/docs/08_faq.md
6.2	Service Store	Verify the certification results that also hold the logs.	https://gitlab.inesctec.pt/interconnect-public/service-store-frontend/-/wikis/1.4-User-Guide-:-Service-Certification

8.2 SEMANTIC INTEROPERABILITY IN ACTION

Let's consider an example of a Building Energy Management System (BEMS – see Figure 8). With Syntactic Interoperability a BEMS needs to undergo a specific update (development of new software enablers) to integrate smart devices and appliances, considering a predefined set of data models and APIs, to be capable of taking advantage of features and functionalities. If the functionalities change, or if another manufacturer is to be supported, then different data structures need to be considered. Therefore, the interoperability integration is focused on the BEMS and can have large OPEX. With the Sematic Interoperability introduced by the SIF, in the domain plane, the BEMS can ask ANY question addressable in SAREF, to any SAREF-compliant device or system, regardless of the specific API of each semantically interoperable service. It enables a border-breaking interoperability via the SSAs with combined knowledge from multiple services. The Figure 5 presents the advantages in using the SIF, with a BEMS benefiting from the competitiveness of being able to integrate a different service provider (e.g., Energy Retailer) or smart appliances from different manufacturers (e.g., Bosch, Siemens, Miele, Whirlpool, etc.) without having to incur into additional developments and integration, which is costly and undermine the ability to more easily and quickly react to new functionalities or features, avoiding lock-ins. It's in line with the essence of Plug&Play. This is not to say that integrating SIF and achieving semantic interoperability does not require significant updates on the side of the service providers. The InterConnect project works towards providing a framework that will streamline this process. With such approach, the interoperability is achieved by all stakeholders instead of being pushed to single integrators (like BEMS in this example). With broad cross-domain semantically interoperable ecosystem, all stakeholders will find the motivation for pursuing updates to their service and interface logic towards semantic interoperability.

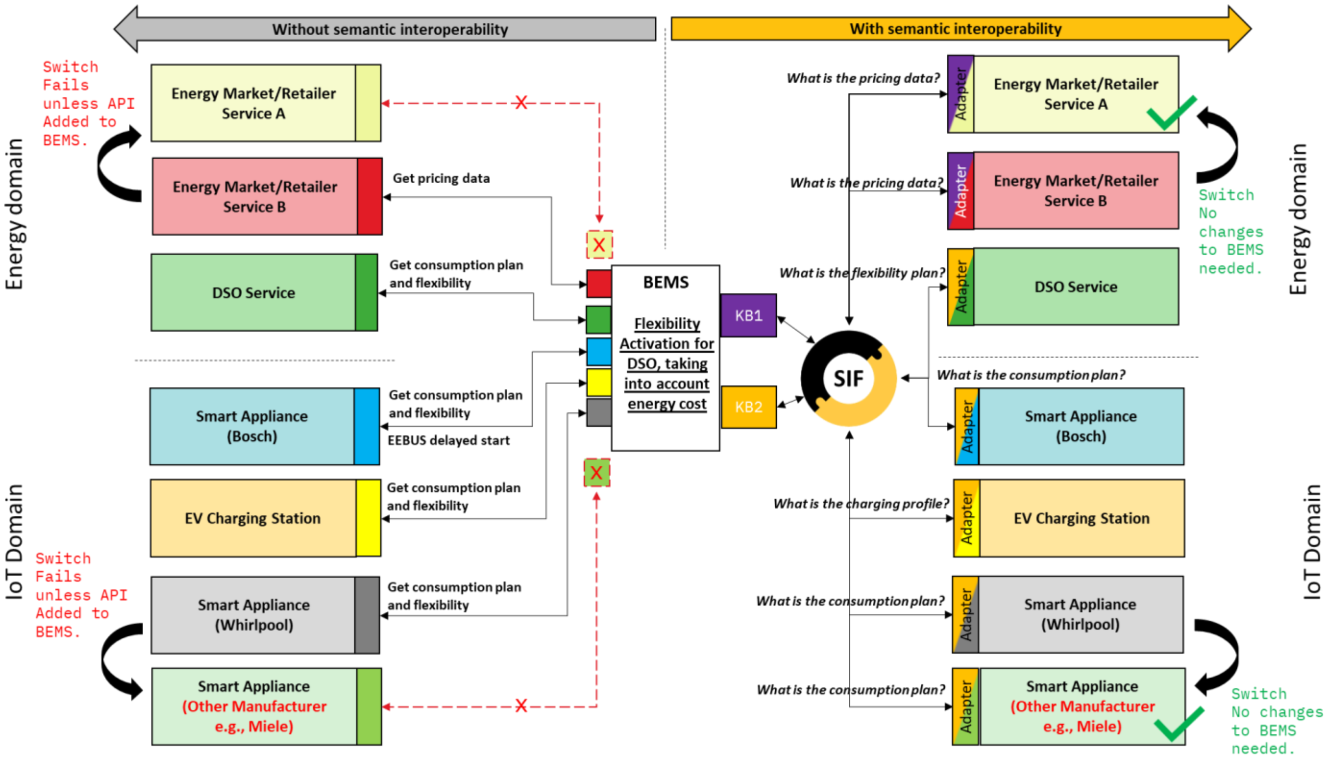

FIGURE 8 - SIF IN ACTION - EXAMPLE OF BEMS.

9. CONTINUOUS SUPPORT PLAN FOR SIF

The SIF is developed and maintained as a software project following closely Agile development practice. The stakeholders (SIF integrators from within the project) participated in SIF specification and tested each feature from the early development stages. This way we have created a well-established feedback loop with the integrators through the project Gitlab. The received feedback and validation results (bugs, new feature requests, performance improvements) were adopted as the new mor stable and complete versions of the SIF were developed and introduced to the integrators/stakeholders. As the project pilots begin testing their use cases in practice, the WP5 core team continues to provide support and to collect feedback. The list of stakeholders is now extended towards open call selected participants – start-ups and SMEs which will extend the existing or introduce new pilots. The WP5/Task 5.5 continuous support and update flow is presented in Figure 9.

The WP5 will continue to organize workshops to introduce the SIF to the new integrators and disseminate the major updates of the future SIF releases to the existing integrators. The SIF will follow the quarterly release plan:

- All bugs and issues that integrators face will be handled immediately.
- All requests for new functionalities, performance improvements and extensions are executed in sprints and bundled for quarterly release of the SIF components (each calendar quarter the WP5 will release a new stable version of the SIF after testing and validating new features and updates).
- Each release will be accompanied with detailed release notes about the main updates and potential breaking changes that the integrators must be aware of. The release notes will be listed for each SIF component on the technical documentation within the project's public wiki page.
- Integrators will make decision if and when they will update their local SIF instances (e.g., on a pilot level) to the new releases. They will be able to skip a release if it does not add value to their current deployment.

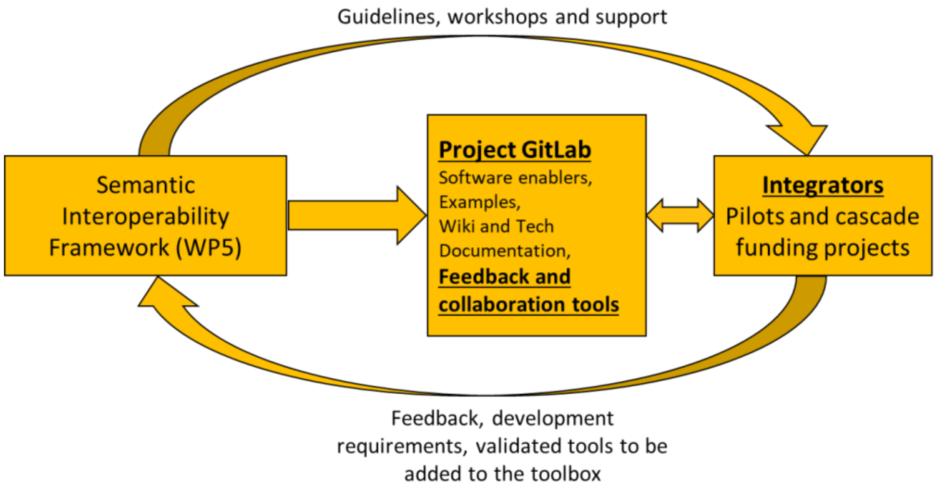

FIGURE 9 - SIF CONTINUOUS UPDATES FLOW.

10.SIF AS A KEY EXPLOITABLE RESULT

The SIF is considered as InterConnect project's key exploitable result. As such, it us at the forefront of project's impact creation and alignment with key initiatives on the EU level that work on or depend on semantic interoperability.

10.1 SIF ALIGNMENT WITH KEY EUROPEAN INITIATIVES

The WP9 and WP10 deal with project standardization activities and collaboration with other initiatives. The Figure 10 presents the flow through which SIF developments are translated into the project's impact generation activities and how developments on the relevant standards, initiatives and policies/strategies are involved into the process of SIF updates (as presented in Section 9 of this document).

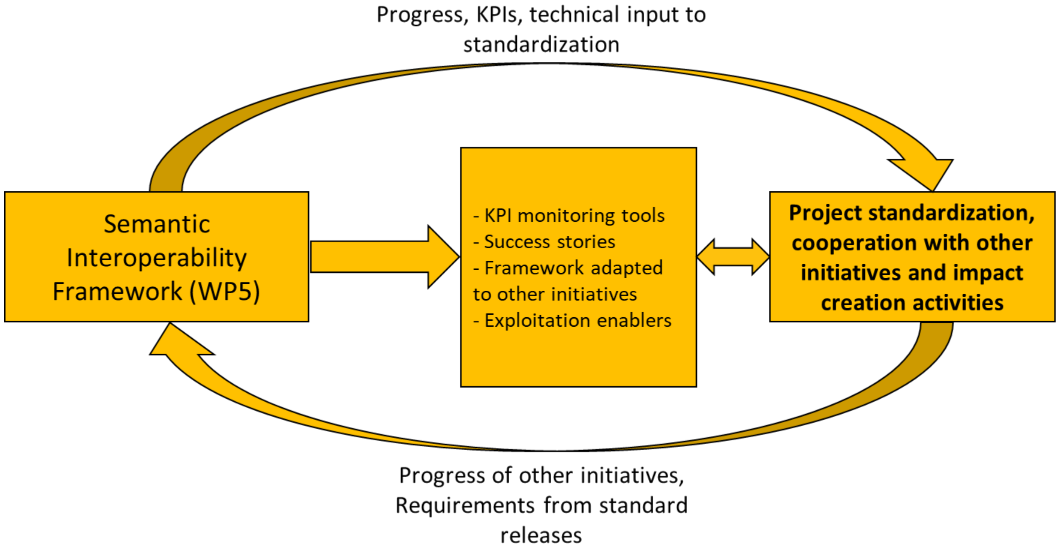

FIGURE 10 - SIF FLOW FOR CONTRIBUTING TO PROJECT STANDARDIZATION AND IMPACT GENERATION.

The **SIF** merges with the concept of **common data spaces** by design, naturally establishing data spaces within and between the Energy and IoT domains. The approach is guided as per IDSA's approach towards GAIA-X regarding the use of distributed architectures, federated connectors, and governance model with configurable data sovereignty by the controller. A seamless integration is possible, where InterConnect (SIF, ontology and services) can be used as facilitator for establishing semantically interoperable ecosystems on top of which data spaces can be organized. The **SIF** unlocks the establishment of semantic enabled knowledge dissemination based on SAREF to be included in the GAIA-X ecosystem, while supporting GAIA-X sovereignty and data governance as part of the instalment of new data space value-chains. The enrolment strategy for external alliances or initiatives like GAIA-X is the same as for the 3rd parties. Meaning that the InterConnect SIF is used to establish semantically interoperable ecosystem and, on that basis, the distributed knowledge federation.

The placement of the InterConnect SIF and GAIA-X areas in the architectural layer of SHBERA as depicted in Figure 11 indicate two important relationships:

1. InterConnect SIF can be used as a technological basis enabling distributed knowledge federation on top of which the data spaces are established with GAIA-X data sovereignty and governance.
2. The InterConnect covers domains of Energy and IoT/buildings, while the GAIA-X covers more domains.

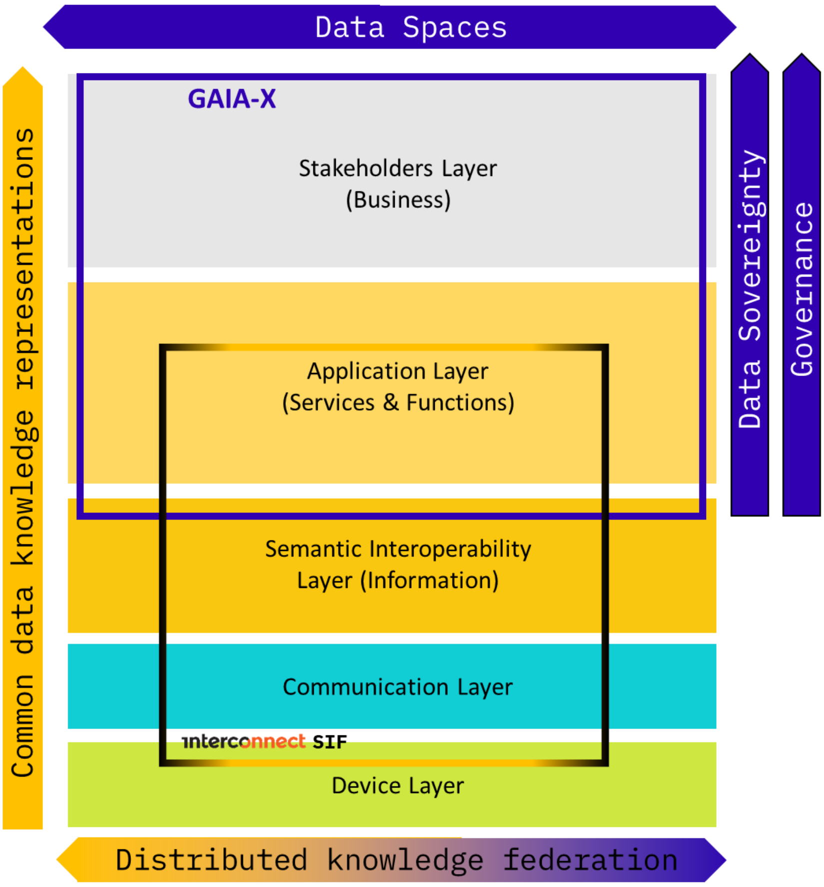

FIGURE 11 - SIF ALIGNEMNT WITH THE GAIA-X AND CONCEPT OF DATA SPACES.

InterConnect is aligned and actively contributes to EC initiatives, such as BRIDGE, promoting the SIF to foster semantic interoperability as the needed game changer to unlock cross-domain data spaces. This work has started in OPEN DEI, with the architectural discussions that will lead to the integration within the European Data Spaces or GAIA-X initiative, particularly in terms of data sovereignty, creation of semantic knowledge capabilities in those associations and leveraging from the learned lessons from manufacturers associations and alliances in the Interconnect large scale pilots. This is also expected to influence the policy plane, by identifying limiting factors and issuing recommendations to address them in several planes. InterConnect provided contributions to the IDSA surveys on data spaces building blocks and how the functional blocks proposed by IDSA are addressed by the SIF.

10.2 SIF EXPLOITATION PLAN

The goal of the consortium is to position the InterConnect SIF as a framework and best practice/benchmark for other European initiatives seeking to achieve cross-domain semantic interoperability. As part of the exploitation plan, the SIF will be regularly aligned with and provide direct contributions to GAIA-X/IDSA, AIOTI, OpenDEI, Dairo/BDVA and Joint Research Centre (JRC). The ultimate goal of these activities is that the SIF becomes recognized as an enabling technology. The positioning of the InterConnect SIF is exemplified with respect to the GAIA-X and FI WARE in Figure 12.

Another direction of the exploitation path is alignment with projects and initiatives like FI WARE and WoT to complement interoperability solutions and show integration potential. The main goal here is to expand SIF with adapters to standardized interfaces and data models.

Overall, the status that will motivate the ETSI and EC to recommend InterConnect SIF to all adopters of SAREF ontologies was pursued.

The SIF exploitation team during, and immediately after the project, includes the following partners: INESC TEC, TNO, VLF, VITO with support of the pilot teams. The mission is to establish technical community around the SIF as an open-source framework, comprising project partners joined by other organizations and individuals.

Further progress of the SIF development, exploitation and impact creation will be regularly documented on the project public Wiki page [4].

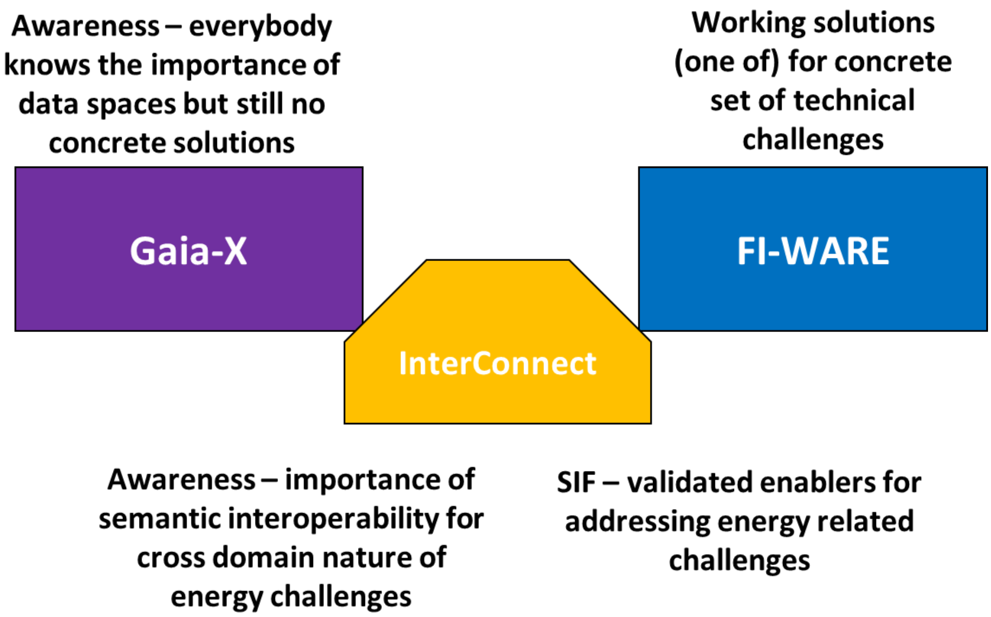

FIGURE 12 – SIF POSITIONING FOR EXPLOITATION.

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INTERCONNECT DOCUMENTS

[1] InterConnect Grant Agreement number 857237.

[2] InterConnect project. "D5.1 Concept, design and architecture of the interoperable marketplace toolbox". 2022

[3] InterConnect project. "D5.3 Security, cyber-security and privacy protection action plan and results". 2021.

[4] Interconnect Public Wiki and repositories, https://gitlab.inesctec.pt/groups/interconnect-public/-/wikis/home

[5] InterConnect project. "D5.4 Prototype for the interoperable marketplace toolbox". 2022.