INTERNATIONAL DATA SPACES ASSOCIATION

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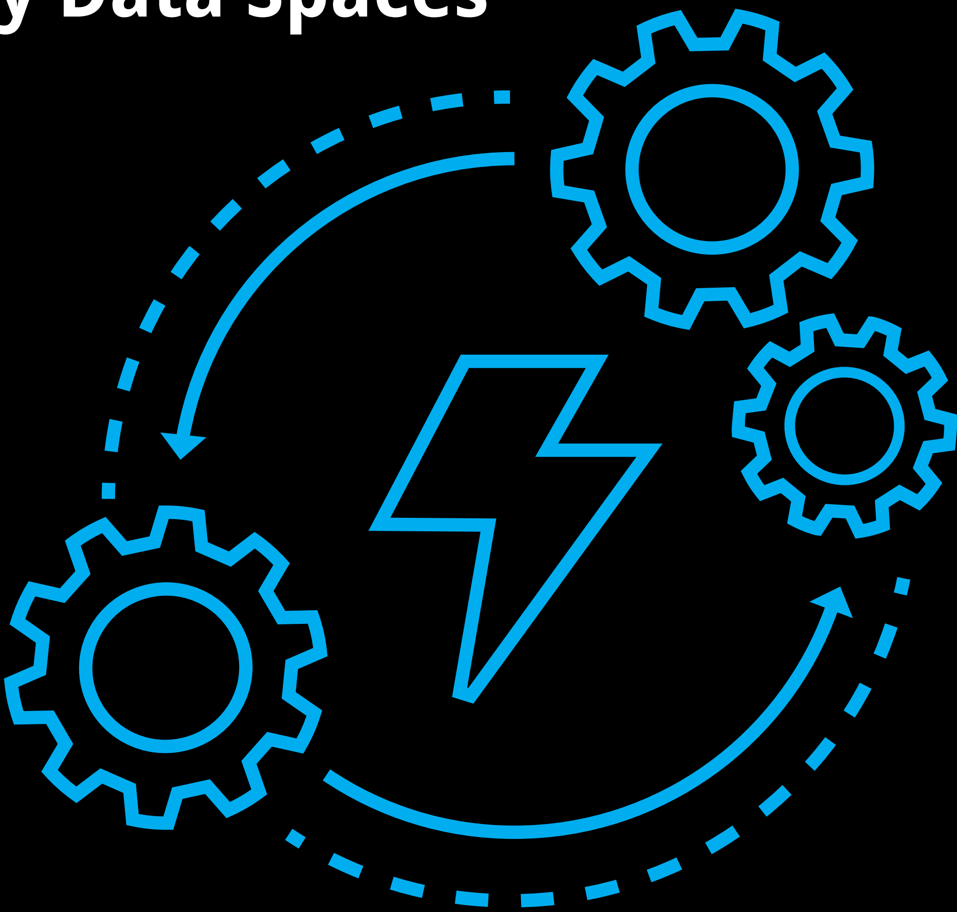
Interoperability Framework in Energy Data Spaces



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This publication is a position paper by the Energy Interoperability Task Force with IDSA is leading. IDSA has coordinated the effort that resulted in this paper. It aims to provide an overview of the state-of-play on the technical and semantical interoperability level. The contents of this publication do not necessarily reflect the position or opinion of IDSA, all the authors or contributors.

Contributing Projects

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1 Introduction

1.1 Purpose of this paper

The purpose of this paper is to define a framework for achieving interoperability within energy data spaces. As the energy sector pivots towards the twin transitions of digitalisation and renewable energy integration, the need for interoperability across technical, semantic, organisational, and legal dimensions becomes crucial. This framework outlines strategies to address these challenges, drawing on insights from collaborative European projects and the evolving regulatory landscape. To accomplish this, it takes the work of the HORIZON-CL5-2021-D3-01 projects as its foundation.

Version 2.0 builds upon the foundation laid in version 0.9, with significant expansions and refinements. Key additions include a detailed description of the system use cases that the projects implemented to demonstrate cross-data space interoperability. Furthermore, new chapters have been added to address organisational and legal interoperability, providing a holistic view of the governance and policy considerations essential for cross-data space collaboration. The updated version also incorporates a dedicated chapter on the benefits of interoperability for energy stakeholders.

1.2 Relationship with other papers

This paper builds upon and aligns with several other papers describing interoperability in data spaces more generally, and more specifically outlines blueprints and interoperability frameworks for energy data spaces. Below is a description of the most central papers.

1.2.1 New European Interoperability Framework

A structured approach to effectively manage and address challenges related to interoperability is presented through the European Interoperability Framework[1], formulated by the European Commission. This framework was originally defined to set up interoperable digital public services for public administrations and has recently been adopted for broader applications. Figure 1 highlights its key aspects.

1 https://ec.europa.eu/isa2/eif_en/

Figure 1: New European Interoperability Framework

As depicted in Figure 1, the framework outlines a stratified model consisting of four distinct functional tiers within a comprehensive integrated governance paradigm. This framework has been used as basis to structure the core content of this paper, with special focus on the technical and semantic layers.

1.2.2 DSSC Data spaces blueprint[2]

According to the definition of the Data Spaces Support Centre (DSSC)[3], the blueprint is "a consistent, coherent and comprehensive set of guidelines to support the implementation, deployment and maintenance of data spaces. The blueprint contains the conceptual model of a data space, data space building blocks, and a recommended selection of standards, specifications and reference implementations identified in the data spaces technology landscape".

This paper uses the building blocks defined in the DSSC blueprint as basis to describe the technical interoperability requirements.

1.2.3 Blueprint of the Common European Energy Data Space (CEEDS) - version 2.0[4]

This document outlines the Common European Energy Data Space (CEEDS) concept, offering detailed strategies and recommendations for its practical implementation. The primary goal of this blueprint is to provide guidance on advancing current data infrastructures within the energy sector, paving the way for comprehensive adoption of data space solutions.

1.2.4 Semantic Interoperability in Data Spaces[5]

This paper explores the importance of semantic interoperability in the context of industrial data sharing. It highlights how semantic technologies and standards facilitate meaningful data exchange and integration across heterogeneous systems. The paper discusses the challenges of achieving semantic interoperability, such as semantic modelling, vocabulary alignment, and ontology development. It emphasizes the need for common data models and semantic representations to enable seamless data sharing and understanding between

[2] Data Spaces Blueprint v1.5 - Home - Blueprint v1.5 - Data Spaces Support Centre
[3] https://dssc.eu/
[4] https://intnet.eu/images/resources/Blueprint_CEEDS_v2.pdf
[5] Position Paper Semantic Interoperability In Data-Spaces (internationaldataspaces.org)

different domains. The IDSA Semantic Interoperability Paper further underscores the significance of semantic interoperability for enabling data-driven decision-making, fostering innovation, and unlocking the full potential of industrial data ecosystems.

1.2.5 EnTEC – Common European Energy Data Space[6]

The EnTEC Common European Data Space full report formulates a strategy for implementing the Common European Energy Data Space, outlining a comprehensive list of entities and services associated with flexibility in the European energy market or those at advanced technological stages within European research initiatives. These identified actors and services are potential participants who could utilize and contribute to the envisioned data space in the future.

This paper documents the current developments being conducted to establish the Common European Energy Data Space (CEEDS).

1.3 Relationship with other initiatives

Several initiatives at European level are developing activities in line with the data spaces concept. In this regard, the SIMPL "streamlining cloud-to-edge federations for major EU data spaces"[7], funded through the DIGITAL Europe Work Programme, is defined as the smart middleware that will enable cloud-to-edge federations and support all major data initiatives funded by the European Commission, such as common European data spaces.

2 Overview of interoperability in the energy domain

Addressing interoperability in the energy domain presents a complex challenge due to its encompassing nature, involving the private sector, public sector, public-private collaborations, and individual citizens, whether they are prosumers or not. The breadth and diversity of these stakeholders necessitate a comprehensive approach to interoperability.

2.1 What makes the requirements and challenges of an energy data space different from other data spaces?

The energy sector is at the core of the twin transition towards digitalization and renewable energies. Therefore, a technological transformation toward renewables is coinciding with an inevitable uptake of innovative digital services. At the same time, fossil fuels are increasingly being replaced by electrification in major sectors such as mobility, heat, and industrial processes.

Supply and demand in the electrical system operation need to be seamlessly coordinated. Markets allow for this coordination through trading on different timescales. With the

[6] https://op.europa.eu/s/y971
[7] Simpl - https://digital-strategy.ec.europa.eu/en/news/simpl-streamlining-cloud-edge-federations-major-eu-data-spaces-updated-october-2023

increasing share of renewable generation and flexible demand, these processes demand ever more stringent time resolutions, which in turn rely on fluent and lower latency communication and the availability of data.

Energy is to a large extent a regulated sector. Non-discriminatory access to the grid and to markets is a key principle that needs to be maintained in a data space setting. Furthermore, European and national regulatory bodies are imposing rules and guidelines that affect interactions and communications in the market. These will feed into the design and the governance of energy data spaces.

In comparison with other industries, energy data spaces need to comply with a larger set of domain-specific regulations. At the same time, there are strong regulatory bodies and industry associations that already have well-established processes to develop market-wide standards for communication, protocols, and data. These existing structures, which have much in common and often show a high degree of commonalities with modern data space reference architecture, should be linked and built-upon to form a uniform and federated ecosystem designated as Common European Energy Data Spaces (CEEDS). This is especially important due to the European principle of subsidiarity and European regulation, which leaves the organization of energy data management to the member states (MSs), as per Directive (EU) 2019/944, Article 23. This federated approach also complies with Article 24 of the directive and the European approach to energy data interoperability coined by implementing Regulation (EU) 2023/1162. Needless to say, it will also comply with future legislative actions.

2.2 Challenges for interoperability in the energy domain

The EC discovered as early as 2010 that technical integration issues will arise while connecting heterogeneous infrastructures to the smart grid. In response, the Commission issued the M/490 mandate to Standards Development Organizations (SDOs). This mandate[8], issued to CEN, CENELEC, and ETSI, focuses on technical interoperability in smart grids. It aims to address the challenges posed by the integration of various smart grid technologies and enable seamless communication between different systems. M/490 provides a framework for standardization activities in areas like data exchange, security, and protocols and promotes the development of harmonized standards that ensure compatibility, efficiency, and reliability across smart grid deployments. The mandate emphasizes the importance of stakeholder collaboration involving manufacturers, utilities, regulators, and other relevant entities. Through M/490, CEN, CENELEC and ETSI seek to foster innovation, enhance grid performance and facilitate the transition to a sustainable and intelligent energy infrastructure. Many of the M/490 deliverables have been standardized by the IEC System Committee Smart Energy[9], while the mandate has also identified a set of reference standards for key SmartGrid data exchanges.

[8] Standardisation Mandate Smart Grids (cencenelec.eu)
[9] https://syc-se.iec.ch/#about

2.3 Recent advances for data spaces in the energy domain

The advancement of communication technology enables the devices of all the stakeholders participating in the energy market to share/exchange information with others in a standardized and interoperable way. In such instances, the data structure, data privacy, security, and regulations for data sharing need to be considered to ensure that the data exchange is protected suitably while following fair rules for data evaluation and compensation. Moreover, to deal with electrical issues of the power systems, the Transmission System Operator (TSO) and Distribution System Operator (DSO) require growing amounts of information from the Grid edge to amounts of information to plan, maintain, monitor, and operate grids under secure and reliable conditions.

To achieve the goals mentioned above, the European Commission (EC) has recently published the "EU action plan for digitalizing the energy system"[10], of which data spaces constitute a fundamental pillar. According to the action plan, data spaces aim to promote interoperability for data exchange among stakeholders in the energy sector based on standardized data structure, cyber-security, and data privacy. In this way, they will enhance the quality of services, promote advanced grid services using data sharing (e.g., planning, forecasting, monitoring, etc.) and foster business across the sector. With so much at stake, it's no wonder the integration and management of vast amounts of data plays such a crucial role.

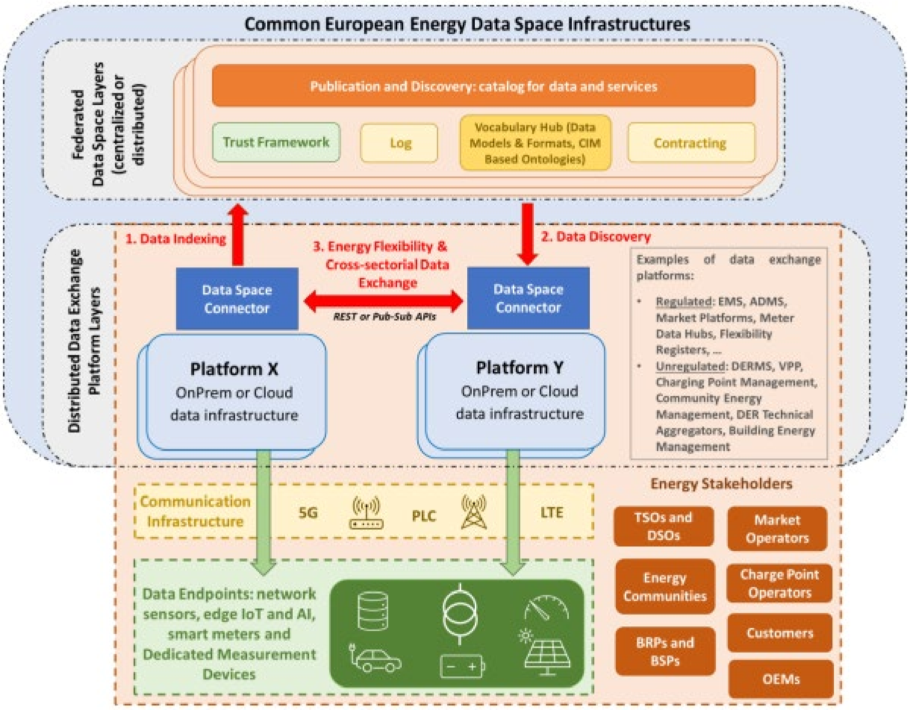

Figure 2: Exchange of energy-related data among different data platforms (as data space participants). Blueprint of the CEEDS v2[11].

[10] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0552&qid=1666369684560
[11] https://intnet.eu/images/resources/Blueprint_CEEDS_v2.pdf

By considering the business models and the specific stakeholders, several energy frameworks and platforms for data integration have been developed in the energy market. To support the market's growth, data integration in systems and platforms – based on the Common Information Model (CIM[12]) – is of utmost importance. This integration demands the expansion of interoperability, transparency, and equal access for all parties. This improvement will facilitate information exchange on a large scale for all parties. Therefore, as the number of market participants is increasing, interoperability is becoming more and more a key aspect for every data space solution across Europe.

In addition to data spaces' increasing utility in wholesale, retail and grid operations, new participative schemas such as energy communities and energy sharing, along with the emergence of self-generation / self-and data-driven services, require a seamless integration of the management of customer consent for numerous digitalized processes. At the same time, it is becoming more important for energy-related actors and end-users alike to harness in-house near real-time data effectively for smart and digital solutions. Countries like Austria or Spain, where these solutions enjoy high adoption rates, require sophisticated digital platforms with challenging data needs.

For a multiplicity of actors, the upcoming Network Code on Demand Response (see ACER Framework Guidelines[13] as of March 2023, proposal by EU DSO Entity and ENTSO-E together with stakeholders as of May 8th 2024[14], and ACER's draft review version from September 5th 2024[15]), will bring a lot of opportunities for participation and similar, yet even more challenging, data integration requirements. For example, for the integration of the pan-European market operations of the TSO backend, TSO exchanges need to be harmonized. This requires the promotion of marketplaces for horizontal power exchange (such as the coupling of European balancing platforms and both day-ahead and intra-day flow-based market coupling), IEC CIM Market extensions, and related ontologies. In this sense, the TSO can take advantage of the extension of CIM to seamlessly interoperate information exchange among participants across Europe. Furthermore, to achieve maximum efficiency in using data to manage the power system from high voltage levels to end users, this concept has been promoted in the flexibility market to enable vertical coordination between TSO and local DSO marketplaces.

Regarding data connection, semantic interoperability is still an issue in the energy domain. Accordingly, a new data model for semantic interoperability has been proposed by SEDMON[16] (Semantic Data Models of Energy), under the PLATOON project[17]. SEDMON

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[12] CIM | DMTF

[13] https://acer.europa.eu/sites/default/files/documents/Official_documents/Acts_of_the_Agency/Framework_Guidelines/Framework%20Guidelines/FG_DemandResponse.pdf , last accessed on February 1st, 2025; Supporting document for this version,

[14] System operators' (EU DSO Entity and ENTSO-E) proposal for a network code on demand response, https://www.acer.europa.eu/sites/default/files/documents/Official_documents/Public_consultations/PC_2024_E_07/1_NCDR_DSO_ENTITY_ENTSO-E.pdf , last accessed on February 1st, 2025; Supporting document for this version, https://www.acer.europa.eu/sites/default/files/documents/Official_documents/Public_consultations/PC_2024_E_07/2_Supporting_Document_DSO_ENTITY_ENTSO-E.pdf, last accessed accessed on February 1st, 2025

[15] ACER revised proposal draft for public consultation, https://www.acer.europa.eu/sites/default/files/documents/Official_documents/Public_consultations/PC_2024_E_07/ACER_revised_proposal_DR_NC_package.zip , last accessed accessed on February 1st, 2025

[16] SEmantic Data MOdels Of ENergy, https://w3id.org/platoon, PLATOON Horizon Europe Project financed by European Commission (Grant agreement ID:872592), last accessed on 21st September, 2023

[17] https://platoon-project.eu/

facilitates information exchange among stakeholders' applications and services, favouring coherent implementations based on the market mechanism's purposes. In addition, the standardized data model is promoted to enable data connections according to the concepts of SmartDataModels[18][19], addressing different applications such as smart energy, smart cities, and smart buildings.

3 Role of each initiative in the contribution to interoperability

The landscape of interoperability within data spaces is expansive, allowing for diverse perspectives and approaches to be explored. This chapter delves into the methodologies of prominent initiatives such as IDSA, FIWARE, and Gaia-X, recognizing these as foundational frameworks that underpin the ongoing endeavours of the projects.

IDSA focuses strongly on technical and semantic interoperability and, with the IDS Rulebook, offering guidance on how to achieve organizational interoperability. FIWARE fosters interoperability with the use of defined open APIs and Smart Data Models. Gaia-X has defined the Gaia-X Trust Framework to provide a worldwide set of rules and specifications to support Data Space Authorities and federations seeking interoperability.

3.1 IDSA

IDSA has defined and developed several assets and mechanisms to achieve interoperability. Following the New European Interoperability Framework, these assets can be mapped as follows (Figure 3):

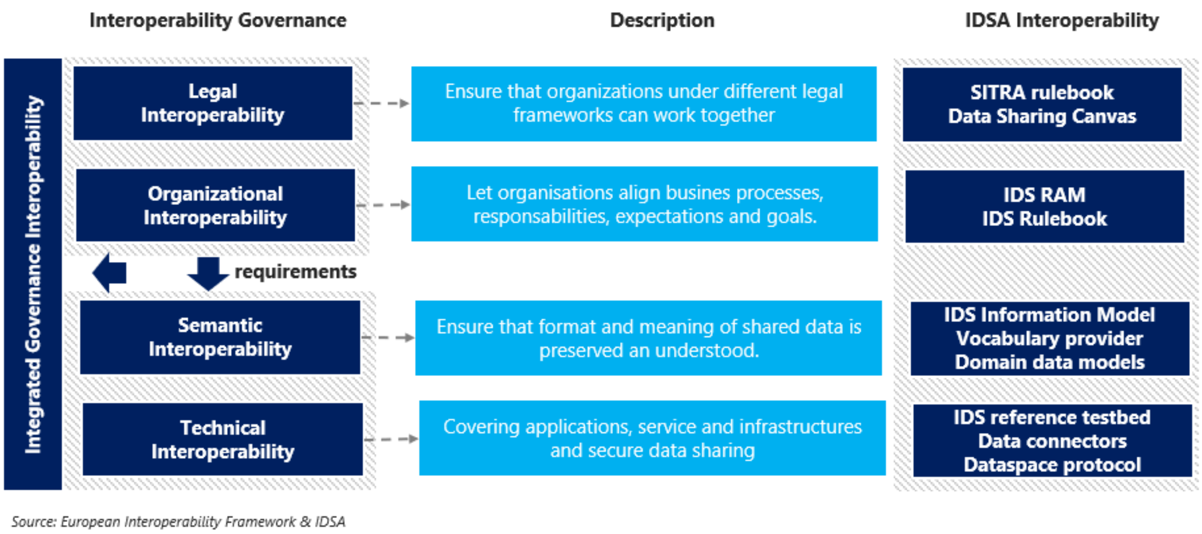

Figure 3: IDSA assets that support interoperability.

[18] https://smartdatamodels.org/

As described in the IDSA Rulebook[20], technical interoperability focuses on establishing physical and logical connections between systems, encompassing protocols, interfaces, and data formats. Semantic interoperability ensures a shared understanding of data meaning through common concepts and ontologies. Organizational interoperability addresses the alignment of processes, policies, and governance structures to facilitate effective collaboration. Legal interoperability involves harmonizing legal frameworks and contracts to recognize the equivalence of data sharing agreements across different jurisdictions and ecosystems.

Technical interoperability is achieved with IDS connectors, which can be considered as the starting point for enabling interoperability in data spaces. These IDS connectors are connectors, as defined in the IDS-RAM[21] and described in the IDSA Data Connector Report[22].

The Dataspace Protocol[23] is a set of specifications designed to facilitate interoperable data sharing governed by usage control and based on web technologies. These specifications define the schemas and protocols required for entities to publish data, negotiate usage agreements, and access data as part of a federation of technical systems termed a *dataspace*.

The IDS reference testbed[24] is a setup with open-source IDS components that can be used to test whether a component is interoperable with all the IDS components in the testbed setup.

The approach of IDSA with regards to semantic interoperability is described in the paper "Semantic Interoperability in Data Spaces"[25]. The IDS information model is the basis for the description of data assets. The vocabulary provider is an intermediary that technically offers vocabularies (i.e., ontologies, reference data models, or metadata elements).

Legal interoperability and operational interoperability can be achieved by the policies and rules of a specific data space instance and are typically managed by a data space authority. More information can be found in the IDSA Rulebook[26] and IDS-RAM[27].

To enhance interoperability, the IDSA emphasizes the adoption of common frameworks, standards, and best practices. Utilizing widely accepted protocols, such as the Dataspace Protocol (DSP), and aligning on semantic models can significantly reduce the complexity of data sharing across different data spaces. Additionally, establishing agreements between DSGAs can facilitate cross-data space interoperability, enabling participants to engage in multiple data ecosystems with greater ease. By fostering a culture of collaboration and standardization, data spaces can unlock the full potential of data-driven innovation.

[20] Interoperability in Data Spaces | IDS Knowledge Base
[21] README | IDS Knowledge Base
[22] Data Connector Report – International Data Spaces
[23] Dataspace Protocol 2024-1 | IDS Knowledge Base
[24] GitHub – International-Data-Spaces-Association/IDS-testbed

[25] https://internationaldataspaces.org/wp-content/uploads/dlm_uploads/IDSA-Position-Paper-Semantic-Interoperability-in-Data-Spaces.pdf
[26] Introduction | IDS Knowledge Base
[27] https://docs.internationaldataspaces.org/ids-ram-4/

3.2 FIWARE

FIWARE[28] achieves interoperability primarily through the use of defined open APIs (NGSIv2 and NGSI-LD)[29] and Smart Data Models[30] (SDM), facilitating the exchange of information among a diverse set of systems, services and components.

The SDM initiative, launched by the FIWARE Foundation, aims to create a robust collection of data models that can be precisely serialized in various formats such as JSON, JSON-LD, CSV, and GeoJSON features, amongst others. Although these models are compatible with NGSIv2, NGSI-LD APIs, and other RESTful interfaces, they are independent of them. They align with universally accepted standards where possible and utilize a community-driven approach to fill gaps in standard data models. Over the years, they have defined the agile standardization paradigm. This agile methodology has led to substantial growth in the number and variety of data models and the number of contributing organizations.

The SDM initiative operates under an open governance model, managing the lifecycle of data models. This model follows best practices from open-source communities, focusing on transparency and meritocracy. Numerous organizations, including TM Forum, OASC, and IUDX, have partnered with the FIWARE Foundation in this effort, with over 100 companies contributing to the data models.

Besides these two tools, FIWARE fosters interoperability with the use and promotion of:

- Shared Components: FIWARE's generic enablers[31] (GE) are open-sourced and offer a wide set of reusable and interoperable functions available for exploitation in a pluggable manner.
- Open Standards: FIWARE heavily relies on open standards, facilitating the integration of any other systems ready to interact with them. This ensures no vendor lock-in scenarios. Currently the NGSI-LD standard is standardized by the independent standardization body ETSI[32].
- Orion Context Broker: As the heart of any FIWARE-based system, the Orion Context Broker acts as a mediator for the exchange of data among components and other systems, increasing interoperability and allowing horizontal and vertical scalability.

Additionally, for the interoperability of digital twins and metaverse systems, FIWARE has teamed up with the Digital Twin consortium, taking the approach of a system-of-systems.

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[28] FIWARE - Open APIs for Open Minds
[29] NGSI-LD FAQ - Fiware-DataModels
[30] Smart Data Models
[31] https://www.fiware.org/catalogue/
[32] https://www.etsi.org/

3.3 Gaia-X[33]

The Gaia-X ecosystem is the composition of all participants and services using Gaia-X Credentials.

Dataspaces and Federations

The participants and services using Gaia-X Credentials can be organized by data spaces. Each data space, commonly organized around a vertical or a market, is composed of:

- a governance – i.e., a set of rules agreed upon by the parties in the data space – which must be operationalised.
- infrastructures – i.e., hardware and software for compute, storage, network services – adopting the governance.
- participants adopting the governance, using the infrastructures to access and use data in a fair, transparent, proportionate, and/non-discriminatory manner with clear and trustworthy data governance mechanisms.

The set of infrastructure services following the same governance is named a federation. A federation contributes to the direct or indirect management of services and datasets according to the data space governance.

A data space can span across several federations and a federation can be used by several data spaces.

The Gaia-X Trust Framework

In this challenging environment, where each data space wants to both be interoperable and yet adapts their governance to their vertical, domain-specific needs and local market regulations, the Gaia-X Trust Framework provides a worldwide ready set of rules and specifications usable by:

- the data spaces authorities, such as data intermediaries from the Data Governance Act[34], to build their governance.
- the federations seeking interoperability and technical compatibility of their services.

Interoperability in terms of governance is assessed by the Gaia-X Compliance and the Trust Index.

[33] Gaia-X Architecture Document - 22.10 Release
[34] Data Governance Act explained | Shaping Europe's digital future (europa.eu)

4 State of the art (papers and standards)

4.1 Introduction

The goal of this chapter is to list and briefly describe the main standards, papers, reference architectures, policies, and regulations that need to be considered when defining the interoperability framework for energy data spaces.

4.2 Papers

An introduction to the semantic interoperability problem is given by the paper "A case study research on interoperability improvement in Smart Grids: state-of-the-art and further opportunities[35][36]", which is a summary – with a less regulatory view – of the ISGAN Annex 6 report on Interoperability for Smart grids[37]. These two discussion papers account for the state-of-the-art in Smart grid ICT interoperability. Based on their findings, experts have agreed to focus on certain standards, reference architectures, and frameworks. These are depicted in the next chapters.

4.2.1 Policies/Regulations which impact interoperability

Within this section we briefly introduce the core conditions impacting interoperability:

- The European Interoperability Framework (EIF)
- The electronic Identification, Authentication and Trust Services (eIDAS) Regulation,
- The Implementing Acts following Article 24 of Directive (EU) 2019/944 (following Implementing Regulation (EU) 2023/1162, published July 2023).

The European Interoperability Framework (EIF) is a strategic initiative with the primary goal of fostering seamless information exchange and collaboration among public administrations within the European Union (EU). It establishes a common framework, and guidelines aimed at ensuring the interoperability of systems and services used by public sector organizations across member states (MSs). The EIF comprises a set of principles, guidelines, and recommendations dedicated to achieving interoperability within the EU.

One of the key objectives of the EIF is to enhance the efficiency, effectiveness, and transparency of public services by facilitating the integration of diverse systems and services. It places a strong emphasis on the adoption of open standards and specifications to ensure compatibility and prevent vendor lock-in. Furthermore, the framework actively encourages the reuse of existing solutions, reducing duplication of efforts and saving costs.

Semantic interoperability is a cornerstone of the EIF, enabling the meaningful exchange of data and information across different systems. It aligns with the broader goals of the Digital

[35] Predictive maintenance für Windenergieanlagen-Energy data space whitepaper. Dortmund. https://internationaldataspaces.org/download/19022/
[36] A case study research on interoperability ... | Open Research Europe (europa.eu)
[37] ISGAN Word Template - Preview (iea-isgan.org)

Single Market Strategy, promoting cross-border interoperability and facilitating citizen-centric services. Additionally, the EIF provides essential guidelines for the development and procurement of interoperable systems and services, which in turn stimulates competition and innovation in the public sector.

Security and privacy measures are integral components of the EIF, ensuring the protection of sensitive information during data exchange. It promotes the adoption of service-oriented architecture (SOA) and modular design principles to further facilitate interoperability. At the national and regional levels, the EIF encourages the use of interoperability frameworks and specifications to align with the EU-wide framework.

Governance and coordination among stakeholders are highlighted as critical factors in ensuring consistent implementation of interoperability standards. The EIF also offers guidance for overcoming legal and organizational barriers that may impede interoperability. Furthermore, it promotes the sharing of best practices and collaboration among member states, fostering an environment where interoperability continually evolves to meet technological advancements and changing needs.

In sum, the European Interoperability Framework is a comprehensive set of guidelines and recommendations that aims to enhance information exchange and collaboration among public administrations within the European Union, promoting efficiency, effectiveness, and transparency in public services through the use of open standards, semantic interoperability, and shared best practices.

The role of common identification and authentication for interoperability

The eIDAS Regulation (Regulation (EU) No 910/2014[38]) establishes a framework for electronic identification, authentication, and trust services within the European Union. It aims to enhance trust in electronic transactions by providing a legal framework for secure and seamless electronic interactions between businesses, citizens, and public authorities. Key features include:

1. *Electronic Identification (eID)*: Allows mutual recognition of national electronic identification schemes across the EU, enabling citizens and businesses to access online services in other Member States using their national *eID/social security insurance login*.

2. *Trust Services*: Defines legal standards for electronic signatures, seals, timestamps, registered delivery services, and website authentication, ensuring their validity and legal equivalence to traditional paper-based processes.

3. *Cross-Border Interoperability*: Promotes seamless electronic interactions across EU borders, fostering the digital single market.

4. *Legal Certainty*: Provides legal clarity and uniformity for electronic transactions, boosting confidence in digital services.

[38] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2014.257.01.0073.01.ENG

The *eIDAS* Regulation is a cornerstone of the EU's digital transformation strategy[39], fostering secure and efficient online services. Especially *electronic IDs (eIDs)* are widely used in eGovernment and public services and – with recent enhancements – are now opened to more private and public-private use cases. EIDAS has established a European Network of Authentication Services that allow not just for simple authentication, but also for digital representations of legal persons by natural persons or natural persons by natural persons. The system works cross-border and EU-wide adoption has come to a high degree (see https://eidas.ec.europa.eu/efda/browse/notification/eid-chapter-contacts).

With its 2024 amendments, *eIDAS* has been extended with the European Digital Identity Framework. All regulated EU–wide IAM strategies are set to leverage a lot of cost savings potential and obstacles across multiple value chains in our sector.

In our sector, more and more digital platforms and data spaces are interacting with each other. These platforms may not be forced to operate on a common data pool, but are acting in a federated manner, which brings a lot of advantages. Use cases demand for more advanced *IAM* solutions, e.g. the possibility for natural persons to represent or take actions on behalf of other natural persons and/or legal persons like companies or associations. All of this is provided by the *eIDAS* European-wide networks and proven-in-use long-time within eGovernment solutions and other sectors and can be adopted easily.

As of status quo, most digital energy platform operators are using proprietary means for identification and authentication, often storing credentials on their own. Data space environments all-too often establish proprietary means for IAM. This leads to a lot of media breaks and the lack of a chain of trust. This lack of trust creates a lot of very expensive obstacles for data-driven solutions to go to market. As an example, and as proven impressively by Project EDDIE, in most MSs service providers need to found domestic companies, which creates a lot of liabilities, costs and unnecessarily slows down time-to-market. The acceptance of cross-border *eIDs* places an available, secure and easy-to-adopt solution to this big issue, in line with European strategies.

In order to provide a detailed look into how *eIDAS* boosts interoperability of data-driven energy solutions, Project EDDIE has released a whitepaper *"Identification and Authentication in a Common European Data Space[40]" in August 2024*.

As shown in the overview below, the EDDIE Data Space is currently applying eIDAS as the primary means for identification and access management – for the integration with established data-sharing platforms, to securing cloud-edge integration, and for the integration with within-sector and other-sector data spaces.

European regulatory approach towards energy data interoperability

[39] https://digital-strategy.ec.europa.eu/en/policies/eidas-regulation
[40] https://EDDIE.energy/files/EDDIE/media/media-library/Identification%20and%20Authentication%20in%20a%20Common%20European%20Data%20Space_v1.0.pdf

The Implementing Acts following Article 24 of Directive (EU) 2019/944[41] pertain to the operationalization of specific provisions within the directive. By detailing non-discriminatory requirements and procedures in the form of European reference models for energy service-related procedures (e.g., billing, supplier switching, access to metering and consumption data, demand response, etc.), these acts aim to establish the full interoperability of energy services across all member states and the effective implementation of the directive's requirements. Member states are asked to report their national practices based on a mapping towards these reference models, and a Joint Working Group between ENTSO-E and EU DSO Entity collects and publishes related information on a single point of reference for the whole Union.

Thus, these Implementing Acts support member states in translating the directive's objectives into practical actions and ensure consistency and harmonization across the European Union. By clarifying technical and administrative aspects, they facilitate the application and enforcement of the directive, promoting transparency, efficiency, and cooperation among relevant stakeholders. The acts serve as a vital tool for overseeing and monitoring the implementation progress, addressing challenges, and fostering the achievement of the directive's goals. Through a collaborative and consultative process, the Implementing Acts contribute to the successful realization of the energy market's liberalization, sustainability, and consumer protection objectives as outlined in Directive (EU) 2019/944. The first in a series of regulations has been published in July 2023 as Implementing Regulation (EU) 2023/1162. See section on standards and some IEC profiles (IEC 62325-451-10, IEC 61968-9) to illustrate standards that support this European regulation.

4.2.2 Reference Architectures known to impact the scope of this position paper

- Reference Architectures and Interoperability in Digital Platforms[42]: This document examines the role of reference architectures in achieving interoperability within digital platforms. It emphasizes the benefits of standardized blueprints, such as improved scalability and reduced development time. Challenges include standardization and managing diverse technological ecosystems. The Reference Architectures and Interoperability in Digital Platforms document also highlights the importance of governance and collaboration among stakeholders for effective reference architectures. Overall, reference architectures play a vital role in building robust and interoperable digital ecosystems.
- DSBA Technical Convergence Discussion Document[43]: The DSBA (Data Spaces Business Alliance) Technical Convergence Discussion Document is an agile paper that defines a common reference technology framework. This framework is based on the technical convergence of existing architectures and models and leverages mutual infrastructure and implementation efforts. The goal is to achieve interoperability and portability of solutions across data spaces by harmonizing technological components.

[41] Directive - 2019/944 - EN - EUR-Lex
[42] https://interoperable-europe.ec.europa.eu/collection/european-interoperability-reference-architecture-eira/solution/eira/eira-v610-online-documentation
[43] Data-Spaces-Business-Alliance-Technical-Convergence-V2.pdf

- Data Spaces Landscape[44] (alignment of Data Spaces initiatives): The Data Spaces Landscape provides an overview of the diverse landscape of data spaces, which are digital environments that facilitate secure data sharing and collaboration. The paper explores various data space initiatives and frameworks, highlighting their characteristics, objectives, and approaches. It discusses the importance of interoperability, governance, and trust mechanisms within data spaces and emphasizes the potential benefits of data spaces, such as enabling data-driven innovation, empowering individuals and businesses, and fostering cross-sector collaboration. The Data Spaces Landscape document serves as a valuable resource for understanding the current state and future prospects of data spaces and their role in driving digital transformation and data-driven economies.
- Design principles for data spaces[45]: The OPEN DEI (Aligning Reference Architectures, Open Platforms and Large-Scale Pilots in Digitising European Industry) project provides a framework of building blocks to accelerate the development and adoption of digital solutions in the four sectors: energy, manufacturing, agri-food, and healthcare. The building blocks encompass a wide range of technologies, methodologies, and standards, such as advanced analytics, digital platforms, cybersecurity, interoperability, and data management. These building blocks are designed to enable technical, business, operational, and organizational capabilities of data spaces from two perspectives: 1) an essential soft infrastructure and 2) services that form data spaces within and across domains. By leveraging the OPEN DEI building blocks, stakeholders can collaborate, innovate, and build scalable and interoperable digital solutions that drive the transformation of the energy sector towards a more sustainable and efficient future.
- Data Exchange Specification of GXFS[46]: The Data Exchange Specification of GXFS (Generic eXchange Format for Sensing data) provides a standardized format and protocol for exchanging sensing data across different systems and platforms. It defines a consistent structure and encoding for data representation, allowing seamless interoperability and integration between diverse sensing devices, applications, and databases. The specification covers aspects such as data formats, metadata, units, and quality assurance. By adhering to the GXFS Data Exchange Specification, organizations can efficiently exchange and utilize sensing data, enabling enhanced data-driven decision-making, analysis, and collaboration in various domains such as environmental monitoring, industrial automation, and smart cities.
- Gaia-X Conceptual Model[47:] The Gaia-X Conceptual Model represents a framework for a European data infrastructure based on principles of sovereignty, interoperability, and trust. It defines the conceptual components and their interrelationships within the Gaia-X ecosystem. The model encompasses four key layers: infrastructure, services, data, and governance. It promotes decentralized data management, data portability, and secure data sharing while respecting data protection regulations. The infrastructure layer includes cloud providers and data centres, while the services layer offers various data-centric services. The data layer focuses on data sovereignty,

[44] IDSA-Position-Paper-Data-Spaces-Landscape-1.pdf (internationaldataspaces.org)
[45] Design Principles for Data Spaces | Position Paper (design-principles-for-data-spaces.org)
[46] Data Exchange Services Specifications - GXFSv2 - Data Exchange - 22.10 Release
[47] Conceptual Model - Gaia-X Architecture Document - 24.04 Release

standards, and formats. Governance ensures transparent and accountable management of the ecosystem. The Gaia-X Conceptual Model aims to facilitate data sharing, innovation, and digital sovereignty across industries and domains.

- Guidance on the integration of IoT and digital twin in data spaces (SC41)[48]: This guidance provides recommendations for effectively integrating Internet of Things (IoT) technologies and digital twin concepts within data spaces. It offers guidance on interoperability, security, and data governance to enable seamless integration, efficient data exchange, and collaboration among IoT devices and digital twins. The document supports the development of innovative and interconnected solutions that leverage IoT and digital twin technologies within the context of data spaces.
- Many national energy data spaces also impact the scope of this white paper, such as the organization of Energy Data Exchange Austria (EDA)[49], the organization and governance structure of energy data exchange in the Netherlands (through MFF-BAS[50]), and Spanish AELEC[51]-led architectures for their services Datadis (aggregated grid data and meter data sharing) and SIORD (real-time data sharing for significant grid users).
- Bridge Data Exchange Reference Architecture 3.1[52]: It provides a comprehensive framework for interoperable data exchange across the European energy sector. It outlines multi-layered interoperability, covering components, communication, information, functions, and business processes. The document emphasizes standardized data roles, feedback from projects, and recommendations to enhance energy data management. It also introduces the BRIDGE Federated Catalogue to streamline data sharing and highlights future steps for improving interoperability.

4.2.3 Interoperability in the Energy Domain

- EG1 Report Towards Interoperability within the EU for Electricity and Gas Data Formats and Procedures[53](2019): This report focuses on achieving interoperability in the exchange of electricity and gas data formats and procedures within the European Union (EU). It aims to enhance collaboration, efficiency, and transparency in the energy sector. The document outlines the current challenges and barriers hindering interoperability, including divergent data formats, lack of harmonization, and varying procedures across member states. It emphasizes the need for standardized data formats and procedures to facilitate seamless data exchange and integration. The report proposes a set of recommendations and actions to promote interoperability. These include the development and adoption of common data models, the establishment of harmonized procedures, the utilization of standard messaging protocols, and the implementation of data governance frameworks. Furthermore, by emphasizing the importance of collaboration among stakeholders – Including regulators, network operators, and data providers – to ensure the consistent implementation and enforcement of interoperability measures, the report addresses

[48] ISO/IEC JTC 1/SC 41 - Internet of things and digital twin
[49] EDA
[50] Home - MFFBAS
[51] Inicio - aelec
[52] european energy data exchange reference architecture-HZ0124020ENN.pdf
[53] 1st interim report_EG1 Data format & procedures

topics such as data security, data quality, and regulatory considerations in achieving interoperability. Overall, the EG1 Report serves as a comprehensive guide for promoting interoperability in electricity and gas data exchange within the EU. It provides a roadmap for harmonizing data formats and procedures, enabling enhanced cooperation and data-driven decision-making in the European energy market.

- ISGAN[54] - How to Improve the Interoperability of Digital (ICT) Systems in the Energy Sector): This report focuses on enhancing the interoperability of digital systems within the energy sector. It addresses the growing importance of information and communication technology (ICT) systems and their role in enabling efficient and sustainable energy management. The document emphasizes the need for interoperability to achieve seamless integration and effective communication between diverse digital systems in the energy sector. It highlights the benefits of interoperability, such as improved system performance, enhanced data exchange, and increased flexibility in managing energy resources. With these benefits in mind, the document discusses key challenges, including the heterogeneity of systems, lack of standardized protocols, and complex regulatory frameworks. It provides recommendations and best practices to overcome these challenges, such as adopting open standards, promoting data sharing frameworks, and establishing collaborative platforms for knowledge exchange. In particular, the document explores the role of emerging technologies, such as artificial intelligence, big data analytics, and blockchain, in driving interoperability. It underscores the importance of policy frameworks, stakeholder engagement, and capacity building to foster a culture of interoperability within the energy sector. Overall, the document by ISGAN (International Smart Grid Action Network) serves as a comprehensive guide for improving the interoperability of digital systems in the energy sector. It provides insights, strategies, and practical recommendations to facilitate the integration and optimization of ICT systems, ultimately enabling more efficient, sustainable, and resilient energy management.
- BRIDGE TSO-DSO report[55]: The BRIDGE TSO-DSO report addresses the collaboration between Transmission System Operators (TSOs) and Distribution System Operators (DSOs) in the energy sector. It highlights the need for improved coordination and information exchange between these entities to enable efficient integration of renewable energy sources and enhanced grid management. The report emphasizes the significance of data sharing, common methodologies, and standardized processes for effective TSO-DSO collaboration. It provides insights, recommendations, and case studies to guide stakeholders in developing frameworks and implementing best practices that facilitate seamless cooperation between TSOs and DSOs, ultimately supporting the transition to a more sustainable and reliable energy system.
- ETIP SNET Energy Data Space Policy paper[56]: This policy paper outlines the status of data spaces within the energy system, providing an overview of the background, domain applications, and the essential steps required to effectively harness such technical solutions on a broad scale.

[54] ISGAN - Homepage (iea-isgan.org)
[55] D3.12.f_BRIDGE-TSO-DSO-Coordination-report_1.pdf
[56] ETIP SNET Energy Data Space Policy paper

4.3 Standards

The smart grid roadmaps and other documents prepared over the last decade have consolidated a list of key standards that will be presented in this section. An introduction to smart grid standards can be found, in the European energy data exchange reference architecture published in 2021 and defined by BRIDGE Data Management Working Group [57], in the European (energy) data exchange reference architecture 3.0[58] published in 2023, and its version 3.1 published[59] in 2024. It describes why standardization is of high interest for the critical infrastructure and which standards demand the greatest attention. Hereafter main Standard Development Organisations with some of their key energy related standards are described.

4.3.1 IEC

Here we focus on IEC committees playing an important role in digitalization of the energy sector.

4.3.1.1 IEC Strategic Group 12

IEC SG12:

- defines the aspects of digital transformation that are relevant to the IEC and its standardization activities;
- develops a digital transformation methodology for international standardization;
- acts as digital transformation and systems approach competence centre within the IEC and provides associated expertise and advisory services to all IEC Committees;
- identifies emerging trends, technologies, and practices needed for the development, delivery, and use of the IEC's work;
- provides a platform for relevant discussion and collaboration with internal and external participation;
- coordinates the IEC's activities with those of external entities (e.g., ISO, ITU).

4.3.1.2 IEC System Committee Smart Energy

The IEC System Committee Smart Energy[60] aims to provide a "GPS or Radar" to the TC/SCs and to other standards development organizations (SDOs) and consortia, related to standardization in the smart energy domain. Key standards include:

- IEC 63097 Smart Grid Standardisation Roadmap[61]. This document is to provide standards users with guidelines to select the most appropriate set of standards and specifications based on Smart Energy use cases. These standards and specifications are either existing or planned, and are provided by IEC or other bodies, It also aims

[57] BRIDGE Data Management Working Group - European energy data exchange reference architecture. https://energy.ec.europa.eu/system/files/2021-06/bridge_wg_data_management_eu_reference_architcture_report_2020-2021_0.pdf
[58] https://op.europa.eu/en/publication-detail/-/publication/dc073847-4d35-11ee-9220-01aa75ed71a1/language-en
[59] https://op.europa.eu/en/publication-detail/-/publication/6c3b1add-a0a7-11ef-85f0-01aa75ed71a1/language-en
[60] Home - SyC Smart Energy
[61] https://syc-se.iec.ch/deliveries/iec-tr-63097-smart-grid-roadmap/

at creating a common set of guiding principles that can be referenced by end-users and integrators who are responsible for the specification, design, and implementation of Smart Energy Systems.

- IEC 62559 series[62]: a series of documents associated with use case methodology. This series leverages several M/490 results.
- IEC 62913 series[63]: use case methodology associated with smartgrids. IEC 62913-1 has introduced business use case and system use case and has been leveraged by several European projects (e.g., EvolvDSO, TDX-ASSIST, EU-SysFlex, and energy data space projects such as OMEGA-X and EDDIE).
- IEC 63200[64]: smart grid architecture model basics. This document leverages the M/490 SGAM proposal.

The SmartGrid architecture model (SGAM) is an essential architecture rule book for the energy sector. Furthermore, the DERA3.1 is analysing how to expand it to new dataspace interactions leveraging IEC based data models and ontologies (derived from the CIM)

The SGAM and GWAC Stacks are two separate frameworks that serve different purposes in the context of smart grid architecture. The following figure illustrates the GWAC stack.

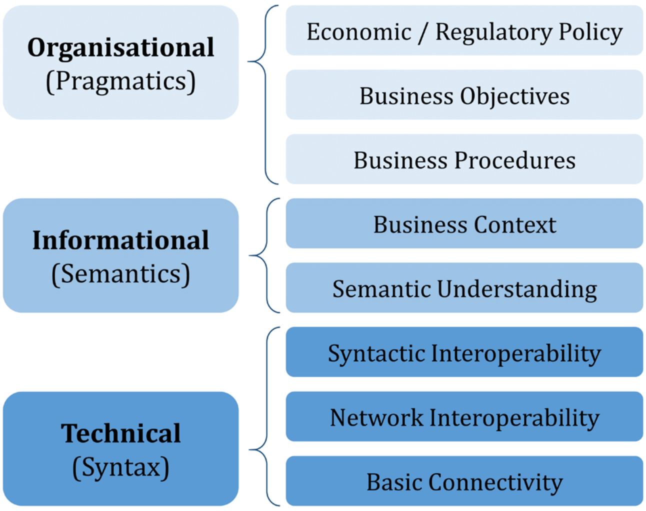


Figure 4: The GWAC-Stack

[62] https://syc-se.iec.ch/deliveries/iec-62559-use-cases/
[63] https://syc-se.iec.ch/deliveries/use-case-approach/
[64] https://syc-se.iec.ch/deliveries/sgam-basics/

The GWAC Stack is a conceptual framework created by the Grid Wise Architecture Council (GWAC[65]) that outlines the key layers and components necessary for designing smart grid systems. It provides a structured approach to building a comprehensive smart grid architecture, considering aspects such as business, integration, information, and infrastructure layers.

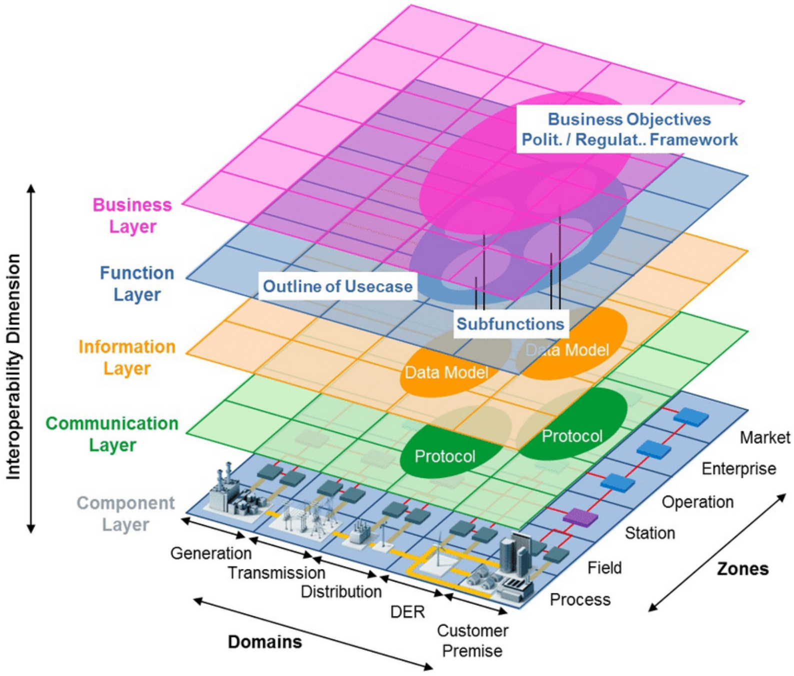


Figure 5: The SGAM architecture

The SGAM was born at the time of the European mandate M/490. Its formalization happens first through the CEN-CENELEC-ETSI Smart Grid Coordination Group and was then standardized by IEC.

SGAM is a reference model developed by the International Electrotechnical Commission (IEC) to provide a standardized framework for understanding, describing, and analysing the architecture of smart grids. It defines various viewpoints, including functional, information, communication, and physical viewpoints, to represent the different aspects of a smart grid system.

While the SGAM and the GWAC Stack may share some similarities in terms of addressing smart grid architecture, they are independent frameworks developed by different organizations. The SGAM provides a standardized model for describing the architecture of smart grids, whereas the GWAC Stack offers a conceptual framework for designing smart grid systems.

[65] https://gridwiseac.org/

The main objectives were to help all different stakeholders (Generators, TSOs, DSOs, DERs, home/building/industries), to share a common framework, with a specific emphasis on interoperability.

Through the implementation of Mandate M/490, IEC SRD 63200:2021(E) emerged, which is a System Reference Deliverable that defines the framework elements, associated ontology, and modelling methodology for designing the Smart Energy Grid Reference Architecture using the SGAM. It may come to describe the interaction between the grid and heat/gas systems, with easily understandable examples. This standard also provides a machine level representation of the concepts associated with the SGAM in the form of an ontology including diagrams and a code component presented as a ZIP file.

- IEC 63417: This publication provides a Guide and Plan to develop Smart Energy Ontologies and other domain-based ontologies within smart energy to achieve semantic interoperability through various stakeholders such as standards or projects. This includes but is not limited to:
- Assessment of a selection of existing ontologies for Smart energy applications
- Guide and Development plan for smart energy ontologies development and usage

4.3.1.3 IEC TC 57

The IEC Technical Committee 57 is focused on developing international standards for grid management and associated information exchange. Their work involves creating frameworks and protocols that ensure interoperability and seamless communication between different components of power systems, including generation, transmission, distribution, and utilization. The group's efforts aim to enhance the efficiency, reliability, and safety of power systems worldwide. Through the development and maintenance of standards, the IEC TC 57 contributes to the advancement and harmonization of power system technologies and practices on a global scale. IEC TC57 is developing key data models: the IEC Common Information Model (CIM) series (IEC 61968, IEC 61970, IEC 62325, IEC 62746) and IEC 61850. It is also developing IEC 60870. These standards are described below.

- IEC 62357-1 represents the power systems reference architecture.
- IEC 61850 is an international standard for communication and interoperability in power utility automation systems. It defines a comprehensive framework for the design, configuration, and operation of substation automation systems. The standard focuses on data modelling, communication protocols, and system engineering processes. It enables seamless integration of devices from different vendors, simplifies system configuration, and supports advanced functionalities such as real-time monitoring, control, and protection. IEC 61850 promotes interoperability, flexibility, and scalability in power system automation, facilitating efficient and reliable operation of electrical grids while enabling future-proof infrastructure upgrades and digital transformation in the energy sector.
- IEC 60870 is an international standard for telecontrol communication protocols in electrical power systems. It defines a set of communication protocols and data formats used for the remote control and monitoring of power system equipment. The standard enables reliable and efficient exchange of information between remote

terminal units (RTUs) and supervisory control and data acquisition (SCADA) systems. IEC 60870 supports various communication media, such as serial and IP-based networks, and provides mechanisms for data transmission, error detection, and system configuration. It plays a crucial role in ensuring effective control and monitoring of power system assets, contributing to the overall stability and reliability of electrical grids.

- IEC 61968/61970/62325/62746: Known as IEC CIM, this set of standards focuses on the integration of information and communication technology (ICT) systems in utility operations. It covers areas such as system interfaces, data exchange formats, and common information models for managing various aspects of the grid, including assets, networks, market operations, and resources connected to the grid.
- IEC 61970, also known as the Common Information Model (CIM), is an international standard for data exchange and integration in electrical energy systems. It provides a standardized data model and information exchange framework for power system management, including generation, transmission, distribution, and market operations. The CIM facilitates seamless integration of diverse systems and applications, enabling interoperability and effective communication between different software tools and devices. It supports functions such as network modelling, asset management, energy scheduling, and market transactions. The standard enhances efficiency, reliability, and collaboration in the energy sector by promoting consistent data representation, enabling accurate analysis, and facilitating system optimization.
- IEC 62325-301 is a standard that focuses on the exchange of data for the wholesale electricity market. It defines the data format and communication protocols to facilitate reliable and efficient information exchange between market participants, enabling accurate and timely transactions and grid management.
- IEC 61968-11 specifies the distribution extensions of the CIM specified in IEC 61970-301. It defines a standard set of extensions of the CIM, which support message definitions in IEC 61968-3 to IEC 61968-9 and IEC 61968-13. The scope of this standard is the information model that extends the base CIM for the needs of electrical networks, as well as for integration with enterprise-wide information systems typically used within electrical utilities. Note that the IEC CIM model is based on the CIM UML Model provided by the UCA CIM user group[66].
- IEC 61968-1 represents the Interface Reference Model (IRM). IEC 61968-1 is the first in a series (61968-3 to IEC 61968-9) that, taken as a whole, defines interfaces for the major elements of an interface architecture for power system management and associated information exchange. This document identifies and establishes recommendations for standard interfaces based on an IRM.
- IEC Common Grid Model Exchange Specification (CGMES[67]) is standardizing the ENTSO-E CGMES library[68]. CGMES facilitates the exchange of operational and grid planning data among transmission system operators. The CGMES is required to implement a series of network codes including those for capacity calculation and congestion management and for system operation.

[66] CIMug
[67] IEC 61970-CGMES:2022 | IEC
[68] Common Grid Model Exchange Standard (CGMES) Library

- IEC European Style Market Profile (ESMP) is a set of standards (IEC 62325-351[69], IEC 62315-451 series) supporting European Market regulation. ENTSO-E is developing the Electronic Data Interchange (EDI[70]) library which is then standardized through IEC.
- Common information model profiles associated to European My Energy Data (EUMED) include IEC 62325-451-10, known as the EUMED market profile, and IEC 61968-9 Ed 3, known as the EUMED Metering profile. These two profiles support the Implementing Act on Access to Customer Data (Article 20, 23, 24 of EU Directive 2019/944). They have been described (using webinars and guides) by the BRIDGE Standards User Group[71] as they originated in the FP7 Flexiciency European Project. They have been leveraged by some of the European Energy Data Space projects in the context of a semantic interoperability test organized by int:net in March 2025 Energy among Data Space projects: OMEGA-X, Enershare, DATA CELLAR. EDDIE is based on CIM dictionaries derived from IEC62325 ESMP profiles developed by ENTSO-E as well as IEC62746-4 CIM models for DER flexibility. JWG ENTSO-E and EU DSO Entity is also analysing the data models which can support the implementing act on access to Customer Data.
- IEC 62746-4 describes CIM profiles for Demand-Side Resource Interface and is based on the use case shown in Annex A of this document. Schemas associated with this document were generated using the CIM101 UML and leverage the Market package. This document defines profiles complimentary to other standards, namely those in IEC 61970, IEC 61968, and IEC 62325. The EDDIE common dictionary dataspace has been directly derived from aligned ontologies from IEC 62746-4 and IEC 62325 while demonstrating interoperability with the CIM EUMED profile with Omega X.
- IEC 62351 series: This series addresses the security requirements and measures for protecting communication networks and systems in the smart grid. It provides guidelines for authentication, encryption, access control, and other security mechanisms.

4.3.1.4 IEC TC 13

Standardization in the field of a.c. and d.c. electrical energy measurement and control, for smart metering equipment and systems forming part of smart grids, used in power stations, along the network, and at energy users and producers, as well as to prepare international standards for meter test equipment and methods. Standardization of data exchange for smart metering and load control systems for all energy types. Excluded: Standardization for the interface of metering equipment for interconnection lines and industrial consumers and producers (covered by TC 57).

4.3.1.5 IEC SC23K

Standardisation in the field of Energy Efficiency products, systems and solutions, to be used in existing and new electrical installations, for monitoring, measuring, controlling, managing

[69] IEC 62325-351:2016 | IEC
[70] EDI Library
[71] BSUG webinars: https://t.ly/n9aiQ

and optimizing the overall efficient use of a.c. and d.c. electrical energy for household and similar.

4.3.1.6 IEC TC 69

TC69 mission is to prepare publications on electrical power/energy transfer systems for electrically propelled road vehicles and industrial trucks (hereafter EV) drawing current from a rechargeable energy storage system (RESS). Possibilities to transfer power/energy include conductive power/energy transfer, wireless power/energy transfer, and battery swap.

4.3.2 ISO/IEC JTC 1/SC 38 – Cloud computing and distributed platforms

SC38 started in March 2023 ISO/IEC PWI 20151 – Data spaces, to support trusted data sharing and to start the development of a standard for the foundational concepts and essential characteristics of data spaces.

4.3.3 ISO/IEC JTC 1/SC 41 – IoT and Digital Twin

SC41 started discussing the opportunity to address data spaces in 2021:

- In May 2022, the Alliance for IoT and Edge Computing Innovation (AIOTI, through a liaison category A) submitted a preliminary version of a report on the integration of IoT and digital twins in data spaces[72]. In November 2022, China proposed a PWI on the same topic (i.e., application of data factors in digital twins).
- In December 2021, SC41 started a PWI on policy and behavioural interoperability. It covers the case of trusted data sharing. As a result, SC41 is currently working on three projects:
- PWI JTC1-SC41-8 – Behavioural and policy interoperability. This PWI is preparing a standard proposal covering trusted data sharing, leveraging the results of the European data space projects OMEGA-X, Enershare, and int:net.
- PWI JTC1-SC41-16 Digital Twin – Started in May 2023, this PWI is preparing a standard proposal for the extraction and transaction of data components.
- PWI JTC1-SC41-17 – Started in May 2023, this PWI is preparing a standard proposal on the integration of IoT and digital twins in data spaces.

4.3.4 IEEE

- The P3158[73] standard, titled “Standard for Trusted Data Matrix System Architecture,” defines an architecture for a trusted data matrix system. It provides a framework for ensuring the security, integrity, and reliability of data stored within a data matrix. The standard focuses on establishing a system that can authenticate, verify, and protect data against unauthorized access or tampering. It outlines the necessary components, interfaces, and protocols required for a trusted data matrix system. The standard aims to enable organizations to implement robust and trustworthy data

[72] Document published in September 2022. https://aioti.eu/wp-content/uploads/2022/09/AIOTI-Guidance-for-IoT-Integration-in-Data-Spaces-Final.pdf
[73] IEEE SA - IEEE 3158-2024

matrix systems, fostering confidence in the accuracy and integrity of the data stored within these matrices.
- IEEE 2030.5: Also known as the Smart Energy Profile (SEP), this standard focuses on the interoperability of energy management systems, smart meters, and other devices in the smart grid. It supports advanced energy management and demand response capabilities.

4.3.5 Protocols

Industrial protocols/ data models (Modbus, OPC UA): OPC UA (Unified Architecture) is a standardized communication protocol designed for industrial automation and data exchange. It provides a secure and scalable framework for interoperability between various devices, systems, and platforms in industrial environments. OPC UA enables seamless and reliable communication across different manufacturers and technologies, facilitating the integration of diverse systems. It supports robust security mechanisms, data modelling, and standardized information models, allowing for efficient and standardized data exchange. OPC UA promotes interoperability, simplified system integration, and enables seamless connectivity in industrial automation, thus fostering efficiency, flexibility, and collaboration in industrial settings.

Modbus is a widely used communication protocol in industrial automation systems. It provides a simple and efficient method for exchanging data between devices, such as sensors and controllers. Modbus uses a master-slave architecture, where a master device initiates communication with one or multiple slave devices. The protocol supports various communication media, including serial and Ethernet connections. Modbus is known for its simplicity, versatility, and wide compatibility across different manufacturers and devices. It allows for real-time monitoring, control, and configuration of industrial processes, making it a popular choice for applications in industries such as manufacturing, energy, and building automation.

4.3.6 CEN/CENELEC

- Coordination Group on Smart Grids (CG-SG[74]): This CEN/CENELEC/ETSI group advises on European standardization requirements relating to smart electrical grid and multi-commodity smart metering standardization, including interactions between commodity systems (e.g., electricity, gas, heat, water), and assesses ways to address them. This includes interactions with end-users, including consumers/prosumers. It aims to promote the deployment of open and interoperable data architectures, based on European and international standards. In 2024 November 27th CG-SG organized a workshop on Demand-Response and Standards with the following standardisation representatives: TEC TC8/CLC TC8, IEC TC57 WG21, IEC TC57 WG17, TEC TC13, DLMS association, IEC SC23K, IEC SyC Smart Energy. Other organisations participated: JWG ENTSO-E EU DSO entity, JRC, SEEG Data for Energy subgroup, BRIDGE.
  - CEN/CENELEC JTC 25[75] and ISO/IEC JTC 1/SC 38: The EU Commission has proposed a request for harmonised standards for 'Data Management,

[74] CEN-CENELEC-ETSI CG on Smart Grids - CEN-CENELEC
[75] CEN and CENELEC launch a new technical committee on Data management, Dataspaces, Cloud and Edge - CEN-CENELEC

Dataspaces, Cloud and Edge' based on the Data Act. The request is expected to be published during Spring 2025. The harmonised standard consists of 5 main parts:

- European standard on Trusted Data Transactions
- Technical specification(s) on a data catalogue implementation framework
- Technical specification(s) on an implementation framework for semantic assets
- European standard on quality assessment of internal data governance processes
- Technical specification(s) on the maturity assessment of Common European Data Spaces

Each standard has individual deadlines from the issuing date, and CEN/CENELEC JTC 25 has already started the work. Established in September 2024, JTC 25 will develop standards to support the widespread adoption of digitalization and the establishment of a fully functioning Single Digital Market for the EU. The goal is to ensure the European industry is more efficient, productive, competitive, and fully integrated in the global digital market. Furthermore, the work in JTC 25 will be delivered based on and in coordination with international standardisation activities in e.g. ISO/IEC JTC 1/SC 38

4.3.7 ETSI Smart Applications REFerence Ontology (SAREF):

In 2024 two workshops about standardisation attracted our attention: The first one was organized by CEN/CENELEC/ETSI CG-SG on January 31st, 2024, with the participation of ETSI SAREF experts, IEC and CENELEC experts. The following two SAREF extensions were presented and discussed:

- SAREF4ENER: a standardized ontology for energy domain data representation, enabling interoperability and integration of energy-related information systems.
- SAREF4GRID: a standardized ontology specifically designed for the electricity grid domain, facilitating interoperability and data exchange among diverse grid-related systems and devices.

SAREF Guidelines for IoT Semantic Interoperability; Develop, apply and evolve Smart Applications ontologies (EN 303 760) is Giving provisions, how to implement, prove and show SAREF compliance with the EN SAREF process and the SAREF Technical Specifications. This European Standard was produced by ETSI Technical Committee Smart Machine-to-Machine communications (SmartM2M).

The second one "Enhancing IoT Semantic Interoperability by SAREF for Digital Twins" was organized[76] on September 26th, 2024.

4.3.8 Other standards of interest

OpenADR[77]: The Open Automated Demand Response standard provides a common language and protocol for demand response communication. It enables utilities to send signals to customers, allowing them to adjust their electricity usage based on grid conditions and price

[76] https://digital-strategy.ec.europa.eu/en/events/workshop-enhancing-iot-semantic-interoperability-saref-digital-twins
[77] https://www.openadr.org/

signals. The OpenADR2.0b has been recognised as an IEC standard by the TC57 Working group 21 labelling it as IEC62746-10.

4.4 Conclusion

Standards play a crucial role in ensuring technical interoperability in smart grids. As the energy sector increasingly adopts digital technologies and ICT (Information and Communication Technology) systems, the need for seamless integration and communication among various devices, systems, and stakeholders becomes paramount.

There are several reasons why standards are essential for achieving technical interoperability in smart grids. Firstly, standards provide a common language and a set of rules that enable different components of a smart grid to communicate effectively. They define standardized data formats, communication protocols, and interfaces, ensuring that devices and systems can understand and interpret information consistently. This uniformity eliminates compatibility issues and facilitates smooth interoperability.

Secondly, standards enhance system scalability and flexibility. They allow for the addition of new technologies, devices, and services to the smart grid ecosystem without disrupting existing functionalities. By adhering to established standards, system integrators and technology providers can ensure compatibility and seamless integration with minimal effort.

Thirdly, standards promote competition, innovation, and market growth. When multiple vendors comply with the same standards, it fosters a competitive market where customers can choose from a variety of solutions. This competition drives innovation and accelerates the development of advanced smart grid technologies, ultimately benefiting consumers and the energy industry as a whole.

Moreover, standards enhance security and resilience in smart grids. They establish the best practices for data protection, authentication, and cybersecurity measures, mitigating risks and vulnerabilities. Standards also contribute to the establishment of robust interoperable security frameworks that ensure confidentiality, integrity, and availability of critical energy infrastructure.

Additionally, standards facilitate regulatory compliance and harmonization. They provide a reference point for regulatory bodies to enforce interoperability requirements and assess the conformity of smart grid systems. Compliance with standards promotes harmonization across different regions and countries, enabling cross-border data exchange and collaboration.

In summary, standards are essential for achieving technical interoperability in smart grids. They ensure consistent communication, scalability, innovation, security, and regulatory compliance. By embracing and adhering to standards, the energy sector can realize the full potential of smart grid technologies, leading to a more efficient, reliable, and sustainable energy infrastructure.

5 Benefits of interoperability for the different Energy stakeholders

When working with instances of energy data spaces, it often becomes clear how difficult it may be to speak the same language and to develop a shared vocabulary around data exchange across the different stakeholders in the energy use case. Interoperability and understanding the value creation for the different stakeholders participating in a data space is key to developing and implementing good and sustainable use cases.

The full value of energy data spaces is only reached if all the different stakeholders in the energy market engage in the project of creating interoperability in the energy sector. They only do so if they understand what the value of interoperability is for the role they play and if they see how interoperability may help them carry out their tasks and succeed with the existing and upcoming challenges that they are faced with in an ever more stressed energy system. This section will outline the value to the different energy stakeholders including grid operators, balance responsible, producers, end-consumers, aggregators, energy communities, and balance service providers. Moving forward, it is essential to align the roles of these various actors with the European Harmonised role model as defined through past electricity regulations and illustrated in Figure 6:

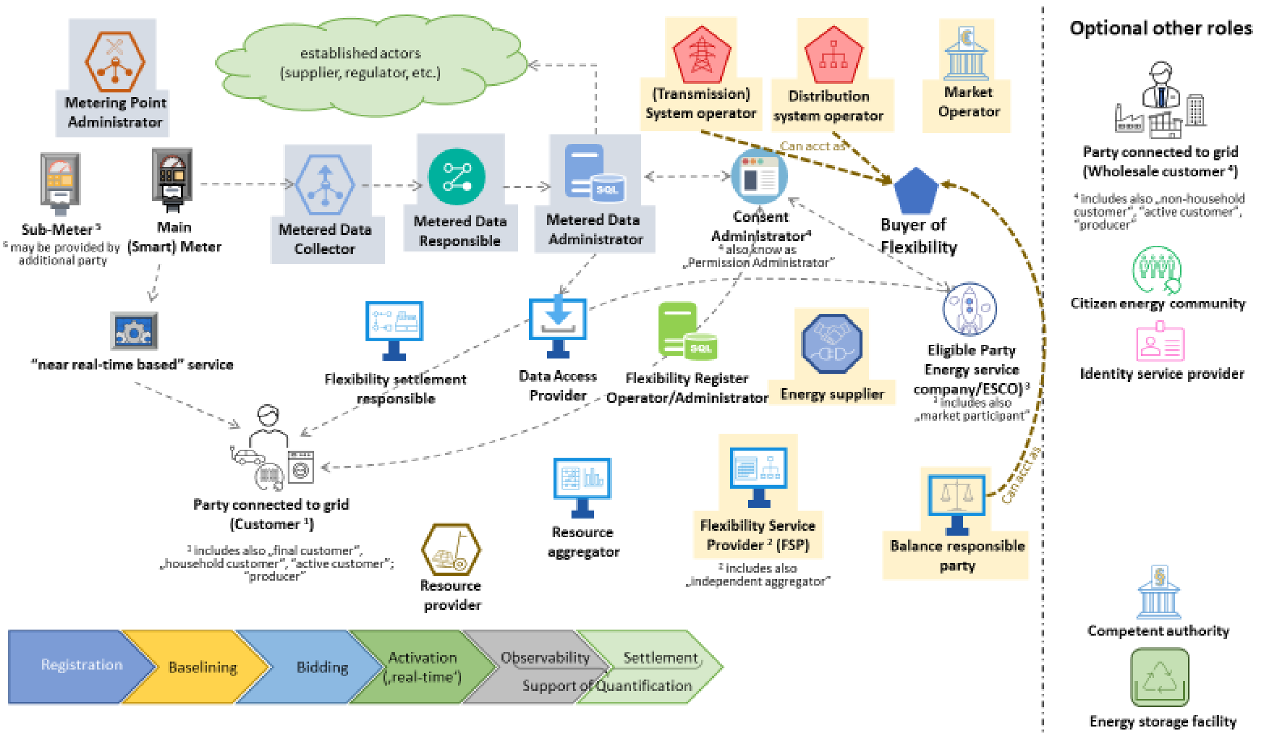


Figure 6: Extract from the ENTSO-E EU DSO Joint Working Group on flexibility data interoperability

5.1 Benefits of interoperability for Producers

Producers, irrespective of primary energy sources, need to be digitally connected to the integrated grid, meaning that all identified interoperability requirements are essential for seamless connectivity and active participation. Legal, organizational, semantic and technical interoperability play an important role in allowing producers to benefit from the digitalized evolution of systems.

As we have already underlined, supply and demand in the electrical system operation needs to be seamlessly coordinated. Markets allow for this coordination through trading on different timescales. With the increasing share of renewable generation and flexible demand, these processes demand ever more stringent time resolutions, which in turn rely on fluent communication and the availability of data.

Aiming to operate the system avoiding discrimination, calls for digitalised access to the grid and market that are embedded in the developed energy data spaces that require producers to be seamlessly connected, be responsive to requirements, and especially in flexibility needs, timely and faultless. Market operators following strict regulations that are based on agreed principles at European level, require producers and other participants to have active digital systems that are harmonised to the operating systems they provide. Hence, producers need to align with the semantic requirements of the developed systems and their internal systems responsive to the digitalised operational signals received.

Technical interoperability is of paramount importance for producers since protection and operating systems are digitally connected to the wider operating systems operated by nominated Operators following IEC and European standards. The IEC61325 ESMP originally developed by ENTSO-E and EFET is the common reference currently used through European TSOs and market operators, hence playing a crucial role through the dataspace reference library.

Time stamp reliance is fundamental for the stability of the system and latency of control signals highly restrictive to allow secure operation of protection systems. Cyber secure operation of the control systems of producers by operators that are situated kilometers away is of increasing importance for achieving a reliable interconnected system capable of utilizing efficiently the available sources in strict compliance with the prevailing market rules.

Finally, Producers do not want to be locked in the use of proprietary software and smart equipment / operating systems, hence interoperable solutions are increasingly on demand, facilitating freedom in development and operation, providing a healthy environment for growth, facilitating strategic evolution into more responsive systems. For this reason, standards are constantly expanding, covering the needs of interoperability and hence, producers are more comfortable in adapting and aligning with the demanding needs of energy transition.

5.2 Benefits of interoperability for Local Energy Communities

Energy communities have been introduced as an initiative for collective ownership, operation and participation in renewable energy projects, involving consumers and small-scale producers. The European Commission has been supporting the development and expansion of energy communities to incorporate residential, commercial consumers, and the public sector, thus providing a participatory approach to small-scale electrical energy production, towards reducing carbon emissions, increasing energy independence, and promoting environmental sustainability.

Under this perspective, data spaces in energy communities can be a basis for sharing insights, providing solutions to communities that help them overcome the barrier of large-scale energy production and increase prosumers' participation in the energy system, by ensuring data sovereignty and local data sharing control. Energy data collected at LECs can be further exploited for system operation, e.g. energy aggregators, flexibility markets, DSOs, and provide a means for decentralized access into the operation of the electrical energy systems.

Therefore, enabling interoperable local energy community data spaces will help interconnecting end-users with other energy communities, sharing data, data models and insights for improved operation of their systems. By providing interoperability with other energy system stakeholders, local energy community members can have access to the data of energy system operations, promoting a more democratized energy system. It is of high importance for the energy data spaces design and deployment to support decentralized energy stakeholders, such as LECs, to the data ecosystem of the electrical energy production and operation, where the generated data can be aggregated to support operation, visualization and inference, prediction of energy consumption and production, and market operations. Data spaces can also promote the development of sustainable energy communities, both supported by municipalities and the public sector in general, and further by privately owned initiatives. These initiatives can boost the participation of consumers and producers in the data ecosystem, mainly by interoperable data spaces that connect the relevant stakeholders. Regarding enabling market operations in data sharing, interoperable data spaces are the basis for sharing data across the European data spaces, exchanging data models by using blockchain technologies and integrating generated data.

Let us consider an end-user for the data space deployed at a local energy community. Interoperability across the European energy system data spaces provides the end-user with access to the data produced in all interconnected energy communities, to the data produced by DSOs and TSOs, energy markets and other relevant information. Even if the case seems of less importance for a residential consumer or producer, the prospects of data utilization by enabling interoperability in energy data spaces are vast and new application scenarios can be considered. In these scenarios, local energy communities should play an active role as participants in the European data spaces.

5.3 Benefits of interoperability for metering data aggregators

Going back to 2009, and the mandate M/441 to CEN, CENELEC and ETSI by the European Commission and European Free Trade Association (EFTA) for the development of an open architecture for utility meters involving communication protocols enabling interoperability (smart metering). This in tandem with the M/490 mandate for interoperable smart grids proved to be the cornerstone for the evolution of interoperable communication protocols and respective hardware, freeing the users of metered data from the difficulties posed by the proprietary predecessors.

Metered data is fundamental for home/building energy management and at the same time achieving the requirements of smart substations offering possibilities for optimal control of energy neighbourhoods and communities. Following this operational need, the local DSO in close cooperation with operating aggregators, energy community operators and others, can independently use the generated interoperable data for managing the needs of end users, maximizing the use of local infrastructure and achieving collective benefits for all connected users.

Interoperable last mile equipment, that can easily plug into operating systems without being vendor locked, generates the operational platform that facilitates the use of generated data by all relevant stakeholders facilitated through the advance features of Meter and Data Management Systems (MDMSs) serviced by local DSOs but made accessible by metered data Aggregators and other interested parties. No need for duplicating sensors and metered data equipment since communication protocols are in line with adapted standards and generated metered data is freely available for interested stakeholders that have the right to access the data. This free use of data facilitates energy management objectives both within the home/building under the jurisdiction of metered data aggregators but also in aggregated form for managing the wider needs of the neighbourhood, local substation, and or energy community.

The adapted architecture overcomes issues of latency that operators were posing as an obstacle to wider use, and this gives the required freedom to Aggregators acting on behalf of the end users generating the data, to maximize its use to meet planned services to their customers.

Work in these fields is ongoing since the evolution of distributed resources for generation, storage, and use needs to be optimally operated with the aggregated needs of the neighbourhood, local substation, energy community, etc., generating the need for effective sharing of data by all connected stakeholders for achieving the desired aggregated benefits.

5.4 Benefits of Interoperability for Resource Aggregators

By ensuring seamless communication between various systems and devices, interoperability provides several benefits for resource aggregators that can enhance operational efficiency and market penetration.

One of the primary advantages is the access to interoperable metering and device data. This capability allows aggregators to access the metering information for all their clients in a common way. Similarly, device data including master data on location, capacity rating, control parameter or optional setpoints can be better integrated and updated, ultimately improving service delivery.

Cost efficiency is another vital benefit. Interoperability reduces the onboarding costs for assets, facilitating faster integration into existing systems. This translates into an increased speed of market growth, as resource aggregators can deploy their services faster and more effectively. A fast-onboarding process also enhances customer satisfaction, as the friction often associated with installation efforts is reduced. Furthermore, customers benefit from a lower risk of vendor lock-in effects, thanks to the interoperable nature of services provided and the related data that is required.

Additionally, the effort required to offer services in multiple regions or systems is significantly minimized. Thus, interoperability fosters a unified European market for services and enables resource aggregators to offer their service across borders.

5.5 Benefits of Interoperability for Balancing Responsible Parties

Balancing responsible parties (BRPs) take responsibility in the energy system to balance their portfolio of generation and loads and have a key role in maintaining grid stability. Therefore, communication and data exchange across various systems and devices is vital for BRPs.

One of the primary benefits of interoperability for BRPs is the reduction in effort required for asset integration. This simplification accelerates the onboarding process. By effectively integrating smaller generating assets through fully digital and automated processes, BRPs can broaden their asset base to and contribute to the grid integration of renewables. Interoperability also enhances data ingestion capabilities. Increased data usage can improve forecasting of loads and generations and lead to reduced imbalances within portfolios. With access to comprehensive, real-time data, BRPs can make more informed decisions, thus improving overall portfolio management.

Discoverability of flexibility services is another potential benefit of interoperability to BRPs. This will increase the amount of flexibility offerings that can be processed by a BRP. Interoperability in combination with discoverability could also allow for the identification of assets that align well with a BRP's portfolio needs.

Finally, as described by resource aggregators, interoperability also facilitates Europe-wide market access for services, enabling BRPs to expand their operations across Europe.

5.6 Benefits of Interoperability for Balancing Service Providers

One of the primary advantages of interoperability to balancing service providers is access to various flexibility markets. By enabling seamless communication between different platforms and systems, BSPs can tap into a wider array of markets, enhancing their service offerings and revenue potential.

Interoperability extends beyond the energy sector, facilitating integration with other industries, especially mobility and heat. This cross-sector collaboration yields large opportunities but often requires interoperability of data and processes to enable the scaling of sector coupling applications of BSPs. It also plays an important role in baseline calculation, ensuring that algorithms are compliant with national and European regulation and also transparent to market actors.

Additionally, interoperability facilitates access to balancing markets for resource aggregators. Strong interoperability improves the usability of the asset portfolios and enables aggregators to meet pre-qualification criteria and participate in balancing markets. This holds also true for small renewable or controllable assets that currently do not participate in balancing services. By lowering the barriers to entry, these assets can contribute valuable flexibility, promoting a more diverse and resilient energy landscape.

5.7 Benefits of interoperability for system operators

The roles of the system operators are to operate the power systems by managing and coordinating with the other stakeholders in the energy sector to ensure the system's reliability and security, as well as achieve goals related to their business. According to their roles and business, the core competencies are power system operation and information exchange with the other stakeholders such as the balance responsible, the power station, etc.

With the energy transition to digitalization and decarbonization, technological advancements have been applied to the energy sector to enhance the quality of services of stakeholders in the energy communities. This results in the requirement of interoperability among stakeholders in modern grids, especially system operators who interoperate with the others for technical and business viewpoints. Interoperability in the energy sector is becoming more important, as stakeholders can interoperate with each other based on standardized data formats. Also, the costs and complexity of integrating data from different devices/platforms and technologies to the grids are reduced. This will ensure the harmonization of the data coming from various sources and compatibility once the data needs to be exchanged across platforms.

Since one of the core concepts of the EU energy data space is to promote data sharing among stakeholders in the energy sector, in this regard, system operators can access real-time data from several sources to enhance data availability and transparency for decision-making and system management. Moreover, the EU energy data space framework for data sharing has been developed in compliance with the General Data Protection Regulation (GDPR). This enables system operators to leverage data while respecting stakeholders' privacy and data security concerns.

By implementing interoperability and the EU data space concepts in the energy sector, system operators can enhance their quality of services from technical and business perspectives and ensure more sustainable integration of data from different sources. Examples include cross-border collaboration for crisis management, the integration of renewable energy, market integration, etc.

5.8 Benefits of interoperability for Energy Service Company (ESCO)

An ESCO is functioning based on providing energy services, which may include energy-efficiency projects, including renewable energy projects, and in many cases on a turn-key basis. ESCOs provide their services based on:

- energy savings and/or provision of the same level of energy service at lower cost.
- remuneration is directly tied to the energy savings achieved.
- financing, or assisting in arranging financing for the operation of an energy system by providing a savings guarantee.

To achieve the targeted efficiencies and succeed in providing the financial benefits to the end users, interoperable data coming from equipment connected to end users and the interconnected grid is of paramount importance, avoiding duplication and costly evaluation algorithms that will generate errors as well, hence introducing the risk element, meaning higher cost. Accurate interoperable data from all required resources will offer an optimal platform to build operational regimes that are highly beneficial to end users and the system at large.

Any emerging technology that is energy-related, capable of generating efficiencies in use for achieving similar or better results, is a candidate. Examples such as lighting systems, combination of PV with storage, vehicle to grid services coupled with heat pumps, etc., are possible targets. These can be in single buildings or aggregated neighbourhoods, relying on interoperable source data to facilitate optimal planning and operation covering all real-life needs, providing the anticipated comfort to end users. ESCOs are the facilitators and hence seek interoperable benefits to reduce costs and raise benefits for end users and most importantly, reflecting in lower energy cost for the system.

5.9 Benefits of interoperability for a Consumer / Prosumer

The end users of energy are traditionally called consumers. The emergence of distributed generation on the roofs of buildings gives the possibility of generating energy for our use, and the term Prosumer emerged to describe the combined role of consumer and producer. Building on this added role, further active energy elements are introduced in buildings/houses such as storage, e-vehicles, intelligent appliances, including heat pumps, etc., calling for introducing energy management systems capable of achieving attractive efficiencies for the benefit of the end user and the system.

For energy management systems to operate efficiently, measured data from equipment in use is a must. This data is already measured partly by smart meters installed by the local DSO and hence needed by the in-building management system. This requires data generated to be interoperable and shareable to facilitate local and remote use for the benefit of the consumer/prosumer and the local operator.

Added to the above is the need for optimal use of local resources by the DSO, Energy Community operator, Aggregator, etc., requiring the timely response of consumers/prosumers to system needs that can mean more efficient use of energy resources, hence lower tariffs for the consumer/prosumer. This need generates the common use of system data facilitated by the local operator sharing interoperable data that energy management systems need on the side of the building, and the local substation, etc.

6 Data space governance and interoperability

According to the DSSC definition, the Data Space Governance Framework[78] encompasses a set of principles, standards, policies (rules/regulations), agreements, and practices. These apply to the governance, management, and operations (encompassing both business and technology aspects) of a data space. They also extend to the enforcement of these principles and the resolution of conflicts.

Data space governance aims to address fundamental questions about power dynamics, decision-making authority, stakeholder participation, and accountability within a given data space. It involves a collective effort by relevant actors who share a common goal, focusing on determining how decisions are reached, who has the authority to make them, and how they are communicated and enforced. Through this evaluation, we aim to ascertain the specific governance requirements for each unique data space.

Currently, there exists a notable gap in the precise definition of data space governance. Therefore, we must delve deeper into this aspect of governance. OPEN DEI[79] have established an initial framework for defining data space governance across four distinct layers, which will serve as a foundational blueprint for further refinement and development.

[78] 2. Core Concepts - Glossary - Data Spaces Support Centre (dssc.eu)
[79] Microsoft Word - 2022.10.26_Building Blocks assessment report_draft_3 (internationaldataspaces.org)

Layer 4	Common European framework for data ecosystems	Public-private data governance. Data Act, DGA, DMA, DSA, Data Innovation Board Data spaces initiatives (IDSA, BDVA, Gaia-X,…)
Layer 3	Domain specific building blocks governance	Governance for data spaces interoperability (inter-data spaces governance)
Layer 2	Data space governance	Governance from an ecosystem perspective (intra-data spaces governance)
Layer 1	Governance of a soft infrastructure	Operational level of a data space to provide essential services.

Figure 7. Data spaces governance frameworks

The data space governance framework, as illustrated in the table above, comprises four layers. In Layer 4, a legislative/regulatory and standardization context is established, defining the data space instance responsible for governance execution. Layer 3 focuses on sector/domain governance, specifying interoperability practices and principles while accommodating geographical differences. Layer 2 governs the data ecosystems layer and sets the rules for the data space instances, fostering trust and collaboration among organizations within a data space while emphasizing business-driven rules for value exchange. Layer 1 addresses soft infrastructure governance, unifying generic building blocks, defining the legal basis, and creating a common framework for all data spaces.

The IDSA Rulebook describes the four layers of data space governance[80], as defined by the Design Principles for Data Spaces.

Layer	Description
Data space instance governance	Executes and implements the governance practices and rules of a data space instance. Oversees data space functions and the rules.
Data space ecosystem governance	Defines the rules for the data space instance. Creates the intra data space trust between collaborating organizations. Complements standardization and regulation focusing on business-driven rules. Defines the inter data space interoperability practices.
Data space domain governance	Establishes sector-specific data space principles and mechanisms including semantic interoperability and domain-specific regulation. Leaves room for geographical differences while supporting maximum interoperability.
Soft infrastructure governance	Brings all the generic data space building blocks and concepts together, defines the legal basis and creates the common framework on which all data spaces are built.

Figure 8: Four layers describing data spaces governance

[80] Guiding Principles - IDS Knowledge Base (internationaldataspaces.org)

While the four governance layers need to be addressed, the soft infrastructure governance layer is key for the proliferation of data spaces. The establishment of a soft infrastructure:

- can leverage a wealth of existing standards such as the ISO/IEC 38500 series on IT governance (including 38505, application of 38500 to the governance of data, which provides guidance and principles for the governance of data), or ISO/IEC 27570 (privacy guidelines for smart cities) which describes several ecosystem processes for governance and for data sharing;
- should take into account standards to be developed such as the CEN-CENELEC JTC21 technical report on "Data Governance and Quality for AI within the European context", which is under approval, as well as the latest architectures and standard deployments through IEC SGAM and the demand side flexibility code particularly;
- should be integrated as an integral part of a European roadmap, including further standards, and supporting organizations (like the role of ENISA to support NIS and the cybersecurity act).

In the subsequent chapters, various layers of data space governance are identified, with four layers categorized based on the scope of data space governance. To achieve intra data space interoperability, a recommended approach is to follow the new interoperability framework outlined here. This framework proposes four layers for designing interoperability in data spaces: legal, organizational, semantic, and technical.

Figure 9: New European Interoperability Framework

In accordance with data space governance agreements, the responsibility for legal and organizational interoperability lies with the data space authority.

- Legal interoperability aims to ensure that organizations operating under diverse legal frameworks, policies, and strategies can collaborate effectively. This involves aligning business processes, responsibilities, and expectations across different companies and organizations.

- Organizational interoperability, in practice, involves documenting, integrating, or aligning business processes and the pertinent information exchanged. In the Energy space, this should be considered given the identified SGAM layers and key functions.
- Semantic and technical interoperability encompass adherence to standards and specifications by participants in a data space. Semantic interoperability guarantees the preservation and understanding of the precise format and meaning of exchanged data and information during interactions between parties. This semantic aspect involves defining the meaning of data elements and their relationships, often achieved through developing vocabularies and schemata for describing data exchanges. Best practices developed through European energy markets by ENTSO-e should be considered as part of these developments to accelerate needed deployments.
- Technical interoperability, on the other hand, deals with applications and infrastructures linking systems, functions as defined through the SGAM Layers and services. This includes aspects such as interface specifications, interconnection services, data integration services, data presentation and exchange, and secure communication protocols. An example of a standard for defining data space technical interoperability is the Data Space Protocol[81]. As well as CIM-based data exchange protocols such as IEC62325 ENSMP and IEC61968 CGME Json data exchanges.

6.1 Actors

Regardless of whether a data space is organized in a centralized, decentralized, federated or hybrid manner, common denominators and basic functionalities can be found.

At the core of the system is the Data Space Governance Authority, which oversees the management of Data Space, ensuring compliance with Rules and Policies and maintaining the Data Space Participant Registry. The authority enforces governance rules, issues memberships to Participants, and ensures that the Data Space is properly described and managed through a Data Space Self-Description.

Participants, once granted membership by the governance authority, become part of the data space and are required to maintain a Participant Self-Description that outlines their role and capabilities within the ecosystem. Each participant possesses an Identity, which is anchored and verified by a Trust Anchor, ensuring security and trust within the data space. The identity system ensures that participants are authenticated and authorized according to the rules set by the government authority. This interconnected framework promotes a secure, trustworthy, and well-regulated data-sharing environment.

[81] Dataspace Protocol 2024-1 | IDS Knowledge Base

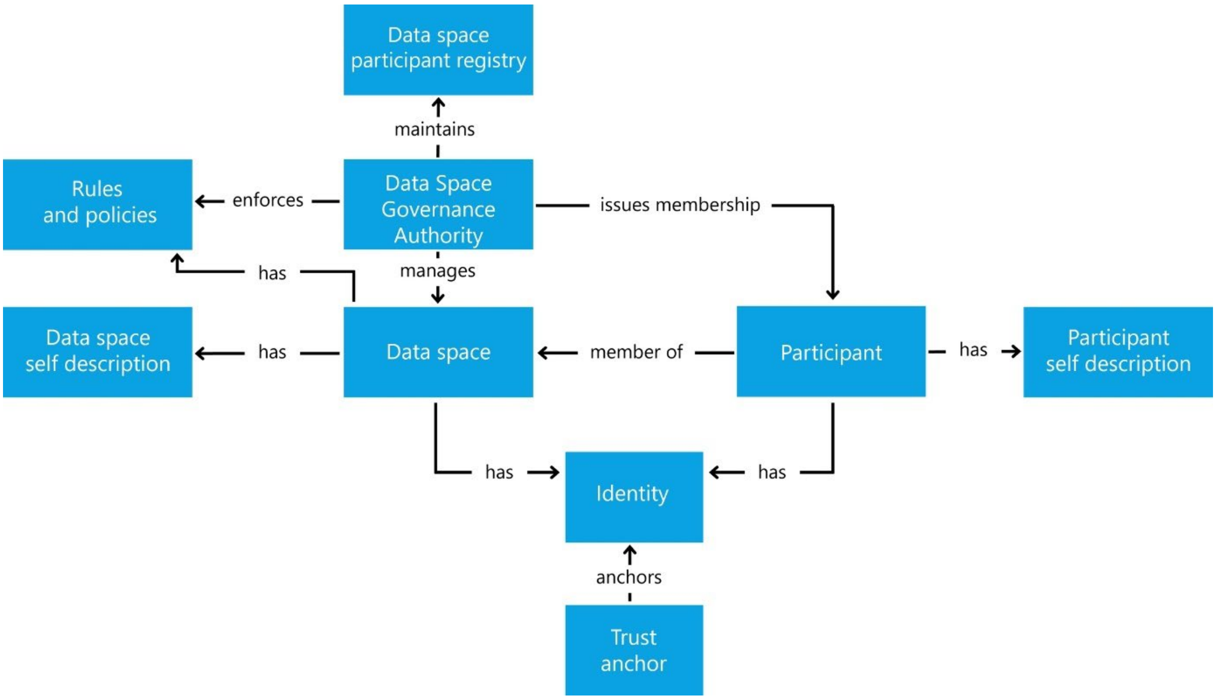


Figure 10: Overview of Data Space entities. IDSA Rulebook[82]

7 Technical interoperability

Technical interoperability refers to the minimum technical framework that is required for all participants of a data space in the energy domain to process and understand the information (meta data) of the services/data offered in the data space and to perform data transfers between them (participants). In addition to receiving the data, the data consumer must be able to interpret it. This requires that the data protocol be standardized, ensuring the data consumer understands both the header and content of the message. Specifically, this technical interoperability framework covers the following aspects:

- Building blocks
- Data formats
- Data transmission protocols

The following subsections cover each of the aspects in more detail.

[82] Functional Requirements | IDS Knowledge Base

7.1 Building blocks description

The blueprint of the Data Spaces Support Centre (DSSC) [83] defines the main technical building blocks for data spaces grouped into three main categories:

1. Data Interoperability:
    - Data Models
    - Data Exchange.
    - Provenance & Traceability.
2. Data Sovereignty and Trust
    - Identity and Attestation
    - Trust Framework.
    - Access and Usage Policies Enforcement
3. Data Value Creation Enablers:
    - Data, Services and Offering Descriptions:
    - Publication and Discovery.
    - Value creation services.

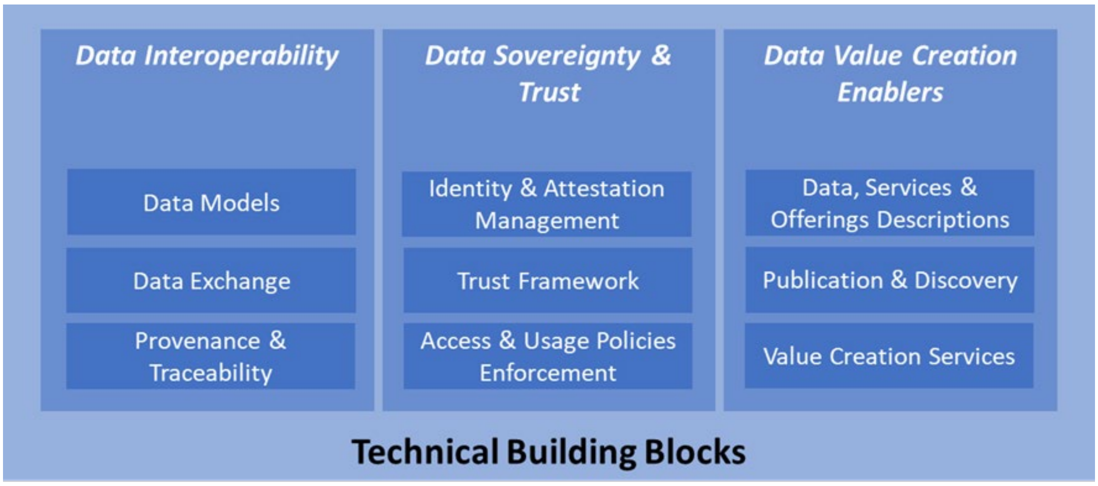


Figure 11: DSSC technical building blocks[84]

Each of these building blocks has specific instantiations in one or more components according to different reference architectures (e.g., Federated Catalogue in Gaia-X, IDS Connector, FIWARE Context Broker, Bridge DERA 3.2 CIM based Data exchange middleware).

While the above-mentioned building blocks are either necessary to build a fully operational dataspace or provide additional value to the data space, not all of them are key regarding technical interoperability. The only building blocks required to exchange data between two parties in a secure and trustworthy environment are the ones related to Data Interoperability (Data Exchange APIs) and Data Sovereignty and Trust (Access & Usage Policies Control and

[83] DSSC Data Spaces Blueprint v1.5 - Home - Blueprint v1.5 - Data Spaces Support Centre
[84] Technical Building Blocks - Blueprint v1.5 - Data Spaces Support Centre

Identity Management). The building blocks related to Data/Service offerings descriptions are desirable (though not required) for discovery purposes in the Marketplace/Data Catalog.

The DSSC, in its blueprint, offers a thorough description of the technical building blocks, including data sovereignty and trust, namely, Identity Management, Trust Framework and trust Anchors, Access and Usage Policy enforcement, as well as organizational and business building blocks.

Regarding the Data/Service Offerings in the Marketplace, Gaia-X has defined some preliminary labels to describe the data and services offerings in the data catalog/marketplace. Now, they are trying to extend these labels, including aspects related to privacy (GDPR), cybersecurity, etc. There are already some reference instantiations of the Gaia-X Federated Catalogue, in particular an MVP[85] built by deltaDAO[86]. The new Bridge DERA architecture has in the meantime conducted similar exercise taking advantage of recent Horizon Europe project activities from Interrface and OneNet projects (leveraging new distributed dataspace infrastructures as lately pursued through the EDDIE dataspace project).

7.2 Data Formats

JSON is a lightweight, language-independent data interchange format, easy to parse and generate. It provides a way to create a network of standards-based machine-interpretable data across different documents, which is usable with no knowledge of RDF. JSON-LD serializes Linked Data in JSON with the following functionalities:

- URIs for unambiguous identification of concepts and properties
- Definition of context
- Associate datatypes with values (e.g., dates and times)
- Express one or more directed graphs, such as a social network in a single document

OMEGA-X and EDDIE will use JSON-LD and Enershare will use JSON-LD and NGSI-LD as data formats for information exchange through the data space.

7.3 Data Transmission Protocols

Regarding data transmission protocols, we must differentiate between the data that is transferred within a single data space and that transferred amongst data spaces. Data transferred within a data platform of a participant of the data space is not within the scope of this paper. We should only focus on the data transmission protocols for data transferred within the data space or amongst data spaces, which involves connectors of data space participants.

[85] https://portal.minimal-Gaia-X.eu/search?sort=_score&sortOrder=desc&text=.

[86] https://www.delta-dao.com/

In this sense, IDSA, along with other organizations such as Microsoft, have defined the Data Space Protocol[87][88]. In this sense, they differentiate between two interoperability models:

- Intra data space interoperability of different connectors from different participants within the setting of one data space.
- Inter data space interoperability between data spaces.

The latter requires the IDS connector protocol-based element of interoperability.

The Data Space Protocol aims to define the minimum standard of communication so that everybody is able to communicate with other connectors, even if those other connectors add features, semantic models, or business procedures.

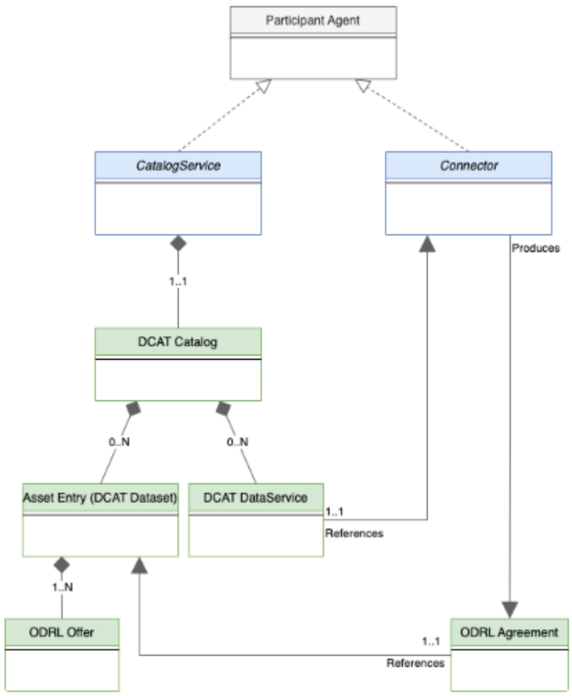


Figure 12: IDS Dataspace protocol: relationships between Participant Agent types.

7.4 Challenges to achieve technical interoperability

- Different projects will use different data connectors (e.g., TRUE, OneNet, EDDIE, EDC, etc.). Some of them are not interoperable, e.g., TRUE and EDC.
- If different projects decide to use different implementations of Federation Services (e.g., for the Catalogue there is the Metadata Broker from IDS and the Federated Catalogue from Gaia-X), how can we ensure interoperability with different implementations of those services?

[87] https://internationaldataspaces.org/dataspace-protocol-ensuring-data-space-interoperability/
[88] Dataspace Protocol 2024-1 | IDS Knowledge Base

- We need to ensure the interoperability of the Trust Framework. Trust certificates from one project should be interoperable with those from another.
- Are data connectors ready to accommodate existing infrastructure?
- Sister projects' reference architectures and identification of gaps to enable interoperability should be analysed, (e.g., are there components necessary to enable interoperability that were not considered in the proposal writing phase? Can these components be shared between projects?)

8 Semantic interoperability

In the European Research Cluster on the Internet of Things (IERC[89]) and IoT Semantic Interoperability Best Practices[90], four kinds of interoperability are distinguished: syntactical interoperability, technical interoperability, semantic interoperability, and organizational interoperability. IERC AC4 interoperability is illustrated by the following figure:

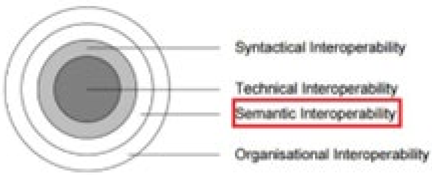


Figure 13: Four types of interoperability.

Semantic interoperability is a crucial aspect of achieving effective communication and coordination in the energy sector, for instance in smart grids. It refers to the ability of different systems and devices to exchange and interpret information consistently and accurately, based on a shared understanding of the underlying meaning and context.

Regarding technical communications, semantic interoperability is necessary for the following reasons:

1. Data Interpretation: In energy sector applications, it is necessary to exchange vast amounts of data among various devices, systems, and stakeholders. Semantic interoperability ensures that this data is properly understood and interpreted by all parties involved. It enables seamless communication between heterogeneous systems, even if they use different data formats, protocols, or vocabularies. By agreeing on standardized semantic models and data representations, stakeholders can ensure that the transmitted data is correctly interpreted and utilized.
2. System Integration: Energy applications comprise diverse components, such as sensors, meters, control systems, and energy management systems, often sourced from different manufacturers. Semantic interoperability allows these components to work together cohesively by establishing a common understanding of the data they exchange. It enables smooth integration and interoperability across different systems, minimizing compatibility issues and enhancing overall system efficiency.

[89] M. Serrano, P. Barnaghi, F. Carrez, P. Cousin, O. Vermesan, P. Friess, *IoT Semantic Interoperability: Research Challenges, Best Practices, Recommendations and Next Steps*, March 2015
[90] IoT Semantic Interoperability Best Practices

3. Decision-Making: Accurate and consistent information is vital for effective decision-making in the energy sector. Semantic interoperability ensures that the data shared between various systems is reliable, complete, and unambiguous. It enables stakeholders to derive valuable insights from the data, facilitating optimal operational decisions, such as load balancing, demand response, and fault detection. By leveraging a shared semantic understanding, stakeholders can exchange actionable information and coordinate their actions effectively.
4. Scalability and Flexibility: Smart grids are dynamic, constantly evolving systems. New devices, technologies, and applications are continuously introduced. Semantic interoperability provides the necessary flexibility and scalability to accommodate these changes seamlessly. By adhering to standardized semantics and ontologies, smart grid systems can adapt to new data types, services, and protocols, ensuring compatibility and interoperability across the evolving ecosystem.
5. Innovation and Collaboration: Semantic interoperability fosters innovation and collaboration within the smart grid domain. By adopting standardized semantic models and open data formats, it becomes easier for stakeholders to develop and deploy new applications, services, and analytics. It promotes an ecosystem where multiple vendors, researchers, and developers can contribute and build upon each other's work, driving advancements and unlocking the full potential of smart grid technologies.

In summary, semantic interoperability plays a vital role in enabling effective technical communications within smart grids. It ensures consistent data interpretation, seamless system integration, informed decision-making, scalability, and collaboration. By establishing a shared understanding of data semantics, stakeholders can communicate and exchange information in a reliable, efficient, and interoperable manner, leading to enhanced grid performance and operational efficiency.

8.1 Challenges to achieve semantic interoperability

Energy systems and networks are composed of and progressively dominated by a high number of heterogeneous nodes, devices, and systems that are tightly coupled and operate in real time. This high heterogeneity across digital assets and applications and the need for their seamless integration in a smart energy system, introduces significant challenges in terms of semantic interoperability. These obstacles mainly stem from the use of a variety of semantic models and the lack of a unified data modelling approach that can effectively integrate them under a common semantic context.

The most important steps to addressing these issues are reflected in the efforts of (i) CEN-CENELEC/ ETSI in the frame of Mandate M490 and the developments referring to the SGAM model that defines, at high level, the information models that are required in the context of the smart grid; and (ii) the IEC 62325, 61970, and 61968 standards (altogether known as the IEC Common Information Model), which provide a common semantic model for information exchange between basic components of distribution networks.

However, these approaches provide basic semantic information models that involve only the core concepts of a smart energy system and, in some cases, do so at a very high-level of abstraction. A more comprehensive unified model has been introduced in the H2020-SYNERGY project and its Common Information Model (CIM) which semantically aligns and harmonizes the most prominent energy data models in an extensive semantic representation of the energy system, while further defining in detail their semantic relations. Given, though, the energy system's decentralized and distributed nature and its coupling with other sectors, a more advanced and orchestrated harmonization approach is required. This should start with the definition of sectorial Common Information Models, (acting as the sectorial harmonization instruments) and extend to further alignment and effective management of the relations created between them within an integrated and smart energy system.

With regards to the semantic representation of the energy system components, the inclusion of new Distributed Energy Resources (DERs) (which progressively penetrate the system across its edges and the management of the relations between the wealth of semantic concepts across the energy sector and beyond) underlines the need for the configuration of highly effective lifecycle management mechanisms. These should be able to dynamically capture new components, facilitate the modelling of new semantic concepts, and instruct the respective relations with existing semantic artefacts, thus enabling the progressive enhancement and enrichment of existing data models. It will otherwise be impossible to semantically represent the integrated energy system reality at once.

Semantic harmonization across energy sector ontologies and data models, as well as across energy and related sectors, needs to be complemented by significant enhancements and extensions of existing sectorial information models to capture previously overlooked concepts and new assets introduced in the energy, mobility, building and other sectors. This marks a fundamental step towards facilitating the orchestrated operation of an integrated and ever extendible energy system.

8.2 Semantic interoperability building blocks

Harmonization frameworks for data sharing under a shared semantic context are beneficial for interoperability as they enable consistent and standardized data exchange. These frameworks establish common vocabularies, data models, and ontologies, ensuring a unified understanding across different systems. By harmonizing data sharing practices, stakeholders can seamlessly integrate and interpret data, facilitating effective communication and collaboration. In sum, harmonization frameworks reduce complexity, improve data compatibility, and enhance interoperability, enabling seamless interactions and promoting efficient decision-making within the smart grid ecosystem.

However, the data transferred is not always in the expected format; it needs to be transformed and adapted according to the established data model. To this end, an additional technical building block needs to be considered, i.e., the System Adaptation which performs the necessary transformation of the data formats for data exchange within the data space.

Semantic interoperability in the context of data models and formats is crucial for achieving seamless communication and collaboration in the smart grid domain. To ensure interoperability, it is recommended to rely on well-known data model standards such as IEC

CIM. These established standards provide a solid foundation for data representation and exchange, enabling consistent interpretation across different systems.

Moreover, the life-cycle management of data models allows for easy adaptation to evolving relationships and the inclusion of new concepts. This flexibility ensures that data models remain up-to-date and relevant as the smart grid ecosystem evolves. By adhering to a common data model, stakeholders can establish a shared understanding and simplify the mapping of data among existing models.

Efficient data transfer relies on the ability to automatically consult and exchange data models between the data provider and the user. This streamlined process enables stakeholders to seamlessly access and interpret transferred data, reducing effort and the potential for errors.

In data spaces where there is data exchange, linked data is a requirement to avoid silos. External systems cannot know about relationships unless they are provided with a machine-readable format. As an example of such a format, RDF is a framework for expressing linked data so it can be exchanged between applications without loss of meaning. RDF allows the expression of simple facts in the form of triples (subject, predicate, and object). The subject and the object represent the two resources being related. The predicate represents the nature of their relationship in a directional way (from subject to object). RDF uses URIs to name the relationship between things as well as the two ends of the link. There are various concrete syntaxes for RDF, such as Turtle [TURTLE], TriG, [TRIG], and JSON-LD [JSON-LD].

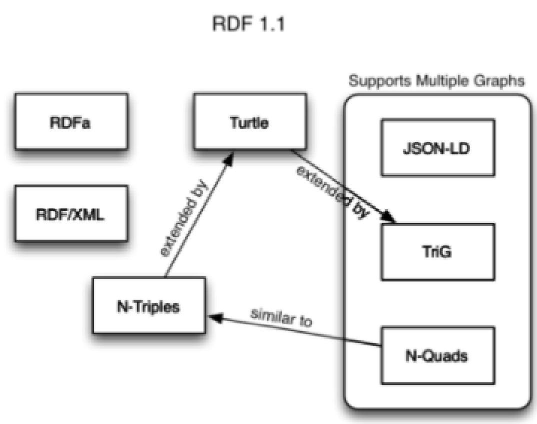


Figure 14: Syntaxes for RDF

Overall, by emphasizing the use of well-known data model standards, enabling flexible life-cycle management, promoting common data models and mapping, facilitating automatic consultation of transferred data models, and adopting common data formats, interoperability in smart grid systems can be significantly enhanced. These measures establish a foundation for seamless data exchange, interpretation, and collaboration, supporting efficient decision-making and optimized performance within the smart grid ecosystem.

Common ontologies provide a shared vocabulary and conceptual framework, enabling a consistent understanding of data. They facilitate interoperability, integration, and fusion of data from diverse sources. Common ontologies also promote reusability, scalability, and knowledge sharing among stakeholders, fostering collaboration and innovation, and establish a standardized foundation for governing semantic interoperability. Thus, they guide the development of guidelines, protocols, and best practices. By adopting common ontologies, stakeholders overcome semantic barriers, enhance communication, and maximize the value of data exchange and integration within the smart grid ecosystems. Vocabulary Hubs, where different data models are published, are key to linking semantics to marketplaces for data /service offering discovery.

8.3 Standards

Standards play a crucial role in achieving semantic interoperability in smart grids. They provide a common framework for defining data models, formats, and protocols and ensure consistency in data representation. This enables different systems and devices to understand and interpret information consistently. By adhering to semantic standards, open data sources can align their data structures and semantics, facilitating seamless interoperability between diverse systems and applications.

By educating stakeholders about standards that support interoperability, such as communication protocols (e.g., IEC 61850, DLMS/COSEM) or data models (e.g., CIM, IEC 61970/62325/61968/62746), the adoption and implementation of interoperable solutions are encouraged. Standards help stakeholders make informed decisions, select compatible technologies, and design systems that can seamlessly interoperate within the smart grid ecosystem.

Standards also facilitate harmonization and collaboration among different stakeholders in the smart grid domain. By promoting the use of shared semantic models, standards encourage stakeholders to work together and contribute to the development and improvement of these standards. This collaborative approach ensures that interoperability requirements are met, and the resulting standards reflect the collective expertise and consensus of the industry.

In conclusion, standards are crucial for achieving semantic interoperability in smart grids. They ensure consistency, compatibility, and interoperability by providing a common framework for data representation, enabling semantic mapping and integration, supporting gap analysis and standard extension, guiding interoperability implementation, and fostering harmonization and collaboration among stakeholders. Standards form the foundation for achieving effective technical communications and data exchange within the smart grid ecosystem.

9 Organizational interoperability

According to the New European Interoperability Framework, organizational interoperability involves aligning business processes, responsibilities, and expectations. This alignment includes documenting and integrating business processes and relevant information to meet user community requirements. Additionally, clearly defining organizational relationships, such as through Memoranda of Understanding (MoUs) and Service Level Agreements (SLAs), especially for cross-border actions, which are preferred to be multilateral or covered by global European agreements and pan European network codes is of utmost importance. Network codes are key legislations to ensure such pan European business process alignment, particularly the new demand side flexibility code

In the context of data spaces in the energy domain, the principles of organizational interoperability could have several implications:

- Efficient Collaboration: Various entities within the energy sector (utilities, regulatory bodies, service providers) may need to collaborate efficiently. Aligning business processes and responsibilities can enhance coordination, allowing for more effective and streamlined operations. The Harmonised Electricity Market Role model (HERM)[91] is a reference guidebook to define key actor roles through the energy value chain.
- Common Understanding: The use of commonly accepted modelling techniques for documenting business processes ensures a shared understanding among different entities in the energy sector. This is crucial for facilitating communication and cooperation, especially when dealing with complex systems and interconnected processes.
- User-Focused Services: Organizational interoperability emphasizes meeting user community requirements. In the energy sector, this could translate into providing more user-focused services for consumers, businesses, and other stakeholders. This may include ensuring accessibility, easy identification of services, and responsiveness to user needs.
- Formalizing Relationships: This could involve agreements between energy producers, distributors, and regulatory bodies to ensure smooth collaboration, data sharing, and coordinated efforts. This is defined at high level through European legislation implementing acts such as the new Implementing act for demand side flexibility data interoperability.
- Cross-Border Cooperation: For cross-border actions in the energy domain, multilateral or global European agreements are recommended. This implies that different countries or regions could enter into agreements for interoperability in sharing energy-related data, ensuring compatibility, and promoting a cohesive approach to energy management and distribution. This role is federated in the energy sector through ENTSO-e and the EU DSO entity, which are central to the development of future dataspaces.
- Data Exchange: Organizational interoperability involves integrating or aligning information exchange. In the energy sector, this could enhance the sharing of data

[91] Harmonised_Role_Model_2023-01.pdf

related to energy production, consumption, and distribution. Standardized processes can facilitate secure and efficient data exchange between different entities, contributing to a more interconnected and data-driven energy ecosystem.

In summary, applying the principles of organizational interoperability to data spaces in the energy domain can lead to improved collaboration, streamlined processes, and better services for both industry stakeholders and end-users. It promotes a more cohesive and efficient approach to managing and utilizing data in the energy sector.

10 Legal interoperability[92]

Legal interoperability in data spaces ensures organizations operating under different legal frameworks, policies, and strategies can collaborate effectively. It transforms the complexity of legal obligations into actionable policies with digital representations that systems can use. This transformation is fundamental to enabling seamless data sharing, fostering trust, and ensuring compliance across jurisdictions.

10.1 Defining Legal Interoperability

Legal interoperability involves creating an environment of laws, policies, and agreements that facilitate data exchange. This process requires the integration of legal, regulatory, and contractual frameworks while maintaining clarity and adaptability. Policies play a central role in bridging the gap between legal obligations and technical implementations.

10.2 The Process of Legal Interoperability

The transformation of legal obligations into policies involves three main steps:

1. Expressing Legal Obligations as Policies:
    - Legal obligations are expressed as a set of policies through collaborative efforts between lawyers, policy makers, and engineers.
    - Validation involves:
    - Lawyers ensuring that the expressed policies reflect the legal requirements.
    - Policy makers validating the structure and applicability of the policies.
    - Engineers ensuring the policies can be implemented and enforced effectively.
2. Creating Digital Representations of Policies:
    - Policies are transformed into digital representations using policy languages (e.g., ODRL).
    - Validation requires:
    - Policy makers to clarify the policies.
    - Engineers to verify the enforcement mechanisms.
    - Policy language programmers to implement policy processing and enforcement.

[92] Legal Dimension | IDS Knowledge Base

3. Ensuring Readability and Accessibility of Policies:
    - Policies must be represented in formats tailored to different audiences:
    - Textual formats for policy makers.
    - High-level representations for engineers.
    - Detailed formats (e.g., ODRL representations) for policy language programmers.

These steps ensure policies are understandable, implementable, and enforceable across various layers of the data-sharing ecosystem.

10.3 Challenges in Legal Interoperability

Legal interoperability faces several challenges that require multidisciplinary collaboration:

1. Complex Regulatory Frameworks:
    - Aligning overlapping regulations (e.g., GDPR, DGA, Digital Services Act) and ensuring compliance with jurisdiction-specific requirements.
    - Addressing legal uncertainties caused by conflicting or ambiguous regulatory clauses.
2. Policy Transformation and Representation:
    - Translating legal obligations into enforceable policies.
    - Creating universally accepted policy languages and templates to facilitate interoperability.
3. Readability and Transparency:
    - Balancing the needs of diverse stakeholders by providing clear and accessible policy formats.
4. Integration of Regulatory and Contractual Frameworks:
    - Aligning regulatory requirements with contractual obligations to create cohesive and enforceable agreements.

10.4 Approaches to Achieve Legal Interoperability

1. Standardization and Harmonization:

    - Developing common standards, such as standardized contractual terms and metadata-driven policies.
    - Collaborating with initiatives like the SITRA Rulebook to build robust legal frameworks.
2. Policy-Based Automation:
    - Leveraging policy languages to automate policy decision-making (Policy Decision Points), representation (as metadata), and enforcement (Policy Enforcement Points).
3. Technical Solutions:
    - Using metadata to describe data access conditions and ensuring automated compatibility checks, as currently implemented by the ENTSO-e EU DSO joint working group.
    - Implementing anonymization and pseudonymization techniques to adhere to data protection laws.

4. Collaborative Ecosystems:
   - Platforms like the IDSA Task Force Legal enable cross-functional exchanges, fostering innovation and alignment with emerging legal and technical requirements.

10.5 Future Vision

Legal interoperability in data spaces requires a balanced approach that incorporates legal expertise, policy-making proficiency, and technical innovation. By creating digital representations of legal obligations, enabling policy-based enforcement, and fostering collaboration, organizations can navigate complex regulatory landscapes, ensuring compliant, efficient, and scalable data sharing. This process paves the way for federated data spaces that drive innovation and trust in the digital economy.

11 Reference Architecture of Energy Projects

11.1 OMEGA-X Reference Architecture

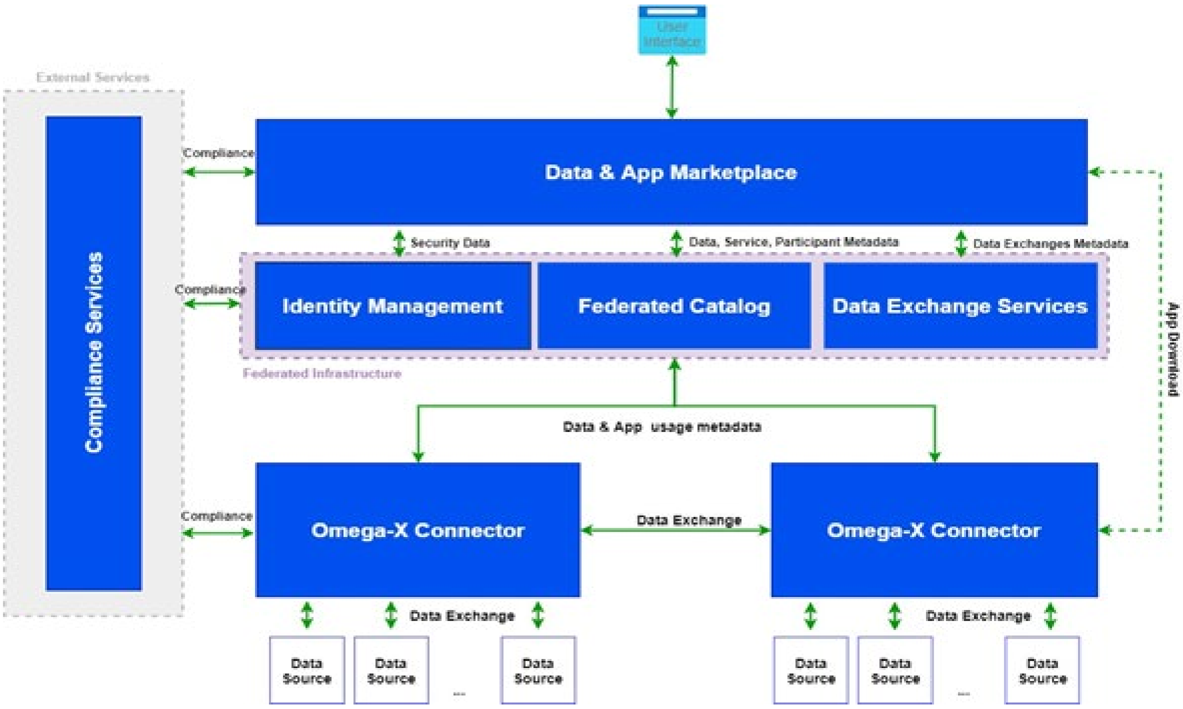


Figure 15: OMEGA-X Reference Architecture

The OMEGA-X architecture is divided into four main sections:

- The Data & App Marketplace, which acts as the main entry point for end-users in the data space. Through its graphical user interface (GUI) it enables operations such as participant registration, management of data/service offers and participants, and searching and contracting of offers.

- A Federated Infrastructure, providing the mechanisms for secure and sovereign data exchange and service provisioning, providing operations related to Identity Management, Catalog of data/services and Data Exchange services.
- Connectors enabling the actual flow of data exchanges and the provision of services enabled by data.
- Compliance Services enabling trust and interoperability, validating the shape, content, and credentials of self-descriptions and compliance with the rules of the Gaia-X Trust Framework and IDSA specifications.

In addition, OMEGA-X is working on the concept of CSDM (Common Semantic Data Model), which may become a key building block for interoperable data sharing. The building of the CSDM will be supported by a methodology to develop ontologies and a framework for its operation. While an initial CSDM will be provided to cover the needs of an OMEGA-X minimum viable product (MVP), the plan is to submit the approach to other energy data space projects, data space support actions (int: net, DSSC), and standardization on policy and behavioural interoperability for data spaces.

11.2 Enershare Reference Architecture

The vision of Enershare is to develop and demonstrate a European Common Energy Data Space which will deploy an intra-energy and cross-sector interoperable and trusted energy data ecosystem:

- Full intra-data space interoperability for cross-sector data sharing across energy sectors (electricity, heat, etc.) and with other energy (e.g. buildings/homes) and non-energy data hubs (e.g. EO-based observation, weather data, energy-efficient financial risks, etc.).
- Multiple use inter-data space interoperability for cross-domain data space data sharing, exchange, and reuse.

The first version of the Data Space Reference Architecture based on BRIDGE DERA 3.0 and OPEN DEI building blocks is depicted in Figure 16.

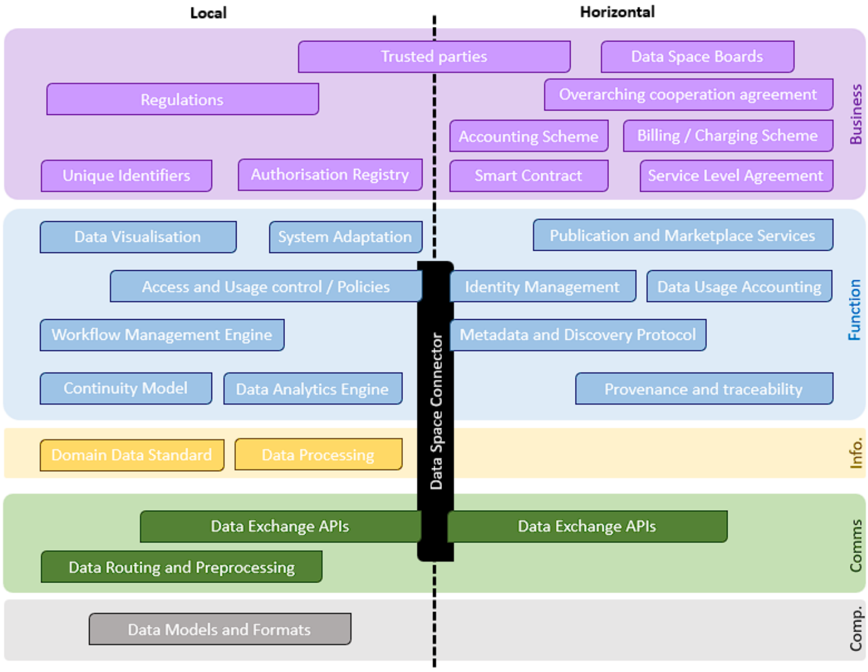


Figure 16: First draft of the Data Space Reference Architecture for Enershare.

The five horizontal layers include the Business, Function, Information, Communication, and Component Layers. The vertical split distinguishes between local building blocks that facilitate the functionalities local to a use case, and the horizontal building blocks that allow requirement-abiding participation in the data space. The central data space connector integrates the local and horizontal domain into the data space.

More precisely, Figure 17 presents a low-level view of Enershare's proposal for the functional components of the two lower layers that deal with semantic interoperability.

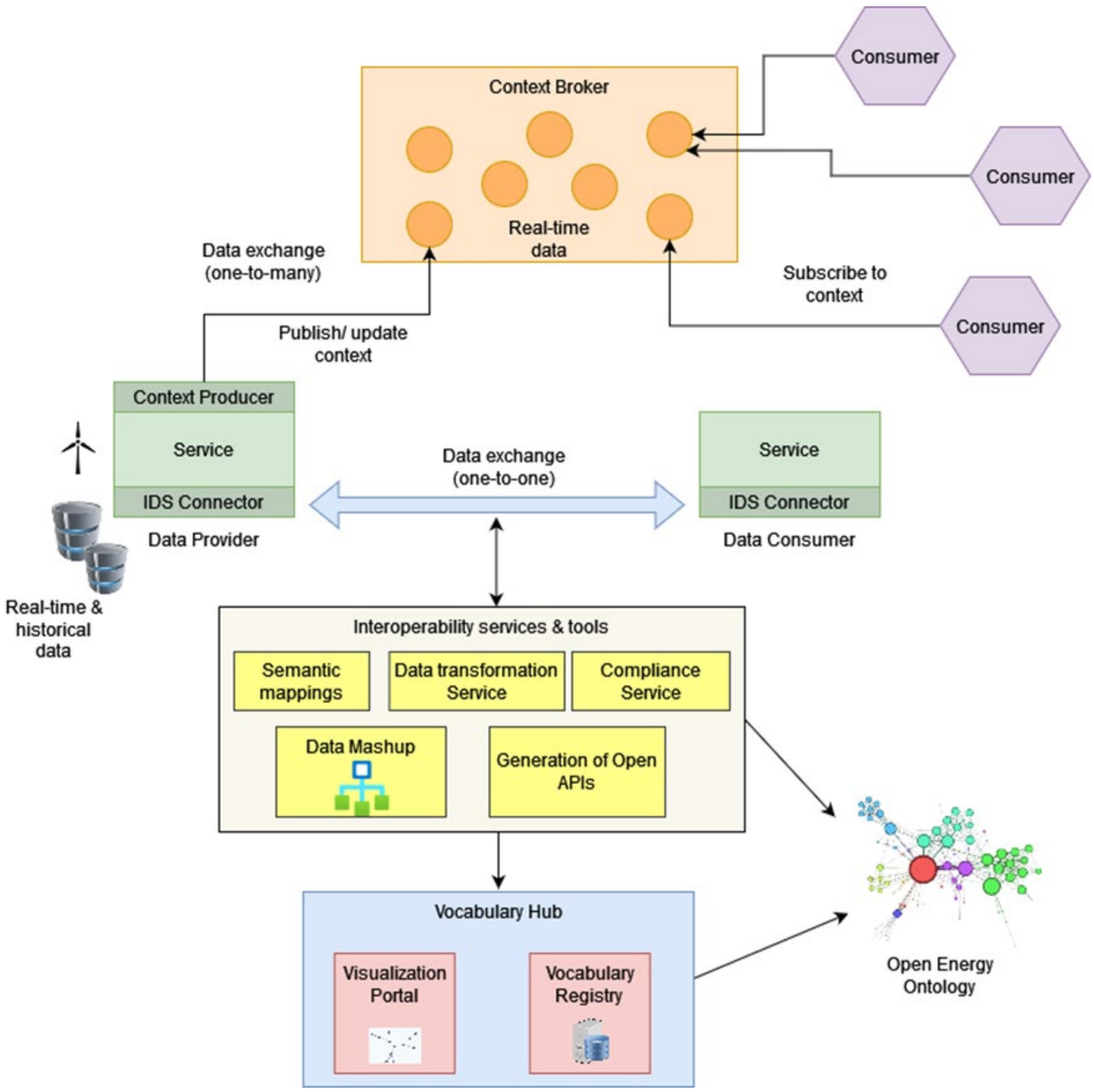


Figure 17: Functional components for data interoperability in Enershare

The purpose of these functional components is two-fold: on the one hand, they provide a semantic model to represent the energy domain that will allow an unambiguous interpretation of all the concepts and the data exchanged in the Enershare pilots. On the other hand, they provide the mechanisms and tools to query, interact with, and foster the adoption of the following semantic models:

- Data models: The Open Energy Ontology (OEO) is the set of interconnected ontologies to semantically model the energy data landscape (renewables, energy communities, flexibility, and electromobility).
- Tools: A Vocabulary Hub or web-based vocabulary registry to host the data vocabularies and a Visualization Portal or web-based GUI for the interactive visualization and querying of ontologies.

- Data exchange: one-to-one, secure, and trusted data exchange is guaranteed between provider and consumer using IDS connectors. One-to-many data exchange following a publish/subscribe paradigm is proposed using the Context Broker.
- Interoperability services and tools: to facilitate data exchange, including data transformations, semantic mappings, the generation of Open APIs, and a data mashup editor to combine data from different data sources.

11.3 DATA CELLAR Reference Architecture

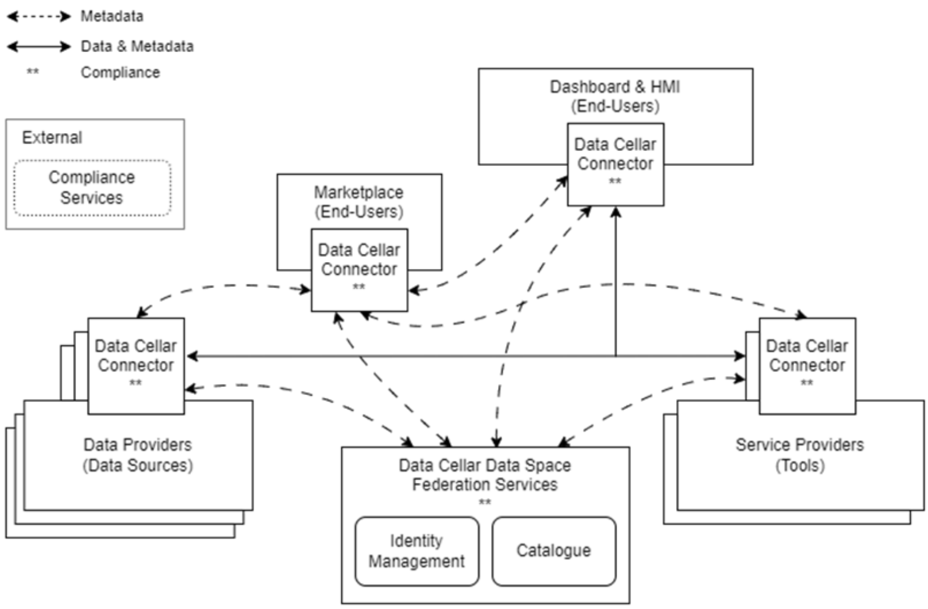


Figure 18: DATA CELLAR Reference Architecture

The DATA CELLAR system/platform comprises a fully operational data space which focuses on the provision of data and services to end-users (physical/natural persons). The main components of the DATA CELLAR reference architecture are the following:

- DATA CELLAR Connectors – all DATA CELLAR data space participants operate and maintain a connector. Via the use of connectors, data sources and tools can be integrated into the ecosystem and comply with the requirements of the data space.
- DATA CELLAR Data Space Federation Services – namely Federated Identity Management and Federated Catalogue services. These are necessary for the operation of the data space and allow secure and sovereign exchange of data and services between data space participants.
- Marketplace (End-Users) – Via the marketplace, end-users can offer their data and acquire data and services.
- Dashboard & HMI (End-Users) – The Dashboard & HMI, as a data space participant, provides end-users a GUI to interact and access all services available on the DATA CELLAR data space.

- Compliance Services – external to DATA CELLAR. Interactions with compliance services are necessary to achieve compliance with Gaia-X and IDSA specifications (validation of Self Descriptions), and to support the onboarding process of data space participants.

11.4 SYNERGIES Reference Architecture

The SYNERGIES reference architecture has been conceptually divided into two main layers:

1. The SYNERGIES Energy Data Space Ecosystem, leveraging the data mesh architecture patterns. SYNERGIES effectively integrates real-time, batch, and streaming data from various sources of the energy data value chain, shares data in a centralized or federated manner (depending on the data provider's preferences), and gains previously unattainable, data-driven insights and added value. Meanwhile, it allows for greater security, autonomy, and flexibility. It relies on the seamless communication and cooperation among:
   - The Cloud Infrastructure that lies at the core of the whole SYNERGIES Energy Data Space and represents the centralized cloud instance in SYNERGIES. Known as the SYNERGIES Data Mesh Coordination Platform – Cloud (also referred to as the Cloud (Coordination) Platform), this infrastructure is responsible for coordinating all data governance, interoperability, sharing, and value accrual functionalities across all modalities of the stakeholders' energy data spaces.
   - The Data Fabric Environments that represent the stakeholders' energy data spaces in which the energy data value chain stakeholders can integrate, host, analyse, and serve/share their data assets in an easily consumable manner. Such environments may reside:
     - centrally (in case the stakeholders cannot allocate the necessary resources and infrastructures to host them) through the SYNERGIES On-Demand, Centralized Cloud Data Fabric, also referred to as SYNERGIES Centralized Cloud Data Space. Here the environments are resolute, isolated, and secure. Such environments are spawned on demand for each organization at any time and may dynamically scale based on usage and resource-consumption patterns. On-demand, centralized cloud environments are also spawned on-demand for shared use in the case of open data collected by Energy Data Portals.
     - in a federated manner in the SYNERGIES On-Premises Environments. These that allow stakeholders to bring their infrastructures and execute the necessary SYNERGIES services. This kind of federated deployment is considered necessary for stakeholders who wish to restrict their data from leaving their premises or their cloud infrastructures. In practice, such environments can be hosted and executed on the stakeholders' side: (a) in a private cloud instance (SYNERGIES Federated Private Cloud Data Fabric), also referred to as SYNERGIES Federated Cloud Data Space; (b) in private server environments, e.g., servers or even laptops, for increased security and trust (SYNERGIES Federated Private Server Data Fabric, also referred to as SYNERGIES Federated Server Data Space); (c) in edge environments

(SYNERGIES Edge Data Fabric, also referred to as SYNERGIES Federated Edge Data Space) that can be installed in gateways to more effectively handle data produced at the edge, allow for control at the edge, and proactively anticipate any potential connectivity issues.

- Each stakeholder may register multiple Data Fabric Environments, i.e., multiple modalities of the SYNERGIES Energy Data Space, on the SYNERGIES Data Mesh Coordination Platform, depending on their needs. Communication across different Data Fabric Environments that belong to the same stakeholder or different stakeholders is performed on a federated basis but is always coordinated in a centralized manner through the SYNERGIES Data Mesh Coordination Platform.

2. The SYNERGIES Energy Services Marketplace, which includes a variety of advanced energy solutions and services available to energy data value chain stakeholders leveraging their SYNERGIES Energy Data Space(s). This marketplace allows the stakeholders to find and acquire energy services of interest from: (a) a range of analytics solutions configured in the SYNERGIES AI Analytics on-Demand Service Platform; (b) different types of digital twins that are configured and offered as-a-service; (c) a bundle of Energy-as-a-Service Applications for consumers, local communities, and network operators that will facilitate human interpretation and contextualization of energy system-wide insights and optimization strategies delivered through the pre-trained AI analytics and Digital Twins. Each Energy Service needs to seamlessly communicate with the overall SYNERGIES Energy Data Space Ecosystem, leverage the single sign-on functionalities it offers and, as in the stakeholders' data spaces, is expected to be deployed centrally or in a federated manner (depending on the location of the data in the data spaces and whether they are allowed to be transferred outside them according to the different data sharing agreements).

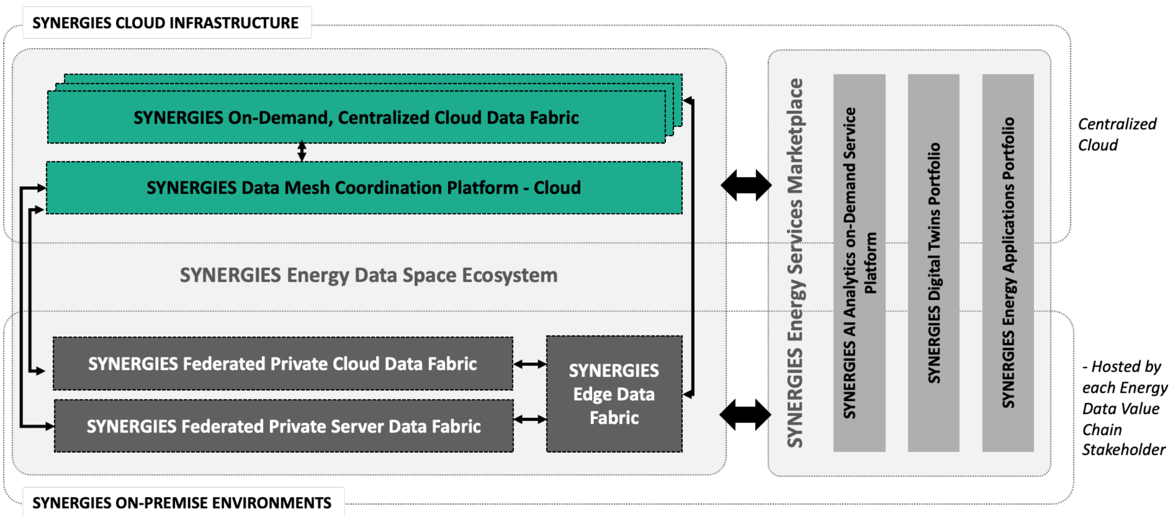
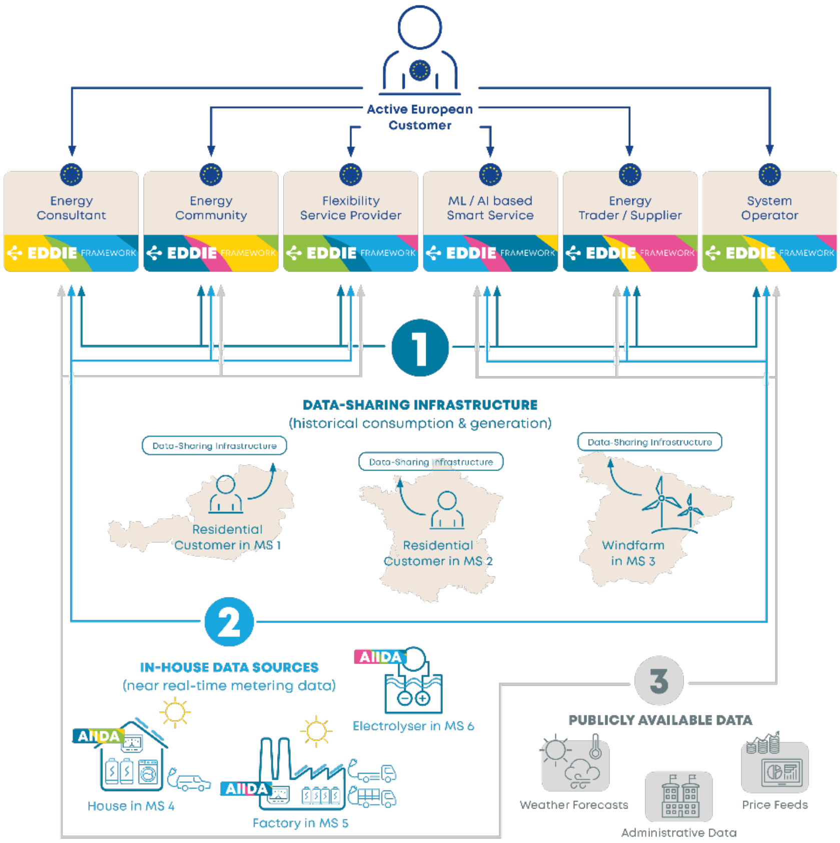


Figure 19. SYNERGIES Reference Architecture Layers

11.5 EDDIE Reference Architecture

The overall methodology of EDDIE is oriented towards the first main objective to provide a dependable, scalable, and extensible *European Distributed Data Infrastructure for Energy*

Framework (*EDDIE Framework*). This means that the overlying European interface will be given priority, and data accessible through data-sharing infrastructure (Figure 18, 1) provided by metered data administrators will be available first. In parallel, though independently, the



work on the second main objective to provide an *Administrative Interface for In-house Data Access (AIIDA)* to feed in-house data (Figure 18, 2) to *EDDIE Framework* users will be started.

Figure 20: EDDIE data integration infrastructure based on Apache Kafka data streaming and integration into national data management environments.

Together, the EDDIE Framework and AIIDA will be put into a consistent overall architectural environment during an extensive architecture and specification phase. This is planned for the first six months of the project. While publicly available data (3) from different member states (MSs) has some hurdles to overcome and should also be part of a unified interface in the future, it is beyond the scope of the initial EDDIE project.

Figure 20 above illustrates the three major data family groups considered within EDDIE. Here, we describe them in detail:

Data-sharing infrastructure: These are national energy data management environments and online data hubs. Historical metering and consumption data is collected, validated, and stored at entities that need to make that data available in turn to established actors or eligible parties. Now, this is done diversely and by different players in each MS. Also, different processes need to be followed, and data is delivered in different formats and schemas. The

EDDIE Framework communicates with these data-sharing infrastructures and provides a streamlined consent management user flow and a transformation towards a common pivotal format.

In-house data sources: Currently, near real-time data can in most MSs be read from the "standardized interface" on the smart meter (if it was ordered and installed after July 4th, 2019). If the customer manages to connect to that interface and make that data processable, it is still only available in-house and it needs to be transformed to a common format. The Administrative Interface for In-house Data Access (AIIDA) will be in the position to read data from different meter models, standards, and configurations and make it available through an online consent-based mechanism. This means that users of services that are based on the EDDIE Framework can be shown a button on, e.g., the service website saying, "connect my in-house data". They will then be routed to their Consent Management Interface (within AIIDA). If consent is given, the AIIDA instance will deliver the requested data to the EDDIE Framework of the service for which consent was granted. Not only the main meter interfaces will be supported, but also others (e.g., sub-meters).

Publicly available data: There is also other – often publicly available – data that is necessary for many processes, but neither directly belongs to the customer nor shows consumption or generation time series characteristics. National weather forecasts, price feeds, or market reference data fall under this category. These data families are still depicted diversely and by different players depending on the country. Optionally, and if time allows, the EDDIE project team will address this field and strive to make it available in a unified pivotal format through the EDDIE Framework.

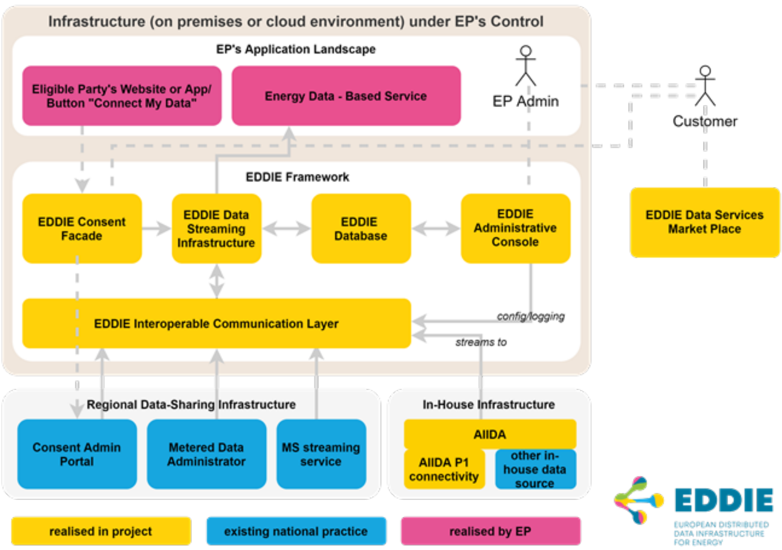


Figure 21: EDDIE Architectural Schema

The online parts of the EDDIE Framework communicating with external systems labelled in the central yellow boxes. They are:

- The EDDIE Administrative Console, providing the administrative interface of the EDDIE Framework
- The EDDIE Consent Façade, providing the user flow and the proper routing of the customer to the appropriate Consent Administrator (CA)
- The EDDIE Interoperable Communication Layer, comprising flexible software applications providing the integration and communication with MS (I/O) CAs and Metered Data Administrators (MDAs)

These three components share a common database (EDDIE Database) to manage authentication information, process states, mapping/reference data, etc., and a common data streaming environment (EDDIE Data Streaming Infrastructure). The latter will also provide the Application Programming Interface (API) for Energy Data-Based Service.

Especially, the EDDIE Database and EDDIE Data Streaming Infrastructure can be provided in a managed, "cloud-native" manner, meaning the users of cloud computing environments can rely on database and data streaming solutions typically offered by most vendors. They do not need to manage additional, proprietary structures. This approach also guarantees for maximum degrees of flexibility and dependability.

With the approach described above, Project EDDIE will provide connectors to other data spaces and direct data users alike. This will occur in three phases in the following countries:

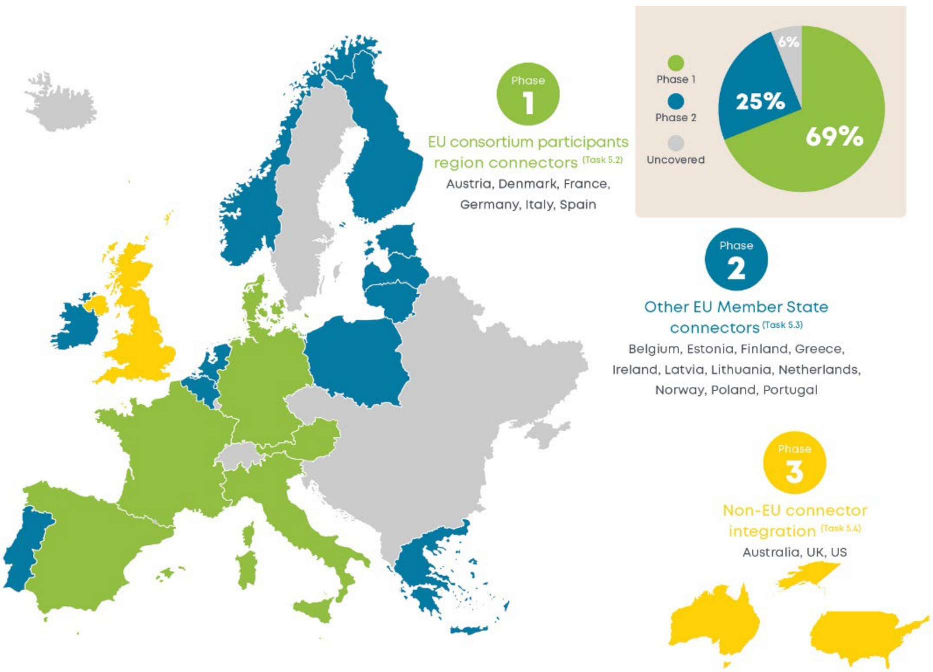


Figure 22: Geographical coverage of EDDIE

As a principle, the Open-Source Framework is installable on stakeholders' own hardware without limitations. To make this as easy as possible, the project features EDDIE Online[93] where, in a matter of minutes, startups and data users can simply register and utilise an infrastructure already set up by the project.

11.6 Analysis and considerations

After the concept of reference architecture has been introduced by the data spaces projects and using models like IDS-RAM, the need for documentation of reference architecture must be examined in more detail. The description of the architecture represents the essential artefact that is visible as the basis for those involved in the development and implementation of the system. The documentation helps to understand the decisions for the division of the problem area and forms the basis for required interfaces, conformity tests and the understanding and management of derived architectures, for example. The reference architecture and its documentation define binding restrictions for the resulting developments and instances in implementations. It is therefore necessary for the documentation to support this as effectively as possible and to record the decisions made in compliance with certain quality criteria, such as accuracy, consistency and completeness. To avoid misinterpretations and misunderstandings, the language (terms, concepts e.g.) used in the documentation must be as clear as possible. Informal and unclear statements in the documentation, on the other hand, could create a false sense of security and thus lead to misguided developments.

In addition, the documentation of the architecture in a project must consider the requirements of the users/stakeholders so that they can obtain the information they need.

Reference architecture is used by different parties for different purposes. For example, they can be used by architects to fundamentally structure a system to be developed and to use the terms defined there to communicate the corresponding architecture, e.g. with developers. For project management, a reference architecture can be used to plan the required qualifications of project staff and for initial cost estimation. A reference architecture can also be used by solution manufacturers to develop compliant systems. Due to the different stakeholders, a reference architecture should have appropriate content to be fit for purpose. This content is therefore not rigidly predefined but ultimately depends on the target group using reference architecture. A recommendation for the minimum content of architecture descriptions can be found in ISO 42010 (which also forms the meta model base for SGAM, RAMI and other reference designation frameworks), which also describes basic terms in the context of documenting software-intensive systems (in particular the 'conceptual framework for architecture description'). These contents include a clear labelling and overview of the document, identification of stakeholders and their architecture-relevant interests, specifications of selected viewpoints from which the architecture should be viewed, corresponding architecture representations, records of known inconsistencies and the documentation of design decisions.

[93] EDDIE Online

The means of conventional architectural description can essentially be used to describe reference architecture, considering the generally valid structures and relationships. It is a guiding principle that architecture is best expressed using multiple views. Various approaches exist for describing software-intensive systems, such as the IEEE standard 1471-2000 or the 'Views and Beyond' approach of the Software Engineering Institute, which pursue a view-oriented approach. IEEE standard 1471-2000, which is currently being further developed and standardized by the ISO and IEEE as ISO/IEC 42010, will also be considered. The terminology defined therein and the proposed content for the architecture description shall be seen as the basis to deal with IDS-RAM based models.

An architecture description consists of a collection of different products that document architecture. Which artefacts are used for documentation depends on the stakeholders of the system (stakeholders). These can be, for example, clients, users, developers, or maintainers of the system, each of whom may have different or complementary interests (concerns). For example, the primary interest of a user will be information regarding the use of the system, whereas developers will be more interested in technical and implementation details. Given the emerging topic of data spaces and the results of the first projects presented in this updated report, it is recommended to re-use existing reference architecture paradigms and the best practices created by the data space projects in the domain to bring forth the knowledge obtained into models like IDS-RAM.

12 Common European Energy Data Space (CEEDS)

As mentioned in the recently published COMMISSION STAFF WORKING DOCUMENT on Common European Data Spaces[94] "The EU Action Plan on digitalising the energy system[95], adopted in October 2022, lays down key actions to establish the common European energy data space and aims at consolidating a comprehensive and coherent EU framework for sharing data to support innovative energy services. This will help the EU reach its overall objectives in terms of energy security, sustainability and integration of energy markets, and it will pave the way towards lower consumer bills."

The five projects mentioned in this paper and their CSA are paving the way for the deployment of the Common European Energy Data Space. To achieve this goal, they have defined four system use cases (SUC) that demonstrate how interoperability can be realized among them.

12.1 System Use Cases

12.1.1 SUC1- Onboarding

This SUC aims to achieve interoperability of participant identities across different data spaces.

[94] COMMISSION STAFF WORKING DOCUMENT on Common European Data Spaces
[95] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022DC0552

Description

Participants should be able to enrol in a Data Space and obtain a valid Verifiable Credential (VC), which can be recognized across multiple Data Spaces if the corresponding VC issuer is accepted and trusted. To ensure consistency and interoperability, the adoption of the OpenID for Verifiable Credential Issuing (OID4VCI) standard has been agreed upon. This standard provides a unified approach to credential issuance and management, fostering trust and scalability. For verification purposes, the accepted methods include DID Web and DID Key, ensuring flexibility and robust mechanisms for credential validation across interconnected Data Spaces.

Diagram

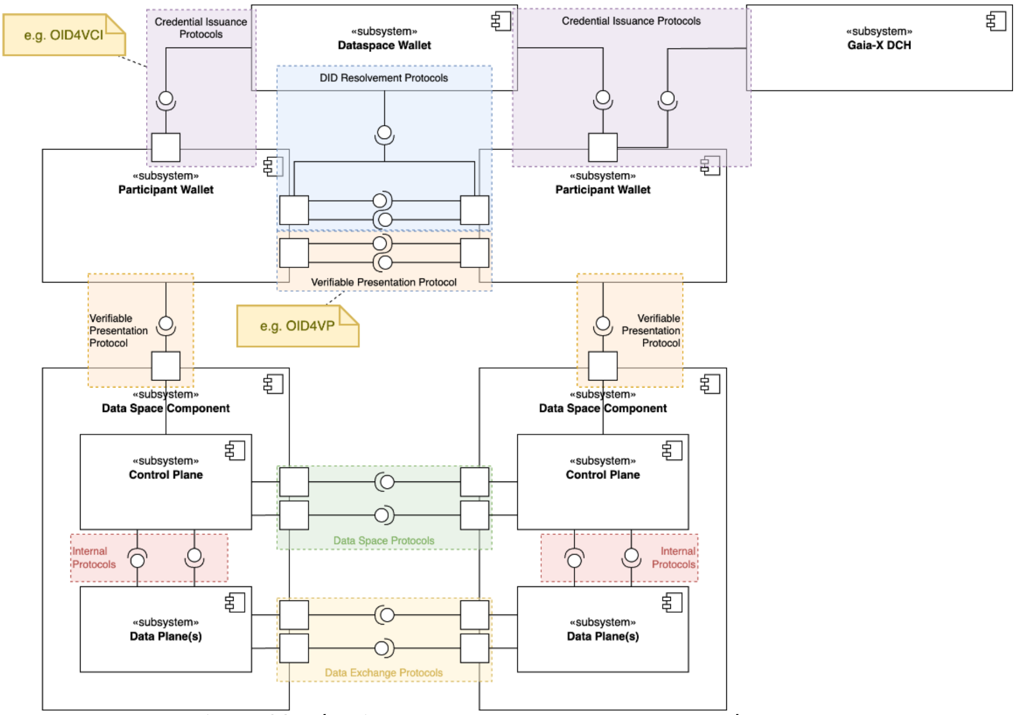


Figure 23. Identity Management common approach

Result

The Enershare and OMEGA-X projects have successfully integrated a Wallet with the connector and implemented the OpenID for Verifiable Presentation Protocol (OID4VP). As part of the incremental demonstration plan, two tests have been defined to ensure interoperability and validate the implementation.

- Test 1: A Verifiable Credential (VC) is generated by the OMEGA-X issuer and sent for testing within connectors using the OID4VCI protocol. Both connectors in this case are Enershare Connectors. Status: Completed.
- Test 2: Upon successful completion of Test 1, the OMEGA-X connector presents the VC generated by the OMEGA-X issuer to the Enershare connector. Subsequently, the Enershare connector will perform the same operation with the OMEGA-X connector,

verifying mutual interoperability. This step implies full interoperability between connectors (SUC4).

Challenges

The main challenge for Test 1 was the interpretation and feature selection of the OID4VCI protocol. With the main difference between OMEGA-X and Enershare being the selection of the Authorization Code Flow and Pre-Authorized Code Flow respectively. To overcome this challenge, the OMEGA-X issuer implementation and the Enershare wallet implementation agreed upon using the Authorization Code Flow for Test 1. Other challenges, with respect to the provided metadata, were solved quickly in synchronization sessions. Also, the used credentials and accompanying trust framework need to be synchronized to ensure the credentials will have a similar value across the dataspaces.

The full interoperability challenge between the connectors (SUC4) remains and will require extensive collaboration.

Recommendations

The agreements on a technical level made between OMEGA-X and Enershare are still valid and reasonable. In the future, additional protocols might be selected for the issuance of credentials, where it is likely that now of issuance the appropriate protocol is selected. Since it can be assumed that implementations will support a multitude of protocols within a single implementation.

Since the issuance of credentials is a process that is not executed often, supporting different protocols is a valid approach. For presenting credentials, however, it can be assumed that in certain situations the protocol needs to be as efficient as possible. In these situations, implementations may restrict the available protocols.

12.1.2 SUC2 - Data Discovery and push into the catalogue

One of the key challenges in energy data spaces is effective data discovery. While catalogues provide a structured way to publish and search for data and services, the ability to accurately find relevant offerings remains a challenge. This is because data must be described with rich metadata, yet existing general-purpose cataloguing models often lack the specificity needed for the energy domain. Without precise descriptions, consumers may struggle to identify datasets or services that meet their technical and business requirements.

Solution

To address this challenge, we propose leveraging existing ontological models, such as DCAT (Data Catalog Vocabulary), which provides a standardized approach for describing datasets, services, and distributions. However, DCAT alone is not sufficient for the energy domain. Therefore, we propose to add metadata with domain-specific taxonomies that incorporate energy properties, components, and relationships. This enhancement ensures that data offerings are described in a way that aligns with industry needs, improving discoverability and interoperability. By integrating structured metadata with energy-specific annotations, we enable more precise searches, ensuring that consumers can effectively find and access the most relevant data and services in energy data spaces.

12.1.3 SUC3 – Contracting

Data Spaces give the possibility to the Data providers to offer their Data sets or service to be contracted by other Data Spaces users that will act as Data Consumers.

Description

A valid contract should be established between them to confirm the validity and the traceability of the transaction signing both (provider and consumer) the asset self-description. In what refers to the contract, the projects work on a process where a double validation takes place, starting and finalizing such contract. Moreover, there are two methods on how to provide any contracted data, following a push or a pull approach.

Diagram

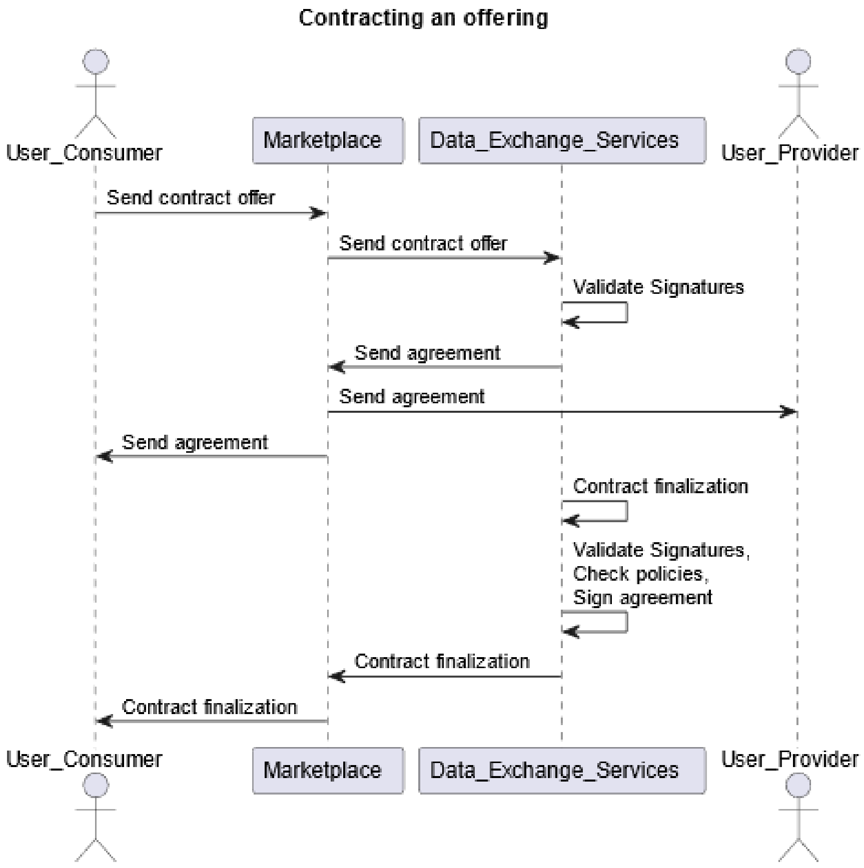


Figure 24: Contracting an offering

PUSH option

In the particular case, a Data Space provides a contracted data offering via a push approach, the connector on the consumer side sends a transfer request message to the provider connector. Then, the latter sends a 'transfer start' message to the former and starts pushing data to the consumer connector.

Once the transactions finish, the provider connector sends a 'transfer completion' message to the consumer connector, which in turn communicates the data transfer success to Data Exchange Services.

PULL option

On the other hand, a Data Space can also provide a contracted data offering through a pull option. Here the consumer connector sends also a transfer request message to the provider connector, which sends a 'transfer start' message to the consumer connector. Once received, this end of the exchange starts pulling data from the provider connector.

As in the previous case, the moment the transaction is completed, the provider connector sends a 'transfer completion' message to the consumer connector, which must communicate the data transfer success to the Data Exchange Services as well.

Currently, there is a proposal in the process to remove an offer available in the DS catalogue behind the marketplace accessed by users. Nevertheless, there is an ongoing discussion on the need to consider some offers that might not be available in the marketplace due to diverse reasons.

Result

The tests conducted in relation to the establishment of contracts within a data space have yielded satisfactory results in each case, resulting in the completion of transactions and the proper connection with the rest of SUCs.

Furthermore, there have been attempts to facilitate interactions between some of these projects within the EDSCP, which have provided valuable insights and conclusions that pave the way forward for the immediate next steps, in both this energy field and hopefully translated into other verticals. These interactions have allowed for a deeper understanding of the dynamics within data spaces, leading to the identification of key challenges and opportunities for improvement.

Challenges

The contracting process within data spaces presents several challenges that need to be addressed to ensure smooth interactions and legal compliance among all parties involved. Key issues have emerged through discussions and implementations in various projects, particularly about contract initiation, validation, and the inclusion of licensing aspects.

- Intermediate "Send Agreement" Step: One point of contention arises from the necessity of an intermediate "send agreement" phase. This step might be crucial in certain scenarios to ensure that all parties are aware of and agree to the terms before moving forward. However, there may be an optimal scenario in which all participants are well-known and trusted, allowing them to skip this phase and proceed directly to finalizing the contract.

- Second "Validate Signatures" Step: Another challenge is the presence of a second "validate signatures" step after the contract has been finalized. Upon questioning the necessity of this additional validation within the members involved in the discussion, there is a reasoning for this split into two phases: one to validate the initiator of the contract, and the second to validate the finalizer. This approach ensures that both parties are properly verified and that the contract is secure. Additionally, some particular approach involves a negotiation phase conducted over the contract, with all actions recorded via blockchain for transparency and immutability. However, the additional validation step introduces complexity and could potentially delay the finalization process.
- Initiator of Contracting Process: A further point of debate is whether the consumer is always the one who initiates the contracting or offering process. There are discussions on whether the provider should have the ability to initiate some processes as well. This highlights an important challenge in establishing a balanced and fair contracting system, where both parties—consumers and providers—can play an active role in initiating and shaping the terms of the agreement. Ensuring that both sides have equitable opportunities in the contracting process can help avoid biases and promote more efficient transactions.
- Incorporating Licensing Aspects: Finally, there is a proposal on the inclusion of licensing aspects in the contract to specify the terms of use for an offering in the marketplace. For example, defining how many times a consumer can use a particular offering would require clear licensing rules to be embedded into the contract. This adds a layer of complexity, as these terms need to be carefully crafted to ensure fairness, transparency, and compliance with any legal requirements. Licensing aspects must be included in the contract clearly to all parties involved and prevents any potential misunderstandings or disputes regarding usage rights.

In conclusion, the challenges in the contracting process within data spaces are multifaceted and require careful consideration of various factors such as agreement steps, roles of parties, validation processes, and licensing terms. The ongoing discussions and implementations continue to provide valuable insights, which are essential for refining and improving contracting mechanisms to ensure a more streamlined, flexible, and secure environment for data exchange and collaboration.

Recommendations

The analysis and trials ran suggest that a one-size-fits-all approach may not be suitable, and the need for flexibility in the contracting process should be considered. The ongoing discussions and implementations continue to provide valuable insights, which are essential for refining and improving contracting mechanisms to ensure a more streamlined, flexible, and secure environment for data exchange and collaboration. However, to achieve an optimal and universally applicable contracting process, further work is needed to address the complexities and uncertainties that still exist.

As previously discussed, the challenges in the contracting process within data spaces are multifaceted and require careful consideration of various factors such as agreement steps, roles of parties, validation processes, and licensing terms. Specifically, in what refers to the contracting procedures, to reduce complexity and confusion, there is a need for the development of standardized contract templates and procedures that can be applied across various projects and platforms. This would help ensure consistency and clarity in the contracting process, while also allowing for flexibility to accommodate specific needs of different actors. Standards for contract initiation, validation, and signature procedures should be agreed upon at an industry level, potentially facilitated by regulatory bodies or industry consortia.

Moreover, future developments should address the imbalance between consumers and providers in the contracting process. A more balanced approach could include allowing both consumers and providers to initiate contracts or offer terms. This would ensure fairness and prevent potential bottlenecks or delays caused by an overly rigid structure. Additionally, systems should be designed to allow for easy negotiation and amendment of contracts during the process, ensuring flexibility for all parties involved.

12.1.4 SUC4 - Data Exchange and interoperability

This case is intended to prove the data exchange interoperability between data spaces, enabling the seamless transfer of data between users of different data spaces.

Description

This SUC assumes all participants have performed SUC1 for onboarding, SUC2 for publishing/discovering datasets and services and SUC3 for contracting a given offering. In turn, System Use Case 4 focuses on the actual data transfer between two instances of data spaces, followed by the storage of the data set in the Data Store of the data recipient, thus making it available for further utilization and fusion with other complex datasets for processing, analysis and insights extraction in external – to the Data Space – services.

Diagram

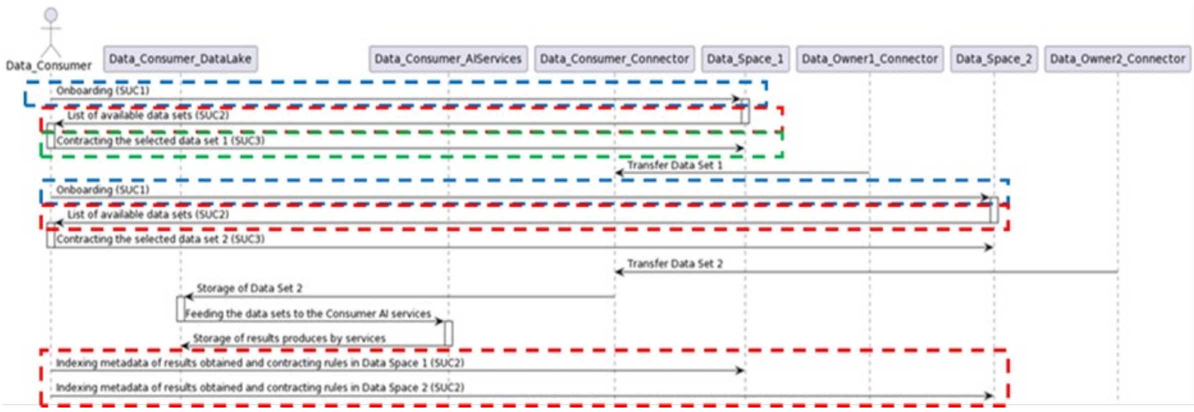


Figure 25: Data Exchange

Result

Bilateral exchange of the traded data among two data spaces needs to rely on the availability of various data transfer methods to allow any participant to retrieve the acquired dataset through:

- API-based retrieval queries, enabling the creation of custom GET/POST API endpoints accompanied by guidelines regarding authentication and pagination.
- Pub-Sub mechanisms (e.g. Kafka or MQTT) for the retrieval of real-time data streams through the subscription to selected topics that have been published to the respective broker.

To this end, SYNERGIES has elaborated on the development of an API gateway for secure data serving and transfer enabling the generation of custom API endpoints automatically, enabling participants to self-serve the data through programmatically accessible interfaces, according to their preferences for data retrieval and provisioning, tailoring the output to meet their specific requirements. Such custom API endpoints for retrieving smart metering data made available through the SYNERGIES Data Space are provided to the rest of the sister projects, for validating the seamless and secure transfer of data among them.

Moreover, SYNERGIES and EDDIE have elaborated on the configuration of appropriate PubSub mechanisms enabling the effortless and secure exchange of real-time/up-to-date data through subscription to the Kafka/ MQTT brokers it provides, while on the other hand allowing for seamless data ingestion through the subscription to external PubSub mechanisms available by the participants/ data owners. This approach facilitates the validation of data transfers with data spaces employing such PubSub architectures, i.e. EDDIE.

Challenges

Interoperable data transfer cannot be addressed as a standalone process in the overall data exchange process between participants in different data spaces. This is tightly connected to semantic interoperability requirements introduced by the fact that the various participants and systems involved utilize a wealth of data models and ontologies that, even if standards-based, present significant misalignments that may hinder the realization of this use case. This issue becomes even more significant when considering, not only the wide variety of standards-based data models and ontologies utilized across the energy sector value chain, but also the emerging integration of the energy sector with coupled ones (i.e. mobility and buildings) which creates an increasingly complex semantic landscape and brings forward the need for the establishment of effective alignment and semantic harmonization mechanisms across all relevant standards.

This comes together with the need for the agreement on common data formats/ schemas (e.g. JSON, JSON-LD) applying across various standardized data transfer methods (REST APIs offering standard HTTP methods, MQTT and Kafka), that can effectively ensure compatibility between the various systems/ participants involved.

Recommendations

In response to these challenges, it is essential that flexible mechanisms for semantic harmonization leveraging commonly used semantics such as CIM[96] and SAREF[97] across various data models need to be put in place that safeguard semantic interoperability and on-the-fly mapping between diverse data models/ ontologies. A first approach for the semantic alignment across the 5 sister projects of the EDSCP has been elaborated in the frame of SUC 5-Semantic Interoperability, however, with the progressive integration of new standards and sectors in the energy value chain, more advanced, dynamic and effortless approaches will be needed to realize and end-to-end interoperable data exchange framework.

Moreover, API Gateways have proven to provide effective means for standardized API access and interoperability across networks of participants, enabling the creation of custom API endpoints according to the preferences of data recipients and ensuring compliance with standardized formats and schemas to safeguard interoperable data exchange.

Finally, a variety of data transfer/ exchange methods must be facilitated, addressing the needs for exchanging data streams through Pub Sub architectures, to effectively address the need for real-time/ up-to-date data exchange across the value chain.

12.1.5 SUC5 – Semantic interoperability

Semantic interoperability ensures that data exchanged between different systems retains its meaning, allowing seamless integration and interpretation. In energy data spaces, where multiple stakeholders handle diverse datasets, achieving semantic alignment is essential for efficient data sharing and processing. Without it, differences in data models, ontologies, and terminologies create barriers that hinder collaboration and automation.

This SUC aims to achieve semantic interoperability across different data spaces, specifically regarding smart meter data. Sister projects have agreed to use the IEC 61968-9 Ed 3, (also known as the EUMED Metering profile), explained in previous sections, as the common data model to exchange data between data spaces. Each project has a defined different type of mappings from their internal data model into the EUMED Metering profile as per depicted in Figure 26:

[96] CIM | DMTF
[97] SAREF: the Smart Applications REFerence ontology

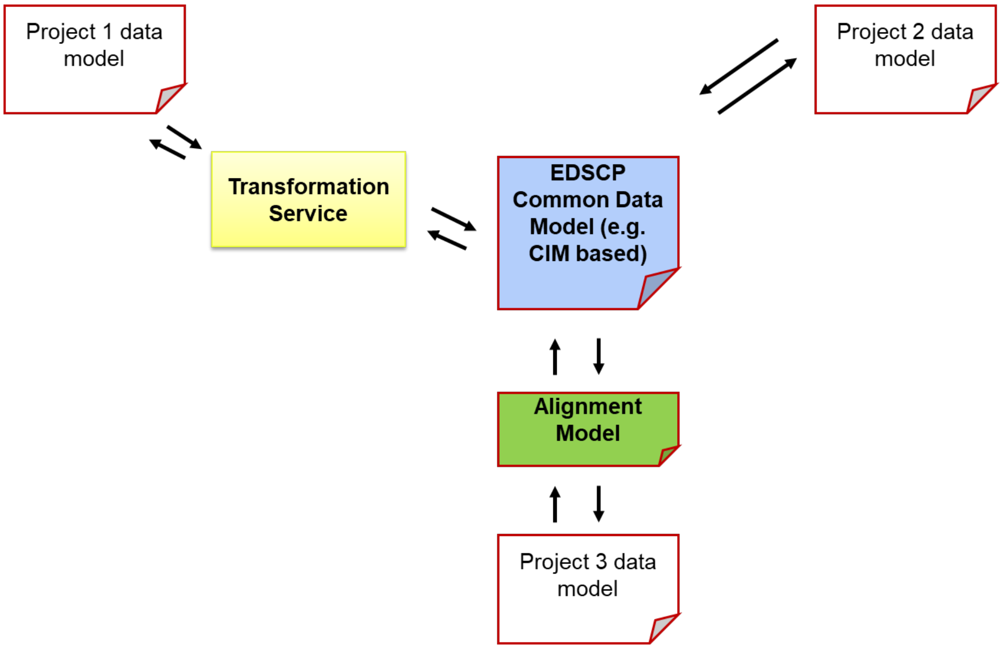


Figure 26: SUC5 - semantic interoperability.

To ensure semantic interoperability between sister projects (DATA CELLAR, OMEGA-X, EDDIE, and Enershare), a common reference model can be used for cross-project data exchange.

Solution:

To overcome these challenges, a semantic interoperability test is being conducted as part of the Energy Data Spaces Cluster Projects (EDSCP) initiative, with support from Int: net and the BRIDGE Data Management Working Group.

This test aimed to evaluate the ability of five different dataspaces within the EDSCP to exchange data with unambiguous meaning and ensure seamless data usage. The primary focus of this test is metering data (My Energy Data), which requires a common energy data model to achieve consensus among sister projects and enable effective cross-domain interoperability. For that purpose, the Common Semantic Data Model (CSDM) developed in OMEGA-X, which includes the EUMED module (based on IEC 61968-9:2024 Ed3) has been adopted. Three integration strategies are being implemented to align with the EDSCP Common Data Model:

1. Native support for at least one pivot model within the EDSCP Common Data Model, as seen in EDDIE and OMEGA-X.
2. Ontology alignment, where projects with similar ontologies establish an alignment model to define semantic correspondences, as done by Enershare.
3. Transformation services, which map internal data models to a pivot model of the EDSCP Common Data Model, a strategy adopted by DATA CELLAR and SYNERGIES.

These approaches ensure seamless data exchange and interoperability across energy data spaces.

12.2 Upcoming Project INSIEME

Answering Digital Europe Programme Call DIGITAL-2024-CLOUD-AI-06-ENERSPACE, Project INSIEME[98] (starting in April 2025), aims to deploy a reliable, secure, and sustainable Common European Energy Data Space (CEEDS), applying the abovementioned system use cases on further steps towards industrialisation. This initiative aligns with the European Strategy for Data and the EU Action Plan on digitalizing the energy system, adopted in October 2022, as highlighted in the recently published Commission Staff working document on Common European Data Spaces[99]. The plan outlines key actions to establish the common European energy data space, consolidating a comprehensive and coherent EU framework for data exchange and interoperability in the sector.

Many key participants on the 5 Energy Data Space sister projects and the int:net CSA have teamed up with key European organisations and individuals in the twin transition to provide – in co-operation with the European Data Spaces Support Centre (DSSC) - a unified, streamlined and securely deployed data space for use cases such as:

- Energy efficiency management and data-driven consumer applications
- A European framework for collective self-consumption, energy communities and energy sharing
- Grid flexibility services such as explicit, market-based flexibility trading and flexible connection agreements
- Electromobility – residential charging and EV charging infrastructure
- Renewables integration
- Network operation and operational planning
- Smart sector integration

The project features more than 50 European partners, has a budget of over 16 million EUR, and will run for three years. It will deploy the abovementioned system use cases across federated data spaces as applicable.

13 Existing interoperability tools, methods, and platforms

13.1 Data format transformation tools

When exchanging data between provider and consumer, it is usually necessary to make transformations on the data format either at the origin (i.e., when the provider acquires the

[98] https://insieme.energy
[99] https://ec.europa.eu/newsroom/dae/redirection/document/83562

data from the source before sending it) or at the destination (i.e., when the consumer receives the data before storing or processing it).

There are different mechanisms to make these data format transformations. One approach is to define JavaScript converters that read the input format, perform the transformation and generate the output format, e.g., JSON-to-JSON, CSV-to-JSON, XLS(X)-to-JSON or JSON-to-RDF converters. A JSON-to-JSON transformer will convert a given JSON structure into another JSON structure using JavaScript instructions. This approach is followed by open-source tools such as Piveau Consus[100].

A second approach is to write a mapping file with key-value pairs that define how the input fields should be mapped to output fields. This solution, called the data model mapper tool[101], was used in the SynchroniCity H2020 project to convert several file types (e.g., CSV, JSON, GeoJSON) to the different Data Models in JSON defined both by the project and by FIWARE. A similar approach has been followed through the EDDIE project, leveraging CIM Data models developed through the DERA3.2 and SGAM architectures and replicating automatic message generation into Json profiles, as historically used by ENTSO-E to develop the IEC62325 ESMP profile.

While both of these approaches are useful, they are not standard based. However, a third approach is to use a generic mapping language such as RML (RDF Mapping Language)[102], which provides more flexibility. RML is defined to express customised mapping rules from heterogeneous data structures and serializations to the RDF data model.

13.2 Common Semantic Data Model tools

It is predicted that a data space for energy will be associated with a CSDM (Common Semantic Data Model) that will be used as a reference to specify and ensure semantic interoperability. To this end, OMEGA-X has defined a methodology called AIME[103] (Agile Interaction Model for Energy Data Spaces) to construct semantic interoperability specifications for data spaces. The methodology will be validated in OMEGA-X and the result will be promoted within the data space projects community and at standardization level (ISO/IEC JTC 1/SC 41).

13.3 Semantic Treehouse[104]

TNO´s vocabulary hub Semantic Treehouse is a collaborative platform designed to assist user communities in the development, maintenance, and adoption of shared data models. By facilitating consensus on common data models, it ensures smooth communication between systems. The platform offers tools for importing, viewing, and exploring ontologies,

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[100] Piveau Consus Microservice for transforming data in a pipe. Available online: https://github.com/piveau-data/piveau-consus-transforming-js (accessed on 06 April 2022).
[101] The data model mapper tool. https://gitlab.com/synchronicity-iot/data-model-mapper
[102] A. Dimou, M. Vander Sande, P. Colpaert, R. Verborgh, E. Mannens, R. Van de Walle, "RML: A Generic Language for Integrated RDF Mappings of Heterogeneous Data", Proceedings of the 7th Workshop on Linked Data on the Web, Seoul, South Korea, 2014.
[103] D4.1 Data ingestion, Common Information Model and semantic interoperability. OMEGA-X Project.
[104] About | Semantic Treehouse

creating message models, and validating data against agreed-upon schemas. Additionally, it provides community management features, enabling the administration of user accounts, organizations, and working groups, thereby fostering effective collaboration among stakeholders.

14 Gaps of interoperability between data spaces

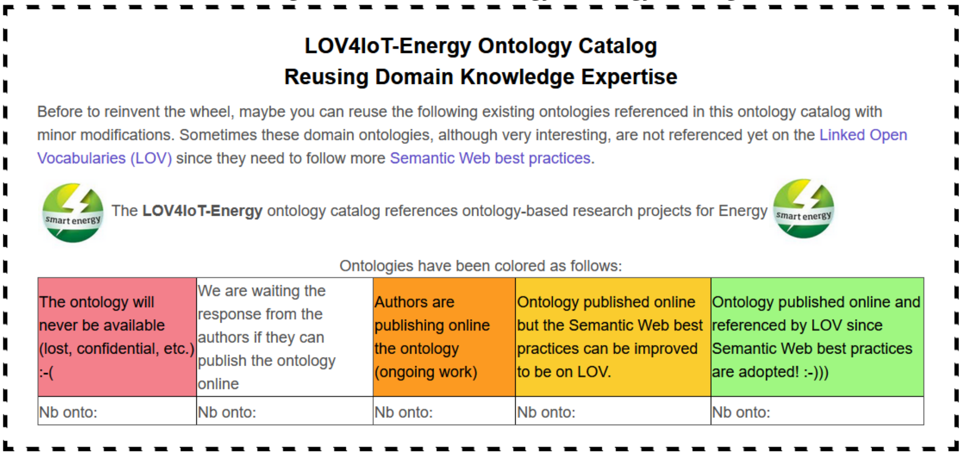
By achieving interoperability of energy data spaces, it is assumed that commonly defined aspects of data spaces, from design to deployment, will be used. Under a technical perspective, common definitions can be used for technical interoperability, which can be set across all data spaces in the energy domain, e.g., when referring to communication protocols, data formats, or data space connectors and architectural elements. The case can be slightly different for the semantic interoperability, where “ontologies and data models” should cover a wider range of application sub-domains. In this case, it might make more sense to use a kind of “union” of all “models, vocabularies, and semantic” information that appears in the energy systems. Thus, interoperability can be achieved under an umbrella that covers all data models that may be involved in the design of the data space. An interesting issue, however, may arise when referring to standards that can be used, and by examining how the data spaces can function seamlessly by applying these standards across different models and energy applications.

Interoperability in the aforementioned categories can be achieved from different perspectives. In any case, it is possible without technical conflicts, since standardized models and technical solutions are generally available. Furthermore, data connectors are being evolved and developed according to the needs and specifications that appear in different application domains, which also influence the design and deployment of energy data spaces. From another point, however, interoperability should be considered for the use case, where the data owners/providers and end-users may belong to quite different groups of interest. At this stage, data sharing, even in interoperable data spaces, may not have the same usage value among all types of deployments in the energy domain, and special focus may be given to different groups of use cases. A possible solution for these distinct use-case scenarios could be to collect what is considered as “common ground” among energy data spaces and attempt to bridge these use cases for the common energy data space utilization. This can be clarified further by the complete listing of the end-user types and their interests in shared data among all involved data spaces. Even if an interoperable energy data space is technically possible, special attention is needed for the use-cases, so that scenarios can be fit-for-purpose.

Finally, interoperability gaps in data spaces can be eliminated when using and evolving proper federation services. This is a vital part of connectivity among data spaces of different domains, and even energy sub-domains. When vocabularies and data models are common, so that, semantically, communication among data spaces is possible, a federation service can connect the dots and provide functional interoperability while following the technical specifications for integration. There are many participants in the energy domain (e.g., TSOs, DSOs, Flexibility Service providers, retailers, RES operators, prosumers and consumers of various kinds), and each of them takes a different perspective on the operation of the energy system. One would be forgiven for thinking it will be challenging to orchestrate these organizations under a common technical data handling solution. However, by standardizing solutions and eliminating communication barriers among, it is possible.

The landscape of ontology work in the Smart Energy domain has been developed through the Ontology Catalog for Energy. Ontology-based IoT energy projects were analysed within the LOV4IoT-Energy ontology catalog [REF LOV4IoT-Energy paper[105][106]. A total of more than 58 projects (in July 2022) published from 2009 to 2022 were related to smart energy and the grid. The knowledge aggregation has been collected since 2012 and referenced within the LOV4IoT-Energy ontology catalog, as described in the following figure[107]:

Figure 27: LOV4IoT-Energy ontology catalogue



LOV4IoT-Energy Ontology Catalog
Reusing Domain Knowledge Expertise

Before to reinvent the wheel, maybe you can reuse the following existing ontologies referenced in this ontology catalog with minor modifications. Sometimes these domain ontologies, although very interesting, are not referenced yet on the Linked Open Vocabularies (LOV) since they need to follow more Semantic Web best practices.

The **LOV4IoT-Energy** ontology catalog references ontology-based research projects for Energy

Ontologies have been colored as follows:

The ontology will never be available (lost, confidential, etc.) :-(	We are waiting the response from the authors if they can publish the ontology online	Authors are publishing online the ontology (ongoing work)	Ontology published online but the Semantic Web best practices can be improved to be on LOV.	Ontology published online and referenced by LOV since Semantic Web best practices are adopted! :-)))
Nb onto:	Nb onto:	Nb onto:	Nb onto:	Nb onto:

More and more expertise and synonyms have been dealt with (e.g., smart grid, renewable energy, power plant, micro-grid, CIM, Flexibility, DSO, etc.). Tools to support the reuse of the analysis outcome (e.g., a dump of ontology code, web services, and web-based ontology catalogue) were also provided.

15 How to achieve cross-domain interoperability

With the digitalization of multiple domains, fostered by the recent advancements in data space deployments, more and more use cases consider simultaneous interactions between different sectors. Examples are given by the increasing research activities among energy and: (i) the manufacturing domain – for the synchronization of production planning with the optimized energy management systems (with the role of local distributed generation); (ii) transportation domain – to align the contingency operations of distribution grids with the power injections (real-time and forecasted) of public and private means of transport; and (iii)

[105] SAREF-Compliant Knowledge Discovery for Semantic Energy and Grid Interoperability IEEE World Forum on Internet of Things (WF-IoT) 2021. Amelie Gyrard, Antonio Kung, Olivier Genest, Alain Moreau https://hal.archives-ouvertes.fr/hal-03336052

[106] LOV4IoT: A second life for ontology-based domain knowledge to build Semantic Web of Things applications. International Conference on Future Internet of Things and Cloud (FiCloud 2016). Amelie Gyrard, Christian Bonnet, Karima Boudaoud and Martin Serrano

[107] http://lov4iot.appspot.com/?p=lov4iot-energy

smart cities domain – to include the control automation and power supply for facilities and services.

The Data Management working group of BRIDGE has analysed the impact and requirements for interoperability of the cross-sectorial use cases in the European energy data exchange reference architecture report [5]. The main contribution of this work is firstly the expansion of the SGAM model, which considers multiple sub-levels on each interoperability layer and the relevant components for the cross-sectorial deployments. These components consist of data models, initiatives, building blocks, etc. The goal of the proposed architecture is the facilitation of cross-sectorial data exchange, considering both the private and public data (including, for example, the relationship with implementing acts for data interoperability and regulations for data spaces).

Further analysis and updates by the BRIDGE Data Management working group are reflected in the successive document titled "European (energy) data exchange reference architecture 2.0" (DERA 2.0) [6]. To achieve cross-sectorial interoperability, particular focus is placed on the identification of common building blocks to be part of standardization activities, starting with data vocabulary.

The OPEN DEI initiative has also addressed the topic, publishing the document "Reference architectures and interoperability in digital platforms". As one of the fundamental recommendations for cross-domain convergence, the document indicates the agreement and standardization of a defined framework. This framework is composed of two construction processes: one for reference architecture and one for interoperability. The construction process for reference architecture follows the guidance specified by ISO/IEC JTC 1/AG 8, whereas the interoperability construction process is deployed according to the achievements of ISO/IEC JTC 1/SC41, and has two starting points:

- the **interoperability case**, corresponding to the justification and agreement of data exchange;
- The **interoperability point**, defined as the specific location in the process and system in which two entities exchange information.

The **interoperability profile** is created by the combination of the interoperability case and the interoperability point. This process, corresponding to the development of an interoperability solution, is shown in Fig. 21 (in which the specific example of the "digital twin" topic is considered). The process steps are: (i) the identification of an interoperability point (as the location in the system where interoperability is necessary), (ii) the description of the interoperability case (composed by justification and agreement), and (iii) the design of an interoperability profile that is implemented in the system.

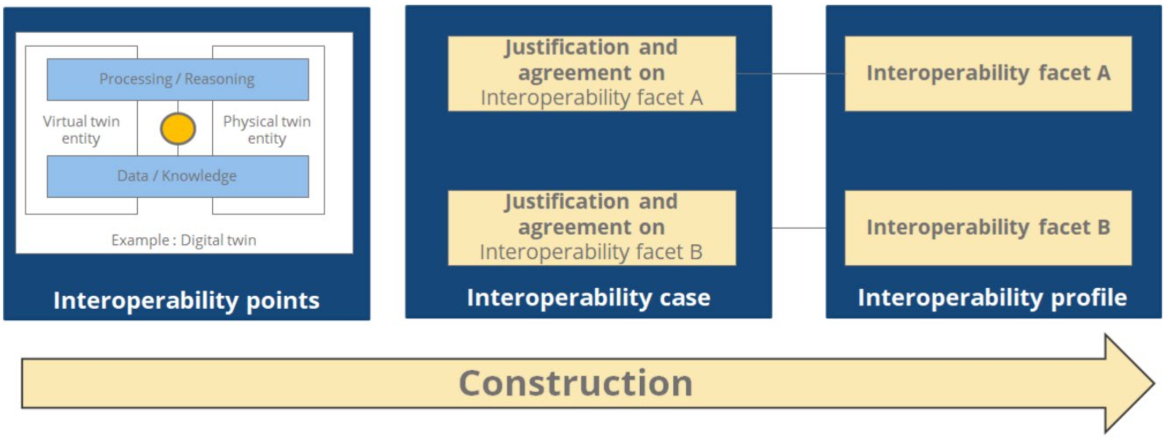


Figure 28: Process for the interoperability construction

Moreover, this process leads to the concept of an **interoperability framework**, defined as a structure of processes and rules that are combined to implement interoperability mechanisms. Each interoperability framework is specified by various aspects: the vertical sector to be addressed, the specific needs for the technology used (e.g., Artificial Intelligence or Digital Twins), and the interoperability facets (e.g., policy, semantic, syntactic, communication, etc.).

Efforts on the development of cross-sectorial interoperability frameworks have also been made by the National Interoperability Framework Observatory (NIFO[108]), which has defined the interoperability model shown in Figure 22. It is composed of four main horizontal layers, in particular:

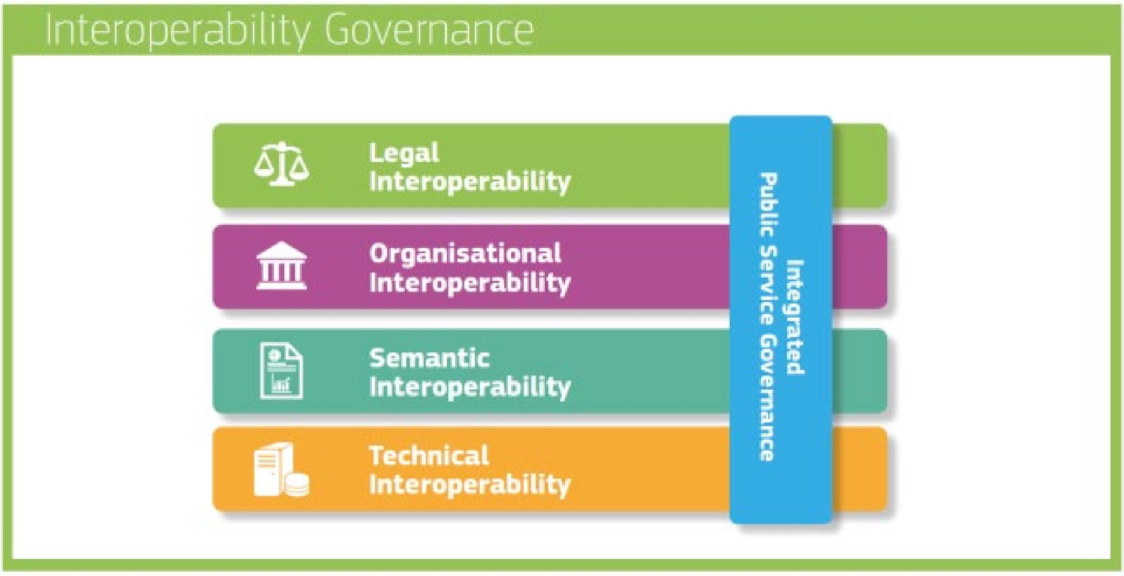
- **Legal interoperability,** addressing the common alignment of policies, legal frameworks, and strategies among different organizations;
- **Organizational interoperability,** specifying common goals and aligning business processes, expectations, and responsibilities;
- **Semantic interoperability**, including the syntactic aspects and addressing the exchanged data formats as well as their semantics (i.e., the preservation and understanding of shared information);
- **Technical interoperability**, defining the requirements of interfaces and deployed services as well as the security aspects and communication protocols.

Integrated public service governance, as a transversal cross-sectorial component, entails governance and coordination by the authorities, and has a mandate for planning, implementing, and operating the European services. **Interoperability governance**, as a background layer, corresponds to rules for the interoperability frameworks, institutional

[108] NIFO - National Interoperability Framework Observatory - 3. Interoperability layers. https://joinup.ec.europa.eu/collection/nifo-national-interoperability-framework-observatory/3-interoperability-layers

arrangements, roles and responsibilities, and organizational structures for ensuring interoperable systems at national and EU levels.

Figure 29: New European Interoperability Framework



Further focusing on the energy sector, the decarbonisation imperative drives the energy system towards a profound and fundamental transition from a centralised, fossil-fuel-based, highly-energy-consuming system to an energy efficient, more decentralised, renewable-energy-based and interdependent system. The growing number of distributed energy resources (DERs) connected to the network continuously expand the energy system "edge", in terms of controllability and operational complexity. The progressive decentralization, which is also accompanied by the introduction of new digitalized assets, not only energy ones but also introduced from other sectors (e.g. electric vehicles), poses significant challenges for the resilience of the system, while introducing increased uncertainty in traditional control routines, given the stochastic and intermittent character of renewable generation and the new control variables (not currently addressed in existing tools for the system management) introduced by new assets.

This progressive transition drastically affects the accuracy of physical models currently utilized for monitoring and planning the operation of energy systems. Under these circumstances, energy systems need to evolve towards integrated ecosystems and, more specifically, integrated and cross-sector data value chains, to enable the data-driven optimization at system and DER level in a coordinated manner, by stepping on trustful data (intelligence) sharing models that will increase stakeholders' data outreach, enhance their intelligence and facilitate the realization of innovative energy services for optimizing energy performance, reducing energy costs, enhancing sustainability and improving operations in a resilient manner, across the value chain.

Today we observe a mesh network of stakeholders transforming the traditional top-down and centralized system management approach into a more horizontal one based on transversality, in which every decision needs to be both individual and collective.

Consequently, the need for "end-to-end" coordination between the energy sector stakeholders and beyond, reaching also to the mobility sector, not only in business transactions but also in exchanging data between them is becoming a necessity for safeguarding energy networks' stability and resilience under increased electrification and decarbonization terms. Such coordination between cross-sector stakeholders lies also in the heart of the Integrated European Electricity Market, which prioritizes motivating e-mobility stakeholders (i.e. Charging Point Operators and EV owners) to obtain an ever-increasing role in the energy system and transform themselves into flexibility service providers.

The progressive penetration of EVs across energy systems and networks introduces new challenges for the resilience of the system since they continuously gain in (i) significance when it comes to energy consumption and (ii) criticality for system resilience, considering that the electrification pace of the mobility sector does not coincide with capacity upgrades across electricity networks. In this context, e-mobility assets shall no longer be perceived as external passive elements of the energy system, but they need to be effectively integrated as active nodes that can effectively contribute to its optimized operation since:

- they are a huge source of flexibility able to support distribution and transmission system operators with the needed services to balance demand & supply and manage power quality and system resilience, and, at the same time,
- They are associated with the generation of vast amounts of data, becoming increasingly essential for improving observability and orchestrating the resilient operation of a decentralized and complex energy system that effectively achieves the decarbonization advantages that come with the increasing penetration of RES and the progressive electrification of the mobility sector.

Transparent, non-discriminatory and secure cross-sector data exchanges between energy and mobility data value chain actors are becoming a necessity towards increasing observability across the edges of the energy system, advancing knowledge around the assets involved in decentralized networks and introducing valuable insights for their operational orchestration and optimization, considering, previously, non-accessible critical information. Improved accessibility and sharing of high quality and resolution data in an interoperable manner is key towards (i) optimizing the "end-to-end" orchestration of energy systems; (ii) introducing innovative energy services to the involved stakeholders; and (iii) empowering mobility stakeholders to get equally and effectively involved in energy markets.

This Cross-sector integration of the energy and mobility sectors is tightly linked to the emergence of Energy Data Spaces that need to act as the facilitators for the data-driven end-to-end optimization of energy systems through the simultaneous integration with the mobility sector under robust interoperability terms. This will allow Electricity Network Operators (DSOs, TSOs) to obtain access to detailed data (and intelligence insights) from e-mobility assets residing across the different edges of the system, which will be fused and processed together with energy and network data to enable the identification of anticipated congestions, voltage or frequency violations and define the requested amount of flexibility that will need to be triggered for ensuring the reliable operation of Transmission and Distribution networks. In turn, such requirements can drive the definition of Virtual Power Plants (VPP) optimal trading strategies effectively (i) consolidating Distributed Energy

Resources (DERs) and EVs for providing the requested flexibility to the Network Operators and (ii) triggering targeted control strategies over selected flexible assets, including the smart bi-directional charging of electric vehicles considering evolving spatio-temporal network requirements for upward or downward flexibility provision.

16 Conclusions and next steps

This paper provides a comprehensive analysis of the ongoing activities towards the deployment of data spaces in the energy sector, with a specific focus on interoperability.

The initial sections describe the current digitalization of energy systems and highlight the demanding requirements of time resolutions when deploying real-time operations. We then present the contributions from the cross-domain and energy-specific initiatives, and detail which contributions enhance the interoperability of smart grids. A preliminary conclusion is that standards are fundamental to interoperable devices from different manufacturers while avoiding vendor lock-in, enhancing scalability, and ensuring data protection and cybersecurity.

Furthermore, the paper also discusses the benefits of interoperability for various stakeholders in the energy domain. This is essential to encourage the participation of these stakeholders and therefore extract maximum value from energy data space implementations.

The paper separately analyses the technical, semantic aspects and legal aspects of interoperability. Technical interoperability corresponds to the necessary building blocks, actors, and data formats. It emerges that, for a successful federation of different data spaces, compatibility among different data connectors, services, and trust frameworks must have the highest priority. Semantic interoperability relates to the ability of different systems to exchange and interpret information. The main challenge for the energy domain is the enormous variety of devices, assets, and applications. It is therefore necessary to place additional effort on the mapping of ontologies and data models (starting from well-established solutions as CIM). Legal interoperability involves the transformation of the complexity of legal obligations into actionable policies with digital representations that systems can use. These representations can help organizations navigate complex regulatory landscapes, ensuring compliant, efficient, and scalable data sharing and pave the way for federated data spaces.

The architecture of energy data spaces being deployed at the European level (e.g., Horizon projects as Innovation Actions) allows for the identification of their SYNERGIES and differences. It is particularly important to identify the common ground for use cases in the context of a common European energy data space (CEEDS). The work of the projects towards demonstrating a CEEDS based on five different System Use Cases also demonstrates how interoperability can be realised for federated data spaces. New projects from the Energy Data Spaces Cluster, like ODEON[109] and Hedge-IoT[110], already leverage the achievements and

[109] ODEON PROJECT
[110] Hedgeiot

developments described in this paper. These projects build upon the established frameworks, contributing to the ongoing evolution and practical deployment of interoperable energy data spaces.

As the energy sector becomes increasingly coupled with other sectors such as transport and manufacturing, utmost importance should be assigned to work on common vocabularies and data models which can foster the benefits of federation services for cross-domain solutions.

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