INTERNATIONAL DATA SPACES ASSOCIATION

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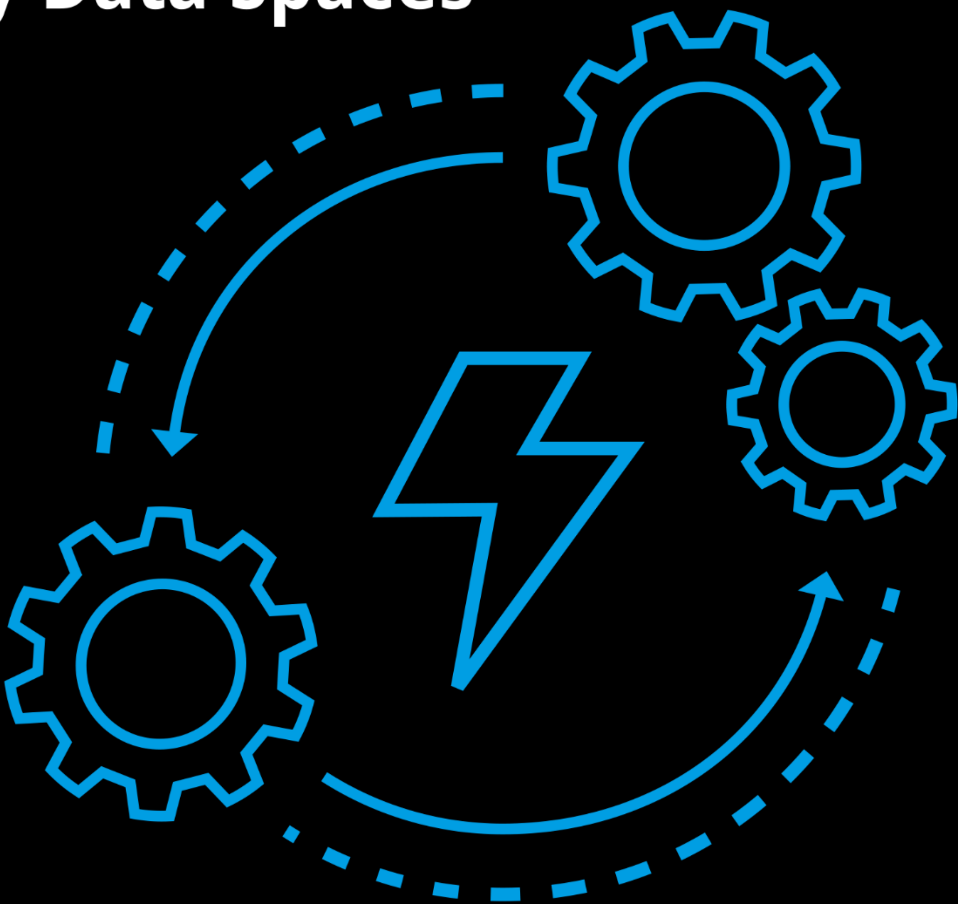
Interoperability Framework in Energy Data Spaces



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Contributing Projects

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omega-x

SYNERGIES

EDDIE
EUROPEAN DISTRIBUTED DATA INFRASTRUCTURE FOR ENERGY

Data cellar

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1 Introduction

1.1 Purpose of this paper

The purpose of this paper is to define a framework for achieving technical and semantic interoperability between data spaces in the energy domain. To accomplish this, it takes the work of the HORIZON-CL5-2021-D3-01 projects as its foundation, and describes the state of the art, and the challenges specific to this context.

1.2 Relationship with other 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.

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

According to the definition of the Data Spaces Support Centre (DSSC)[2], 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".

[1] https://ec.europa.eu/isa2/eif_en/
[2] https://dssc.eu/

In upcoming iterations, this paper will contribute to the blueprint with the documentation of the building block implementations in the selected use cases.

1.2.3 IDSA Semantic Interoperability paper (to be published)

The IDSA Semantic Interoperability paper focuses on the semantic interoperability aspects of data spaces. It describes the IDSA approach to semantic interoperability that can be applied to all domains. The energy interoperability framework extends this work to adapt it to the energy domain.

2 Overview of interoperability in the energy domain

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 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.

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 found out as early as 2010 that issues of technical integration 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[3], 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[4].

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 in a suitable manner 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 tremendous 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”[5], 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.

[3] Standardisation Mandate Smart Grids (cencenelec.eu)
[4] https://syc-se.iec.ch/#about
[5] EU action plan for digitalising the energy system https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0552&qid=1666369684560

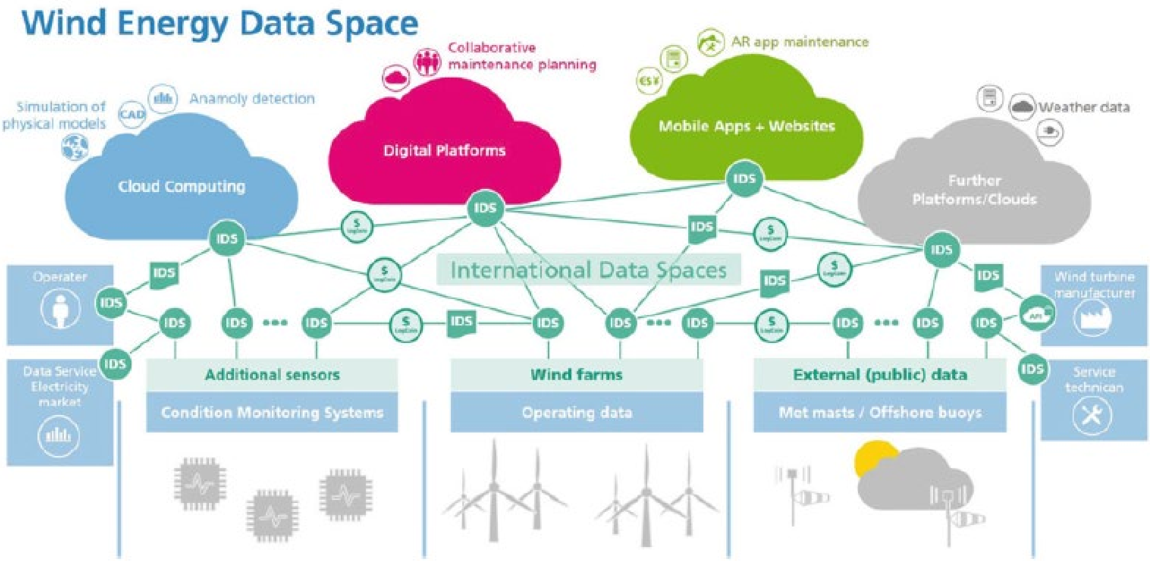

Figure 1: Data exchange in an energy data space for predictive maintenance[6]

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) – is of utmost importance, as reported in the Data Spaces for energy, home and mobility OPEN DEI paper [7](also known as the OPEN DEI energy domain report). 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 to data spaces' increasing utility in wholesale 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 [8]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, in order to achieve maximum efficiency in

[6] Energy Data Space. https://www.springerprofessional.de/energy-data-space/23291854
[7] OPEN-DEI-Energy-Data-Spaces-EHM-v1.07.pdf (opendei.eu)
[8] FG_DemandResponse.pdf (europa.eu)

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 semantic data model for semantic interoperability has been proposed by SEDMON[9] (Semantic Data Models Of Energy), under the PLATOON project[10]. SEDMON facilitates information exchange among stakeholders' applications and services, favoring 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[11], addressing different applications such as smart energy, smart cities, and smart buildings.

3 Role of each initiative in the contribution to interoperability

Interoperability in data spaces is a wide topic that can be covered from different angles. This chapter describes the approach of IDSA, FIWARE and GAIA-X.

IDSA focuses strongly on technical and semantic interoperability and, with the IDS Rulebook, offers 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):

[9] 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
[10] https://platoon-project.eu/
[6] https://smartdatamodels.org/

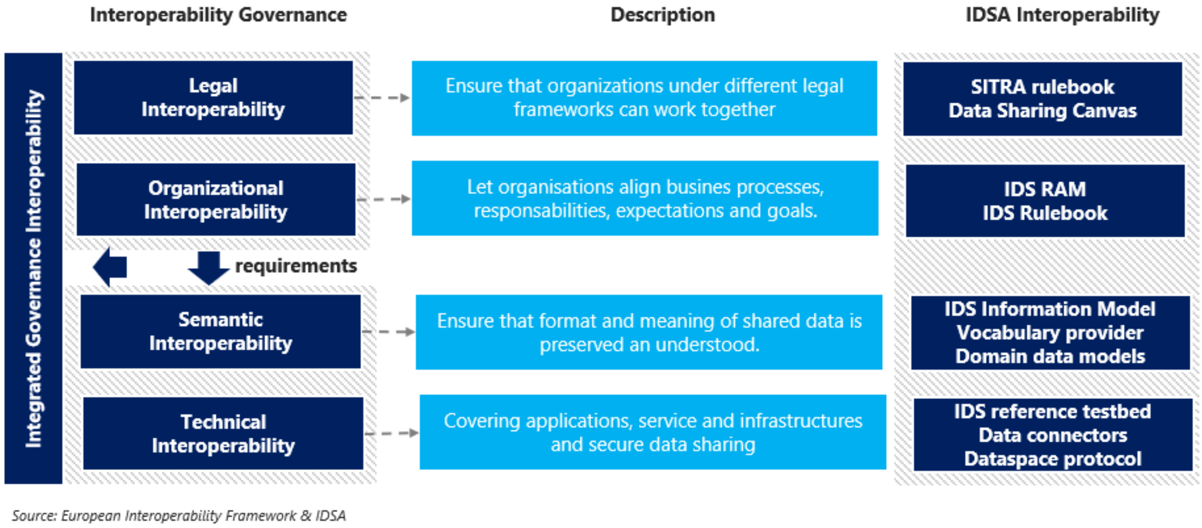

Figure 2: IDSA assets that support interoperability

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 dconnectors, as defined in the IDS RAM (README – IDS Knowledge Base (internationaldataspaces.org)) and described in the IDSA Data Connector Report (Data Connector Report – International Data Spaces).

The Dataspace Protocol 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*. (Dataspace Protocol v0.8 – IDS Knowledge Base (internationaldataspaces.org)

The IDS reference testbed 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. (GitHub – International-Data-Spaces-Association/IDS-testbed)

The approach of IDSA with regards to semantic interoperability is described in the paper "Semantic Interoperability" (to be published). 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 (Introduction – IDS Knowledge Base (internationaldataspaces.org)) and IDS RAM.

3.2 FIWARE

FIWARE achieves interoperability primarily through the use of defined open APIs (NGSIv2 and NGSG-LD) [12]and Smart Data Models (SDM), facilitating the exchange of information among a diverse set of systems, services and components.

[12] NGSI-LD FAQ - Fiware-DataModels

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 enablers13 (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[14.]
- 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.

3.3 GAIA-X[15]

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

3.3.1 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 operationalized;
- infrastructures – i.e., hardware and software for compute, storage, network services – adopting the governance;

[13] https://www.fiware.org/catalogue/
[14] https://www.etsi.org/
[15] Gaia-X Architecture Document - 22.10 Release

- 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.

3.3.2 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 Act16, 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.

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[17][18]", which is a summary – with a less regulatory view – of the ISGAN Annex 6 report on Interoperability for Smart grids[19]. 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.

[16] Data Governance Act explained | Shaping Europe's digital future (europa.eu)
[17] Predictive maintenance für Windenergieanlagen-Energy data space whitepaper. Dortmund. https://internationaldataspaces.org/download/19022/
[18] A case study research on interoperability … | Open Research Europe (europa.eu)
[19] ISGAN Word Template - Preview (iea-isgan.org)

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 ultimately 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 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 eIDAS Regulation, an EU law, establishes a legal framework for electronic identification, authentication, and trust services across member states. Its goal is to create a seamless and secure digital environment for cross-border electronic transactions by recognizing and accepting electronic identification methods, like electronic IDs (eIDs). This ensures the legal binding and recognition of electronic signatures, seals, time stamps, and other trust services throughout EU member states.

In essence, eIDAS adoption in all member states would allow end-users to authenticate themselves using their standard social security service digital identities, irrespective of their location. This enables companies to offer services in other member states in a fully authenticated and trusted manner, representing natural persons by natural persons and legal persons by natural persons. This also streamlines authentication for data-sharing infrastructure operators and covers scenarios such as changing a company's managing director, eliminating the need for each platform to manage its own credential infrastructure.

The regulation establishes mutual recognition of electronic identification and trust services, promoting cross-border interoperability. It empowers individuals and businesses to access digital services securely and conveniently, fostering trust in the digital ecosystem by setting authentication and electronic transaction standards. The European Trust List, created by eIDAS, lists trusted service providers and their qualified trust services, encouraging advanced electronic signatures and secure electronic authentication methods. Public and private organizations across the EU can provide electronic identification services with legal certainty. Moreover, eIDAS ensures personal data and privacy protection during electronic transactions, harmonizing legal and technical requirements across member states.

This regulation also bolsters the development of innovative digital services and e-commerce in the EU. It contributes to the Digital Single Market by removing barriers to cross-border digital transactions and enhancing trust in the digital landscape.

In summary, the eIDAS Regulation is an EU law that establishes a legal framework for electronic identification, authentication, and trust services. It aims to facilitate cross-border digital transactions, promote trust and confidence in the digital ecosystem, and harmonize the legal and technical requirements for electronic identification and trust services across member states.

The Implementing Acts following Article 24 of Directive (EU) 2019/944 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 white paper

- Reference Architectures and Interoperability in Digital Platforms: 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.
- IDSA Semantic Interoperability Paper: 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 modeling, vocabulary alignment, and ontology development. It emphasizes the need for common data models and semantic representations to enable seamless data sharing and understanding between 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.
- DSBA Technical Convergence Discussion Document[20]: 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.
- Data Spaces Landscape [21](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[22]: The OpenDEI (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 health-care. The

[20] Data-Spaces-Business-Alliance-Technical-Convergence-V2.pdf
[21] IDSA-Position-Paper-Data-Spaces-Landscape-1.pdf (internationaldataspaces.org)
[22] Design Principles for Data Spaces | Position Paper (design-principles-for-data-spaces.org)

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 OpenDEI 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: 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[23]: 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 centers, while the services layer offers various data-centric services. The data layer focuses on data sovereignty, 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)[24]: 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)[25], the organization and governance structure of energy data exchange in the Netherlands (through MFF-BAS[26]), and Spanish AELEC[27]-led architectures for their services Datadis (aggregated grid data and meter data sharing) and SIORD (real-time data sharing for significant grid users).

[23] Gaia-X Conceptual Model - Gaia-X Architecture Document - 22.10 Release
[24] ISO/IEC JTC 1/SC 41 - Internet of things and digital twin
[25] EDA
[26] Home - MFFBAS
[27] Inicio - aelec

4.2.3 Interoperability in the Energy Domain

- EG1 Report Towards Interoperability within the EU for Electricity and Gas Data Formats and Procedures (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 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[28] - 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

[28] ISGAN - Homepage (iea-isgan.org)

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[29]: 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.

4.3 Standards

Given the smart grid roadmaps and other documents prepared over the last decade, it is clear that, along with security measures, the following five core technical standards will be needed to integrate systems in a smart grid of the future.

1. IEC 61850: This standard defines the communication protocols and data models for the integration of intelligent electronic devices in substations and power systems. It enables seamless interoperability between various components of the grid.
2. 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.
3. OpenADR: 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 signals.
4. IEC 62351: This standard 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.
5. IEC 61968/61970/62325: 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 different aspects of the grid, including assets, networks, and market operations.

[29] D3.12.f_BRIDGE-TSO-DSO-Coordination-report_0.pdf (europa.eu)

An introduction to these smart grid standards can be found in the Energy Data Space paper[30], the European energy data exchange reference architecture defined by BRIDGE[31], and in the European (energy) data exchange reference architecture 2.0[32], which describes why standardization is of high interest for the critical infrastructure and which standards demand the greatest attention (i.e., the IEC 61850 and IEC 61968/61970/62315 series).

4.3.1 ETSI Smart Applications REFerence Ontology (SAREF):

- 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.

4.3.2 IEC

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

4.3.2.1 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 center 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).

4.3.2.2 IEC System Committee Smart Energy

The IEC System Committee Smart Energy 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 62559 series: a series of documents associated with use case methodology. This series leverages several M/490 results.
- IEC 62913 series: use case methodology associated with smartgrids. IEC 62913-1 has introduced business use case and system use case, which has been leveraged by

[30] Energy Data Space. https://www.springerprofessional.de/energy-data-space/23291854
[31] 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
[32] European Commission, Directorate-General for Energy, Kukk, K., Kotsalos, K., European (energy) data exchange reference architecture 2.0: Data Management Working Group: June 2022, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2833/142689

several European projects (e.g., EvolvDSO, TDX-ASSIST, EU-SysFlex, and energy data space projects such as OMEGA-X).

- IEC 63200: smart grid architecture model basics. This document leverages the M/490 SGAM proposal.
- IEC 63417: a guide and plan to develop a unified IEC Smart Energy Ontology. Trialog and EDF are participating in the development of this standard.

4.3.2.3 IEC TC 57

The IEC Technical Committee 57 is focused on developing international standards for power systems 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 the21eveloppment and maintenance of standards, the IEC TC 57 contri'utes 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 61979, IEC 62325) and IEC 61850. It is also developing IEC 60870. These standards are described below.

- IEC 62357-1represents the power systems reference architecture. Its latest version is based on the Smart Grid Architecture Model.
- 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 modeling, 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 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 modeling, 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 61968-1 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.
- IEC 61968-1represents 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) contains the following IEC 61970 International Standards needed to cover the Common Grid Model Exchange Specification (CGMES): ENTSO-E, which is developing the CGMES library and standardizing it through IEC; and CGMES, which 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. It will also be the technical specification for a European and regional grid-planning study.
- IEC European Style Market Profile (ESMP) is a set of standards (IEC 62325-351, IEC 62315-451 series) supporting European Market regulation. ENTSO-E is developing the Electronic Data Interchange (EDI) 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. They have been described (using webinars and guides) by the BRIDGE Standards User Group as they originated in the FP7 Flexiciency European Project.

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

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

4.3.4 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[33]. 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 behavioral interoperability. It covers the case of trusted data sharing. As a result, SC41 is currently working on three projects:
- PWI JTC1-SC41-8 – Behavioral 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.

4.3.5 IEEE

- https://standards.ieee.org/ieee/3158/10881/
  The P3158 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 matrix systems, fostering confidence in the accuracy and integrity of the data stored within these matrices.

4.3.6 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 modeling, and standardized information models, allowing for efficient and standardized data exchange. OPC UA promotes interoperability, simplifies 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.

[33] Document published in September 2022. https://aioti.eu/wp-content/uploads/2022/09/AIOTI-Guidance-for-IoT-Integration-in-Data-Spaces-Final.pdf

4.3.7 CEN/CENELEC

- Coordination Group on Smart Grids (CG-SG): 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. Its aim is to promote the deployment of open and interoperable data architectures, based on European and international standards.
- **Workshop Trusted data transactions** The CEN CENELEC workshop on "Trusted Data Transactions" focused on the secure and reliable exchange of data in various domains. The workshop aimed to address the challenges and opportunities associated with trusted data transactions, particularly in areas such as cybersecurity, privacy, and data protection. Participants discussed the importance of establishing trust in data transactions to ensure integrity, authenticity, and confidentiality. The workshop explored topics such as secure data exchange protocols, encryption mechanisms, identity management, and certification frameworks. Participants shared best practices, experiences, and case studies related to trusted data transactions. The workshop aimed to promote collaboration among stakeholders, including industry experts, regulators, and researchers, to develop standards and guidelines that enhance the security and trustworthiness of data transactions across different sectors. Ultimately, the workshop aimed to foster trust and confidence in the digital ecosystem by addressing the technical, legal, and organizational aspects of trusted data transactions.

4.3.8 SGAM and GWAC Stacks

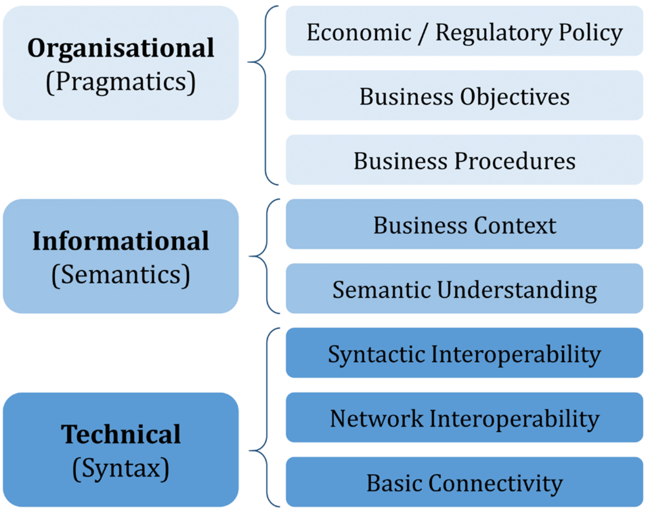

Figure 3: The GWAC-Stack1

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

The SGAM is a reference model developed by the International Electrotechnical Commission (IEC) to provide a standardized framework for understanding, describing, and analyzing 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.

On the other hand, the GWAC Stack is a conceptual framework created by the Grid Wise Architecture Council (GWAC) 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.

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.

The SGAM was born at the time of the European mandate M/490.

Its formalization happens first through the CEN-CENELEC-ETSI Smart Grid co-ordination group (now called SEG-CG as Smart Energy Grid co-ordination group).

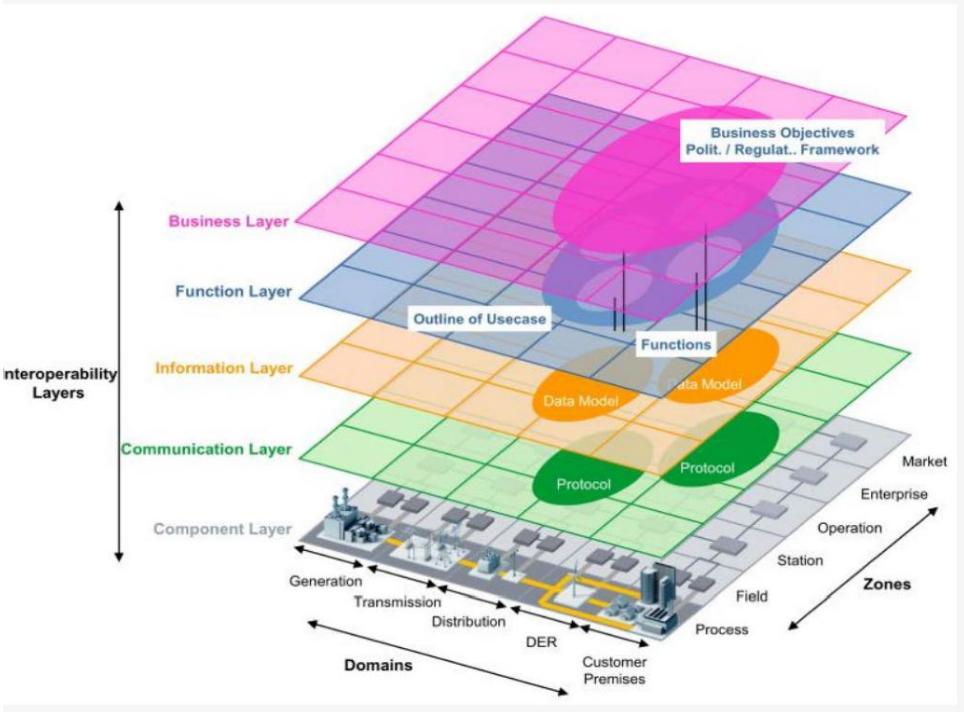

Figure 4: The SGAM architecture

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 Systems 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.

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 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 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 the 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 Data space governance and interoperability

According to the DSSC definition, the Data Space Governance Framework[34] encompasses a set of principles, standards, policies (rules/regulations), agreements, and practices. These are applicable to the governance, management, and operations (encompassing both

[34] 2. Core Concepts - Glossary - Data Spaces Support Centre (dssc.eu)

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, it is imperative that we delve deeper into this aspect of governance. OPEN DEI[35] 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.

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 5: 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[36], as defined by the Design Principles for Data Spaces.

[35] Microsoft Word - 2022.10.26_Building Blocks assessment report_draft_3 (internationaldataspaces.org)
[36] Guiding Principles - IDS Knowledge Base (internationaldataspaces.org)

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 6: Four layers describing data spaces governance

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;
- should be integrated as an integral part of a European roadmap including further standards and supporting organizations (similar to 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 7: 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.
- 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.
- Technical interoperability, on the other hand, deals with applications and infrastructures linking systems 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[37].

6 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
- Actors
- Data formats

[37] Dataspace Protocol v0.8 - IDS Knowledge Base (internationaldataspaces.org)

- Data transmission protocols

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

6.1 Building blocks description

The Data Spaces Business Alliance (DSBA) has recently published a convergence paper[38] defining nine main building blocks grouped into three main categories based on the Design Principles for Dataspaces defined by OPENDEI[39] :

1. Data Interoperability:

- Data Models & formats: A common format for data model specifications and data exchange should be used to describe all information required for the performance of a data exchange.
- Data Exchange protocols: Sharing and exchange of data, i.e., data provision and consumption, between participants of a data space, and among data spaces, should follow common exchange protocols.
- Provenance & Traceability: Tracing and logging all functions and transactions is important for the process of identification in data provision and consumption.

2. Data Sovereignty and Trust

- Access & Usage Policies Control: Enforcement of data access and usage policies are required at the time of data resources and services publication, to prevent misuse of resources and data.
- Identity Management: Acknowledged identities ensure identification, authentication and authorization of stakeholders in a data space, to enable access and usage control.
- Trust Services: Ensuring that in data exchange, participants really are who they claim to be.

3. Data Value Creation:

- Data & Services Offering Creation: Comprising capabilities for publishing data resources following broadly accepted standards and harvesting data from existing platforms.
- Publication and Discovery: Using domain-agnostic and domain-specific descriptions for publishing and discovery of data resources and services.
- Marketplace and Usage Accounting: Offering of data resources and services, and management of processes linked to the creation of smart contracts and access to data/services.

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[38] https://data-spaces-business-alliance.eu/wp-content/uploads/dlm_uploads/Data-Spaces-Business-Alliance-Technical-Convergence-V2.pdf
[39] https://design-principles-for-data-spaces.org/

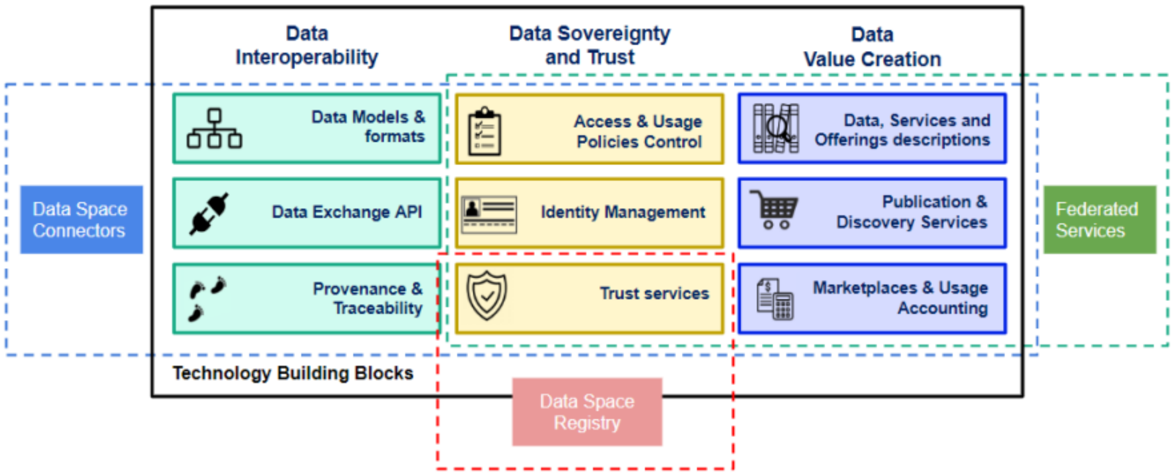

Figure 8: OPEN DEI building blocks

Each of these building blocks have specific instantiations in one or more components according to different reference architectures (e.g., Federated Catalogue in GAIA-X, IDS Connector, FIWARE Context Broker).

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. In fact, 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 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 has recently shared a snippet of the blueprint with the definition and scope of the main building blocks related to data sovereignty and trust, namely, Identity Management, Trust Framework and trust Anchors, and Access and Usage Policy enforcement[40].

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. At the moment 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[41] built by deltaDAO[42].

[40] https://dataspacessupportcentre.atlassian.net/wiki/spaces/CoP/pages/69402637/BLUEPRINT+-+REVIEW+AND+FEEDBACKS
[41] https://portal.minimal-gaia-x.eu/search?sort=_score&sortOrder=desc&text=.
[42] https://www.delta-dao.com/

6.2 Actors

Apart from the building blocks, it is important to have a common definition of actors and their possible interactions. The DSBA has recently published the technical convergence paper[43] where the main actors have been defined:

- Data Space Governance Authority
- Data Space
- Participant
- Participant Agent
- Data Space Registry
- Credential Issuer
- Identity Provider

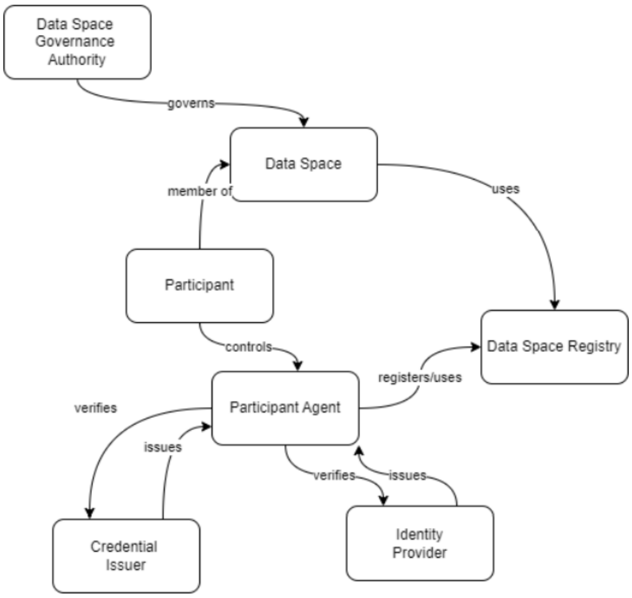

Figure 9: DSBA definition of main actors

6.3 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)

[43] https://data-spaces-business-alliance.eu/wp-content/uploads/dlm_uploads/Data-Spaces-Business-Alliance-Technical-Convergence-V2.pdf

- Express one or more directed graphs, such as a social network in a single document

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

6.4 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. In fact, 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.

In this sense, IDSA, along with other organizations such as Microsoft, are currently working on the definition of the Data Space Protocol[44]. In this sense, they differentiate 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.

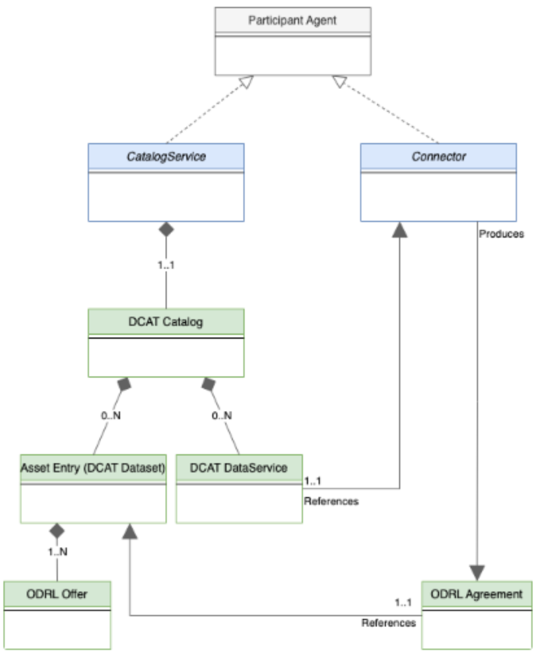

Figure 10: IDS Dataspace protocol: relationships between Participant Agent types

44 https://internationaldataspaces.org/dataspace-protocol-ensuring-data-space-interoperability/

6.5 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?
- 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?)

7 Semantic interoperability

In the European Research Cluster on the Internet of Things (IERC[45]) and IoT Semantic Interoperability Best Practices[46], four kinds of interoperability are distinguished: syntactical interoperability, technical interoperability, semantic interoperability, and organizational interoperability. IERC AC4 interoperability is illustrated by the following figure:

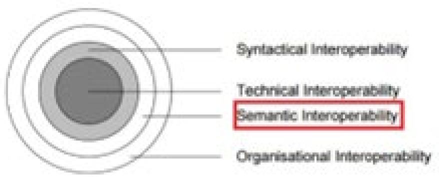

Figure 11: Four types of interoperability

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.

[45] 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
[46] IoT Semantic Interoperability Best Practices

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.
3. Decision-Making: Accurate and consistent information is vital for effective decision-making in 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.

7.1 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 from the definition of sectorial Common Information Models, (acting as the sectorial harmonization instruments) and extend to the 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.

7.2 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 to be 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 in order to avoid silos. External systems cannot know about the 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].

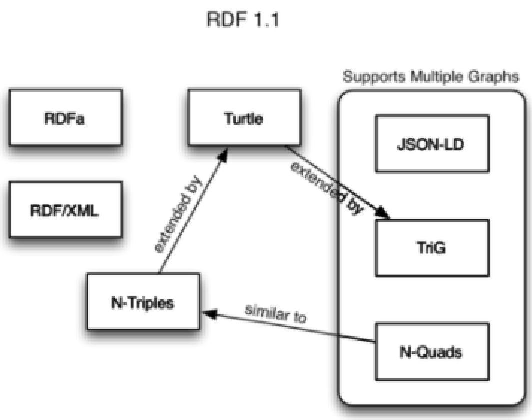

Figure 12: Syntaxes for RDF

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 link semantics to marketplaces for data /service offering discovery.

7.3 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), 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.

8 Reference Architecture of Energy Projects

8.1 OMEGA-X Reference Architecture

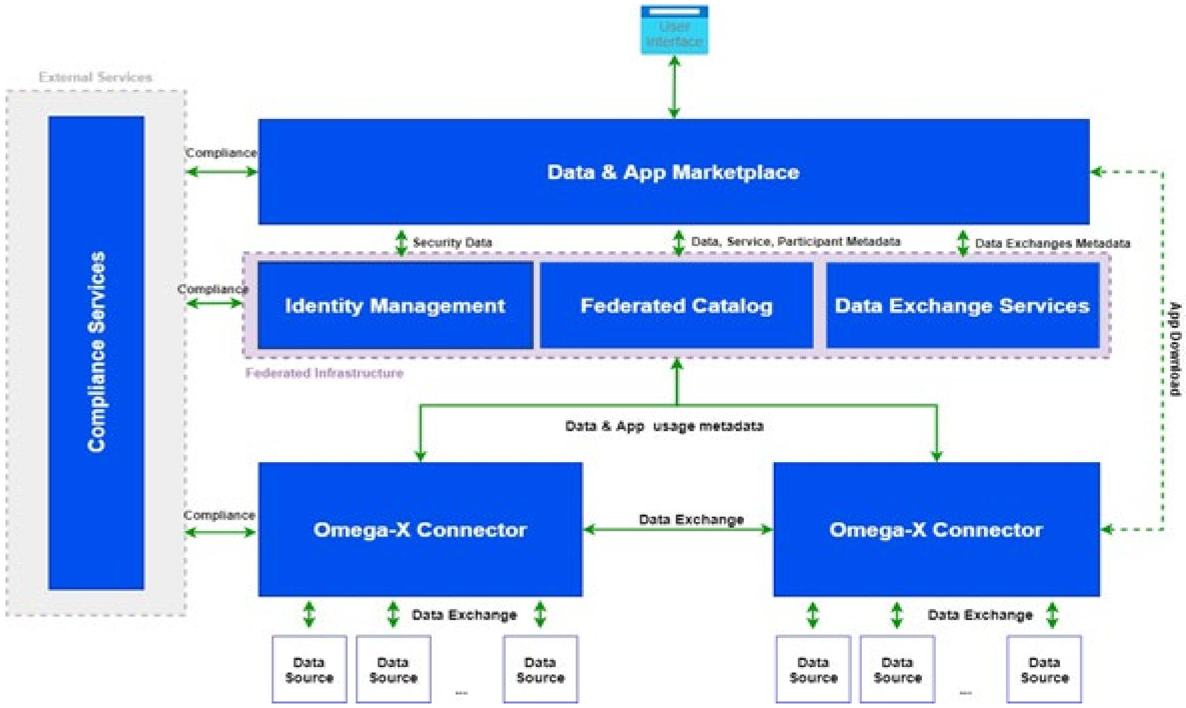

Figure 13: OMEGA-X Reference Architecture

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 to standardization on policy and behavioral interoperability for data spaces.

8.2 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 OpenDEI building blocks is depicted in Figure 15.

The five horizonal 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.

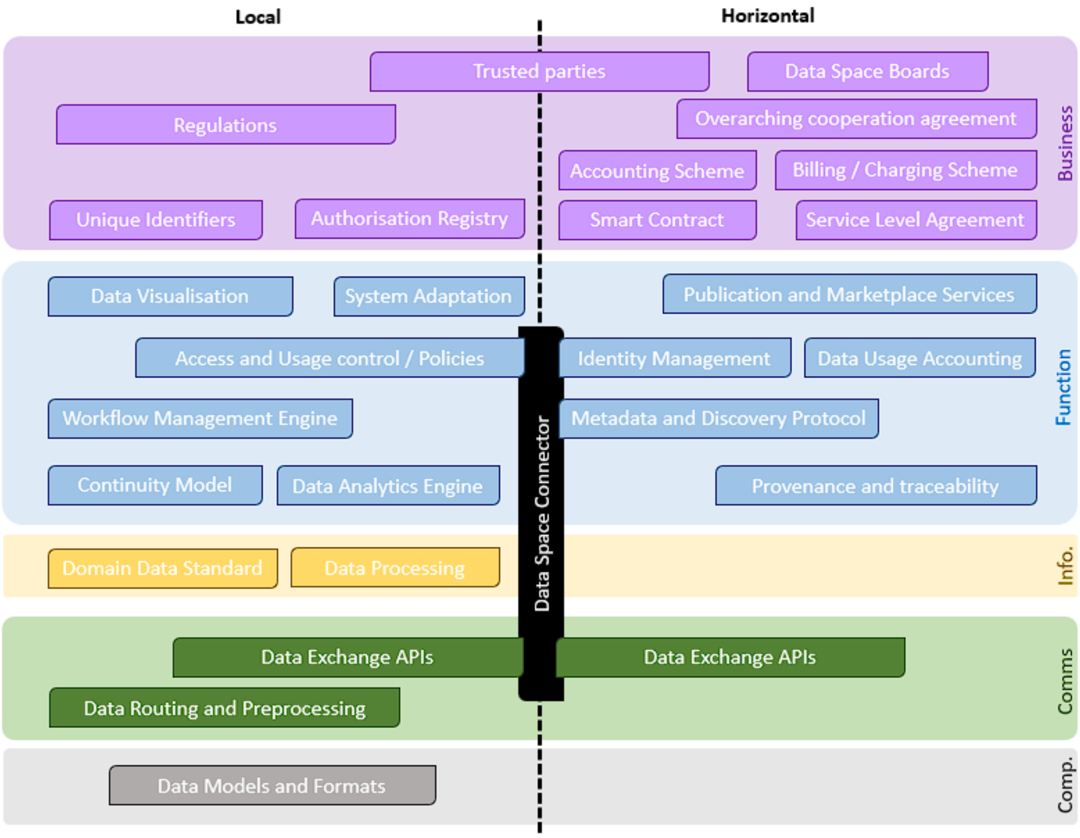

Figure 14: First draft of the Data Space Reference Architecture for ENERSHARE

More precisely, figure 16 presents a low-level view of ENERSHARE's proposal for the functional components of the two lower layers that deal with semantic interoperability.

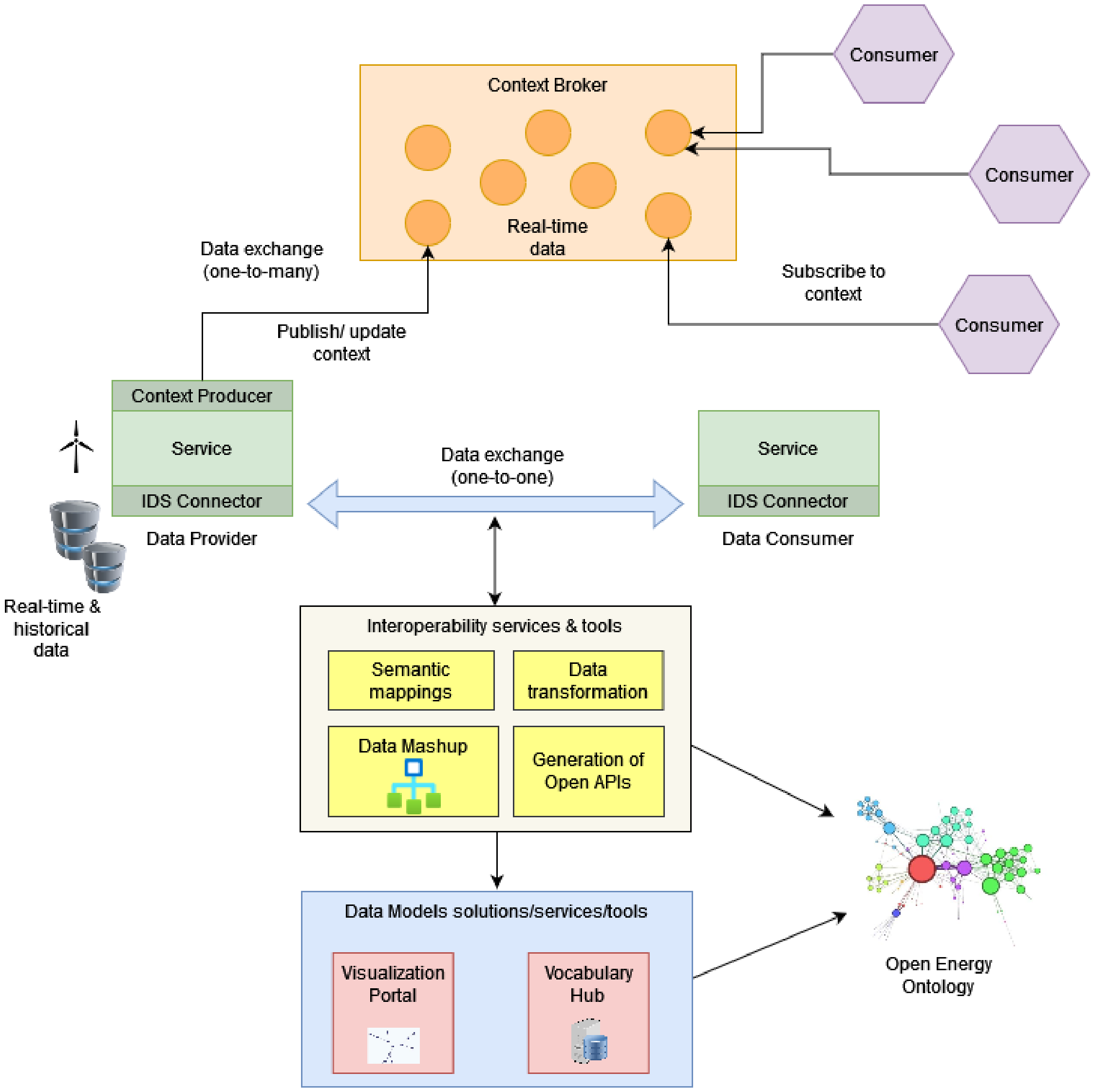

Figure 15: Functional components for data interoperability in ENERSHARE

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.

8.3 DATA CELLAR Reference Architecture

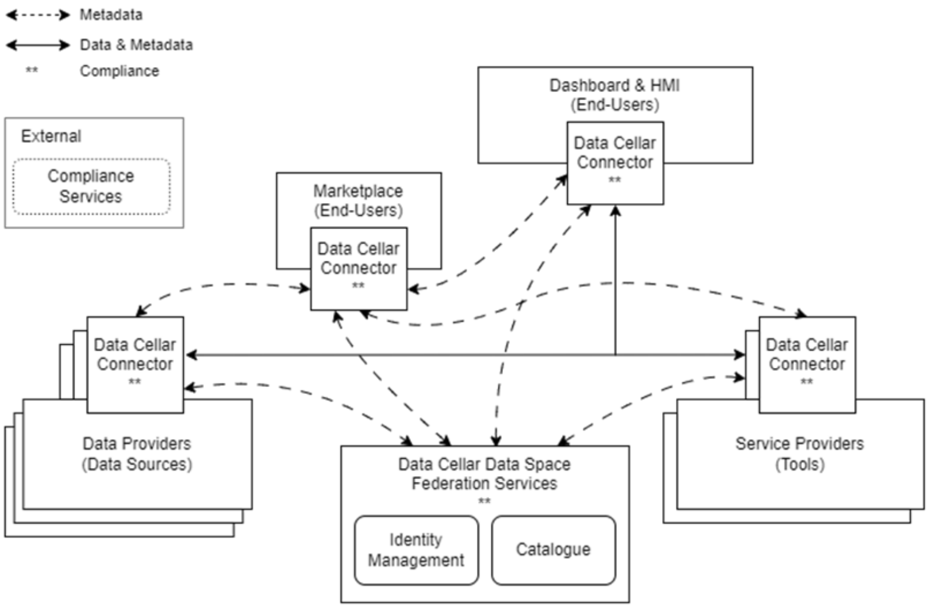

Figure 16

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.

8.4 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 different sources of the energy data value chain, shares data in a centralized or federated manner (depending on the data provider's preferences),s and gain previously unattainable, data-driven insights and added value. Meanwhile it while allows for greater security, autonomy, and flexibility. It relies on the seamless communication and cooperation among:
    a. The **Cloud Infrastructure** that lies at the core of the whole SYNERGIES Energy Data Space and essentially 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.
    b. The Data Fabric Environments that essentially represent the stakeholders' energy data spaces in which the energy data value chain stakeholders are able to integrate, host, analyse, and serve/share their data assets in an easily consumable manner. Such environments may reside:
        i. 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 dedicated, isolated, and secure. Such environments are spawn on demand for each organization at any time and may dynamically scale depending 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;
        ii. in a federated manner in the SYNERGIES On-Premise Environments. These that allow stakeholders to bring their own 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 own 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 in order 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).

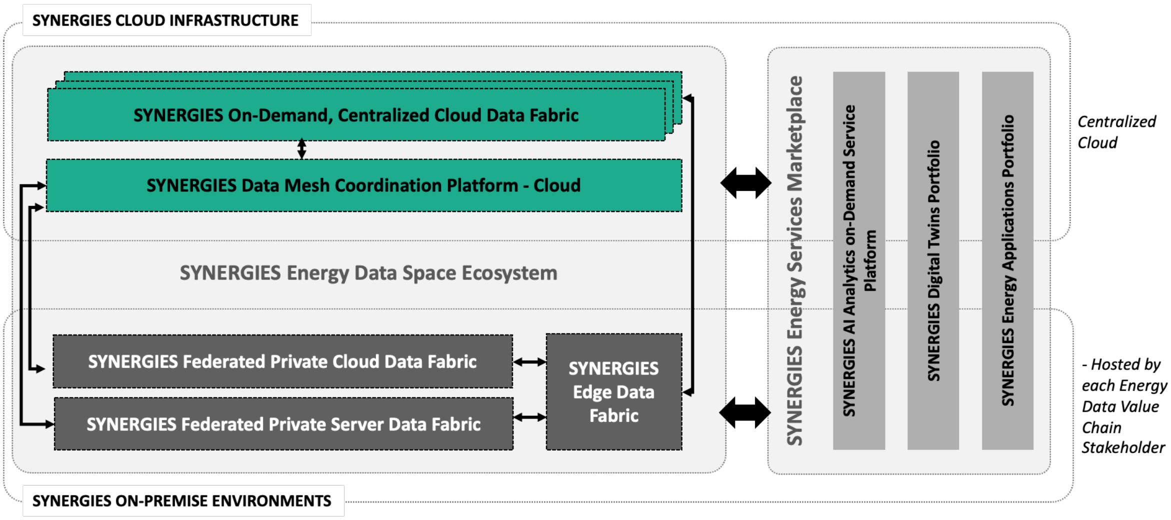

Figure 17: SYNERGIES Reference Architecture Layers

8.5 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 19, 2) to *EDDIE Framework* users will be started.

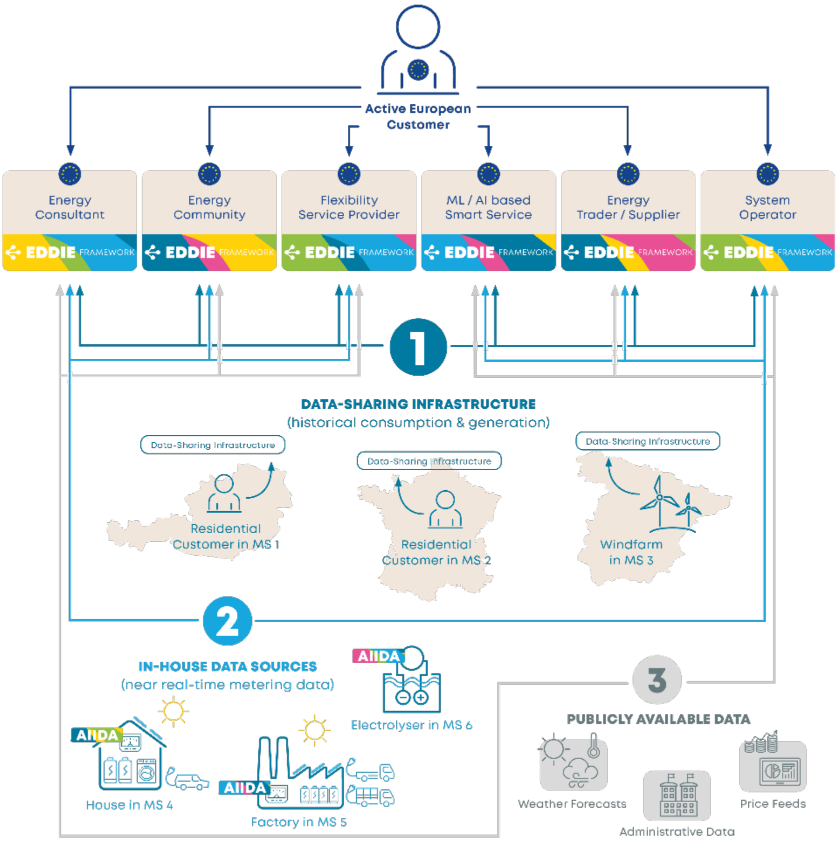

Figure 18: Eddie data integration infrastructure based on Apache Kafka data streaming and integration into national data management environments.

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 18 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. At the moment, this is done diversly 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 a consent was granted. Not only 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.

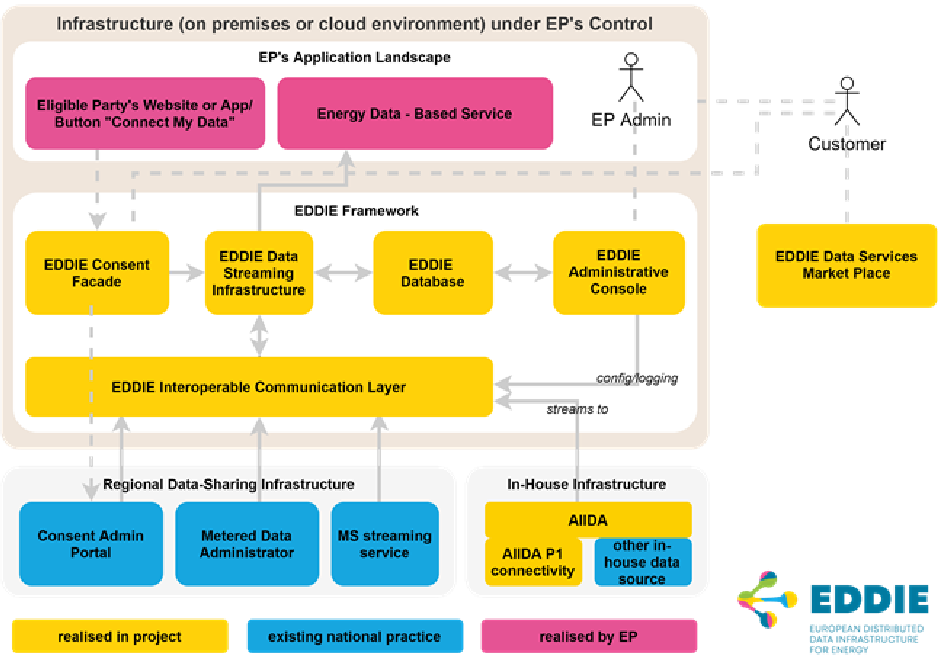

Figure 19: EDDIE Architectural Schema

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:

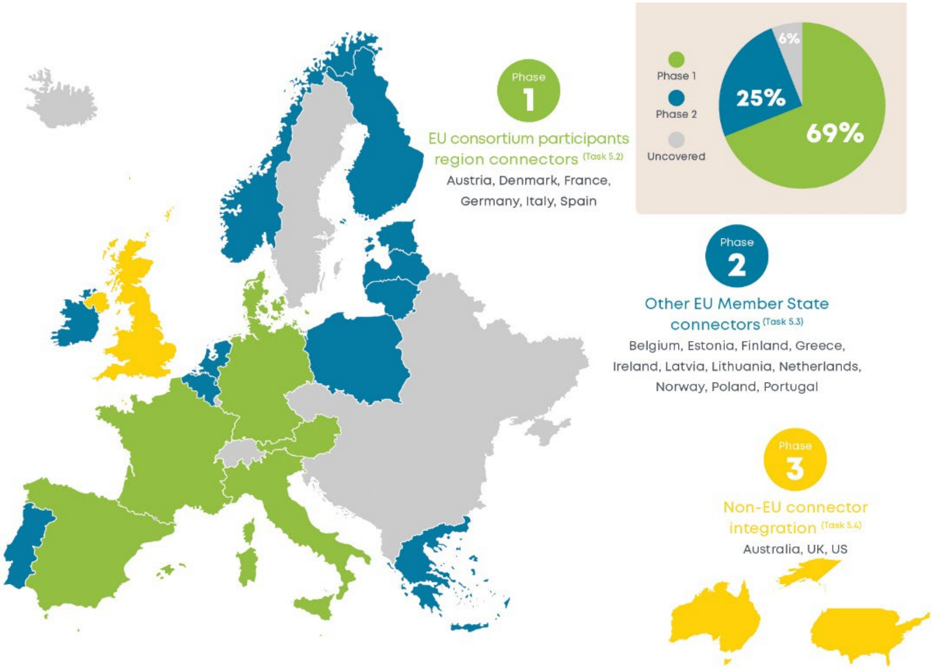

Figure 20: Geographical coverage of EDDIE

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 (https://online.eddie.energy), where, in a matter of minutes, startups and data users can simply register and utilise an infrastructure already set up by the project.

9 Existing interoperability tools, methods, and platforms

9.1 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 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 by means of JavaScript instructions. This approach is followed in open-source tools such as Piveau Consus[47].

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[48], 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.

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)[49], which provides more flexibility. RML is defined to express customised mapping rules from heterogeneous data structures and serializations to the RDF data model.

9.2 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[50] (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).

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[49] 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.
[50] D4.1 Data ingestion, Common Information Model and semantic interoperability. Omega-X Project.

10 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 under different perspectives. In any case, it is possible without technical conflicts, since the 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, RES operators, prosumers and consumers of various kinds), and each of them takes a different perspective of 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 analyzed within the LOV4IoT-Energy ontology catalog [REF LOV4IoT-Energy paper[51]][ref2[52]]. 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[i53]:

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:

Figure 21: LOV4IoT-Energy ontology catalog

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 catalog) were also provided.

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

The Data Management working group of BRIDGE has analyzed 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.

[51] 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
[52] 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
[53] http://lov4iot.appspot.com/?p=lov4iot-energy

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[54]”. 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 the 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 an information.

The **interoperability profile** is created by the combination of interoperability case and interoperability point. This process, corresponding to the development of an interoperability solution, is shown in Fig. 23 (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.

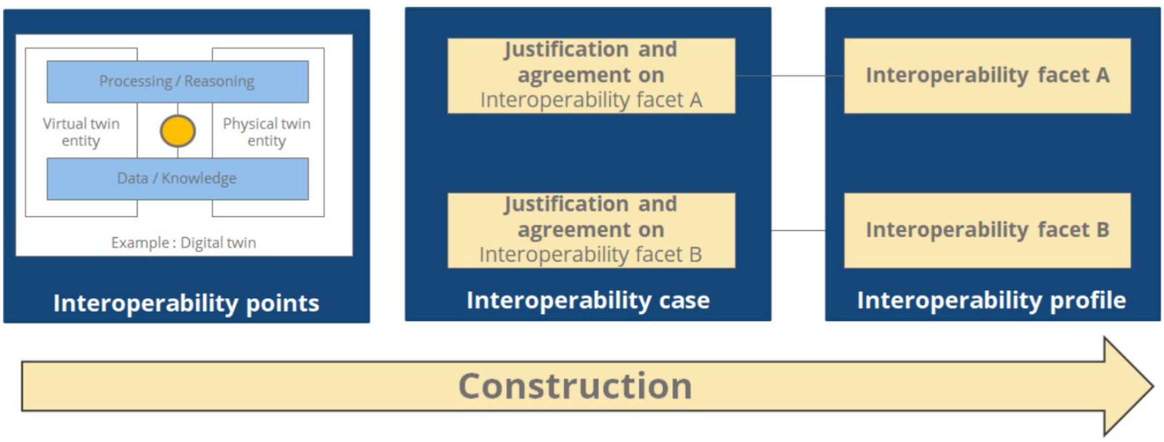

Figure 22: Process for the interoperability construction

[54] OPEN DEI - Reference architectures and interoperability in digital platforms https://www.opendei.eu/wp-content/uploads/2022/10/REFERENCE-ARCHITECTURES-AND-INTEROPERABILITY-IN-DIGITAL-PLATFORMS.pdf

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 used technology (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 been also made by the National Interoperability Framework Observatory (NIFO[55]), which has defined the interoperability model shown in Figure 24. 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 background layer, corresponds to rules for the interoperability frameworks, institutional arrangements, roles and responsibilities, and organizational structures for ensuring interoperable systems at national and EU levels.

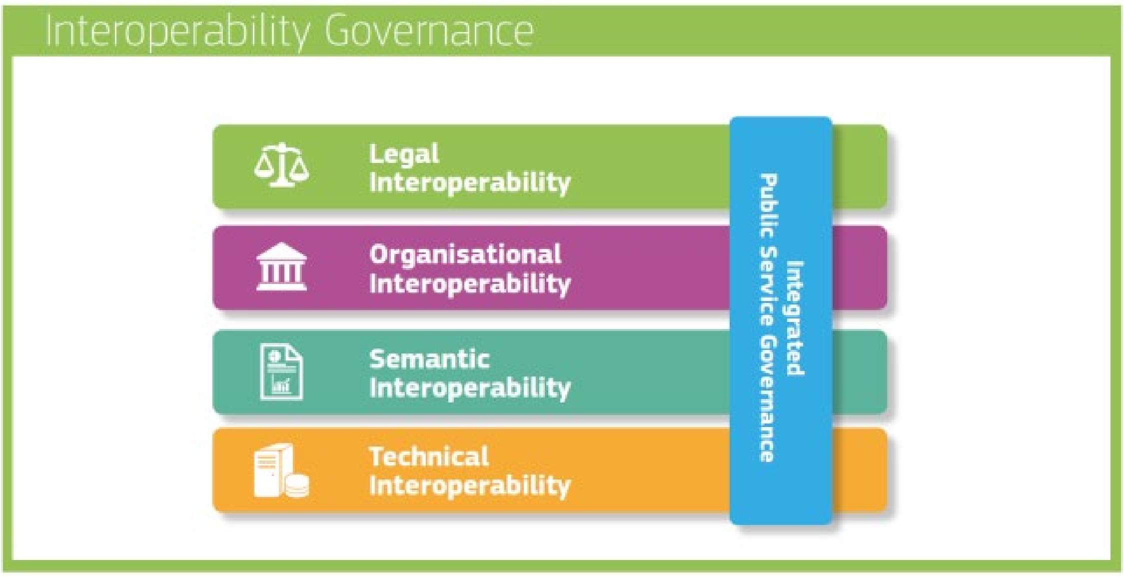

Figure 23: Interoperability model defined by NIFO

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

12 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 the energy systems and highlights 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 interoperate devices from different manufacturers while avoiding vendor lock-in, enhancing scalability, and ensuring data protection and cybersecurity.

The paper separately analyzes the technical and semantic 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 harmonization of ontologies and data models (starting from well-established solutions as CIM).

The architectures of energy data spaces being deployed at the European level (e.g., Horizon projects as Innovation Actions) allow 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. Moreover, 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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