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Energy Data Space

Policy Paper

ETIP SNET

European Technology and Innovation Platform Smart Networks for Energy Transition

Authors

- Antonello Monti (RWTH Aachen University and Fraunhofer FIT)
- Laurent Schmitt (Digital4Grids)
- Alberto Dognini (RWTH Aachen University and Fraunhofer FIT)
- Ricardo Bessa (INESC TEC)
- Elena Boskov-Kovacs (Blueprint Energy)
- Georg Hartner (Entarc.eu/ FH Oberösterreich)
- Tasos Tsitsanis (Suite5 Data Intelligence Solutions)
- Stamatis Diakakis (UBITECH Energy)
- Santiago Gallego Amores (Iberdrola)
- Carlos Damas Silva (E-REDES)
- Natalie Samovich (Enercoutim)

Editors

- Antonello Monti (RWTH Aachen University and Fraunhofer FIT)
- Laurent Schmitt (Digital4Grids)
- Alberto Dognini (RWTH Aachen University and Fraunhofer FIT)

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Contact: Mugurel-George Păunescu

E-mail: mugurel-george.paunescu@ec.europa.eu

European Commission
B-1049 Brussels

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EXECUTIVE SUMMARY

A reliable and secure common European data space for energy is a key element of the system digitalisation, as stated in the EU action plan “Digitalising the energy system” and in the European Data Act, allowing to enhance the integration of renewable energy sources and hence advancing towards the goals set by the ‘Fit for 55’ package and the RePower plan.
This policy paper describes the state of data spaces in the energy system, depicting the background as well as the domain applications, and the necessary steps to comprehensively leverage such technical solution at a large scale.
At the domain-agnostic level, a data space is defined as a framework that enables the data sharing in an ecosystem, subject to precise rules concerning security, legal compliance, and remuneration; each data space is systematically built with specifications, to be iteratively updated, on business, legal, operation, functional, and technology categories. In the energy domain, the development of a European framework for data sharing needs to consider the various strategies of data management across the member states; particularly, the data exchange among market participants can be carried out according to three alternative models: decentralized, centralized and hybrid. Consequently, the design of a common European energy data space must account for the harmonization and interoperability of the various national initiatives and models.

Moreover, the new challenges introduced by the data spaces lead to the use of reference architectures to address commonalities and align different solutions. Among the existing reference architectures, GAIA-X provides a cross-domain structure divided into the infrastructure ecosystem and data ecosystem, whereas the BRIDGE DERA 3.0 starts from the SGAM model to depict the necessary building blocks for the local and federated data spaces.
The current and upcoming transformations in the energy systems fit with the functionalities enabled by the data spaces, enhancing the overall power management. Particularly, the transformations are directed to the following groups: (i) the **control room for system operator**, in which the data spaces foster the TSO-DSO communication and the control of DER, (ii) the **grid flexibility**, requiring new market mechanisms to manage intraday wholesale transactions, (iii) the **role of buildings in flexibility**, enhancing the accessibility to “behind the meter” data and the exchanges with the Flexibility Service Providers (FSP) to improve the congestion management, (iv) the **residential energy optimization & smart charging**, in which data spaces allow the prosumers (as DER owners) to interact with various flexibility markets, and (v) the **operation of the energy system across different sectors**, such as electricity, gas, heating, cooling, transport, and industry.

Starting from these transformations specific use cases, centrally based on data spaces, have been defined and described; this definition considered the existing regulatory requirements, the technological availability, and the relevance for industry or societal challenges. The use cases presented in this document include, among others, the optimization of transmission and distribution systems operations, the instantiation and operation of energy communities, and the inter-borders EV services. Each use case depicts a precise situation in which data sharing allows, on one hand, to generate value without necessarily exchanging the data itself and, on the other hand, to foster optimization via data-enabled analytics solutions.
The systematic deployment of energy data spaces requires to address several key challenges, which are discussed in this document. Technical challenges include the accessibility of data (from smart meters and DER devices), the role of identity management component, and the harmonization of data models and components. These challenges are strictly related to the need of create the conditions for a wider customer involvement. Data spaces are in this respect a great opportunity to make clear the central role of the customers in terms of data provisions.

In general, regulatory and technical challenges have to be addressed together, to avoid further late issues. From the organizational viewpoint, the measures to federate different initiatives in the ecosystem and its long-term maintenance have a foremost importance. It is vital to obtain from the beginning an easy interoperability process and to avoid any possibility of data silos. The current situation is vice versa conditioned by several closed solutions that make the involvement of customers and customers assets quite difficult.
Another relevant challenge corresponds to the entire re-thinking of business processes, in the whole energy sector. In fact, data spaces design must consider the evolution of traditional market roles towards a new decentralized digital energy infrastructure, whose grid control balancing is centrally supported by sector coupling and end-consumers. It is a unique opportunity in this respect to achieve a higher level of democratization making sure customers have the right conditions to participate to the system.
Starting from the identified challenges, policy and regulation recommendations have been derived. Cooperation among different European initiatives is fundamental and thus regulations for the interoperability of local and flexibility energy markets must be made effective, while implementing measures for the data protection and privacy. Rules for interoperability and, at the same time, opening of the data silos should be strictly enforced to make sure that devices can be seamlessly integrated in the energy system bringing also significant advantages not only to the customers but also to the grid operators that would have easier access to flexibility.
Concerning the investments and infrastructures, considerable resources shall address the hardware infrastructures as well as programs to ensure the participation of end users, fostering the full uptake of energy data spaces.

1. Introduction

1.1 Introduction and scope of the document

Energy data spaces are one of the key pillars of the recently published "Digitalization of Energy Action Plan" released by the European Commission (EC) during the Fall 2022[1] as well as the new European Data Act recently finalized[2]. They constitute a necessity to enable a digitalized energy system with more available data streaming from all energy-related sectors that can be shared among trusted parties. A common European energy data space aims to strengthen interoperability among different systems and make it possible for more innovative services to enter the market.

The topic has been already quite actively investigated and it is also at the center of a cluster of projects funded by the European Commission. These projects, being Innovation Actions, have a medium-long range perspective so that we can expect to see results in the market in the next 5 years. Nevertheless, previous work in this field, as also summarized by the Coordination and Support Action (CSA) OpenDEI[3], makes possible to foresee applications also for a shorter term.
Goal of this policy paper is to give a short technical introduction to the topic, providing references for a deeper analysis, and then to focus on the identified opportunities, challenges and necessary actions for a quick deployment of a common European energy data space. For this reason, the document is as much as possible technology agnostic and focuses on the next steps for the concrete implementations.

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Energy data spaces necessitate the use of advanced technologies and robust connectivity, in conjunction with an optimized transportation infrastructure, to establish a secure "Internet of Energy"[4]. The Internet of Energy, whose deployment has the data spaces as fundamental pillar, pertains to interconnected energy systems that leverage digital technologies to optimize energy production, distribution, and consumption. Likewise, the optimized transportation system utilizes digital technologies to enhance transportation efficiency, reduce carbon emissions, and promote sustainable modes of transport.

1.2 Short introduction to data spaces

In 2020, the European Commission's policy titled "A European strategy for data" introduces the concept of a "data space", aiming to protect data generated by European people and enterprises, while at the same time keeping it open for innovative uses. In this view, the data should foster Europe's digital single market and, meanwhile, address the "societal challenges", which in the energy domain include easing the energy transition to carbon-free according to Green Deal and future Electricity Market Design targets.

A data space, as defined by the Data Spaces Support Centre (DSSC) project,[5] is a framework that supports data sharing within a data ecosystem. It is constituted by a clear structure in which the participants collaborate on data assets; in particular, they agree to trade and share data in a way that is compliant with the agreed data values and relevant regulations as well as ensuring fair treatment for all parties involved. From the business perspective, the trusted and secure sharing of commercial data assets is enabled, following automated controls on legal compliance and remuneration.

From a domain-agnostic perspective, each data space deployment is characterized with respect to the following five categories:

- Business: the business model around the data exchange (e.g., the consumption data to deploy flexibility planning in the wholesale market) and the business roles of parties.
- Legal: the legal framework includes (a) the cross-cutting legal frameworks, (b) the organizational aspects and (c) the contractual instruments.
- Operation: including information on operational framework (use cases), the processes and activities.

[1] Digitalising the energy system - EU action plan - COM/2022/552 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0552.
[2] European Data Act. https://digital-strategy.ec.europa.eu/en/library/data-act-proposal-regulation-harmonised-rules-fair-access-and-use-data
[3] OPEN DEI - https://www.opendei.eu
[4] Internet of Energy – Connecting Energy Anywhere Anytime - https://doi.org/10.1007/978-3-642-21381-6_4.
[5] Data Spaces Support Centre - https://dssc.eu/.

- Functional: described according to the technical and governance building blocks, which are deployed according to the required technical services (and their dependencies) as well as the data standards.
- Technology: with specifications on the adopted standards, references or the required software components. A major goal is to ensure interoperability among inner parties and with other data spaces.

Additionally, the following features have to be pursued:

- Security and Privacy: focusing on ensuring the security and privacy of the data exchanged within the data space.
- Quality and Integrity: pertaining to the quality and integrity of the data within the data space. It includes aspects linked with metadata such as data validation, data cleansing, data accuracy, data consistency.
- Governance and Policy: encompassing the governance structure and policies governing the data spaces, addressing decision-making, data governance frameworks (including rules and practices for management and operations), policies for data sharing and access, energy-related policies and regulations. The term "governance body" is used to refer to the role of a specific partner (or set of partners) in the data space initiative, which bears the responsibility for creating and maintaining the governance framework.

The achievement of energy domain transformation depends on the re-shape of complex energy flows, involving different sectors (like consumers, mobility, buildings, retailers, flexibility service providers, grid operation and manufacturing) and relying on the digitalized data exchange to be managed efficiently and in real-time. This digitalized data exchange facilitates an energy system which can accelerate, automate, plan, and anticipate processes far better than at present. Hence, the development of an energy data space cannot be delivered as a single platform but must be built incrementally, meaning that applications and systems must be capable of interoperating and exchanging data across different data spaces. Even more, existing national Data Spaces must be integrated in a federated way.

1.3 Data management strategies

To establish an effective European framework for sharing energy data, it makes sense to reflect, how data management is approached today. Two very important sources on this are the TSO-DSO Data Management Report[6] and the GEODE Data Management Fact Sheet.[7] Especially the latter dives into the fact that following Article 23 of Directive (EU) 2019/944 leaves the approach to data management for energy services to Member States, empowering them to tackle European legal requirements according to their subsidiary needs. That freedom, in fact, leads to three main architectural approaches that we find in many member states, often in parallel for different types of relevant data:

- In the **decentralized model**, data stays where it is captured (e.g., metering information at DSO, contract information at supplier, capability data at Distributed Energy Resources (DER), etc.). Market actors are working together to develop standardized market communication and exchange data either based on explicit consent of the data subject or under the umbrella of clearly defined business processes. Examples are given by frameworks in Austria (EDA), German market communication and France.
- The **centralized model** includes a data hub to which data is sent and stored. All business processes run on that hub and results are sent back to its clients. It is operated and developed by a specific party or service provider. Market participants use its functionalities. This approach is deployed, for example, in Finland and Estonia.
- The **hybrid model** is a combination of the two previous models. All market participants can communicate in a decentralized manner, but in some use cases (e.g., compliance monitoring or brokering access to data), there are task-specific central structures. An example, pertaining the smart meter context, is Spain, where data stays with the DSO as the "metered data administrator", and access for final customers and third parties is brokered by AELEC-operated DataDis[8].

The examples above show just the context of meter data access, yet the classification is also observed for the management of other data. For example, we see decentralized, centralized and hybrid management and sharing organization for flexibility registers, connection point registers, flexibility service provider master data or facilitation of Energy Communities and other collective self-consumption schemas.

[6] https://www.entsoe.eu/2016/07/27/tso-dso-data-management-report/.
[7] https://www.geode-eu.org/wp-content/uploads/2020/05/202005-Fact-sheet-GEODE-Data-Management-FINAL.pdf.
[8] DATADIS - https://aelec.es/datadis/

2. Reference architecture for Energy Data Spaces

The digitalization of European energy systems introduces new challenges in terms of data, knowledge, and technology adoption due to critical interoperability challenges for the underlying digital platforms. These challenges are emphasized in the deployment of energy data spaces and are addressed, consequently, by the developed reference architectures, defined as model for building architectures that exhibit known commonalities.[9] The following section introduces existing prominent examples for data space architectures. However, it is noteworthy that regulatory and legal developments enable a healthy competition and a strive for innovation between data space technologies. Overall, it is therefore crucial to ensure minimal alignment and interoperability of these reference architecture options.

2.1 GAIA-X

One reference at European level is constituted by GAIA-X. Its architecture, shown in Figure 1, employs digital processes and information technology, aiming to facilitate the interconnection between all participants in the European digital economy.[10]

The whole GAIA-X ecosystem, represented in the architecture, is structured into (i) a data ecosystem and (ii) the infrastructure ecosystem. Activity in the infrastructure ecosystem is focused on providing or consuming infrastructure services, whereas in data ecosystems the main asset is given by the data model and data information.

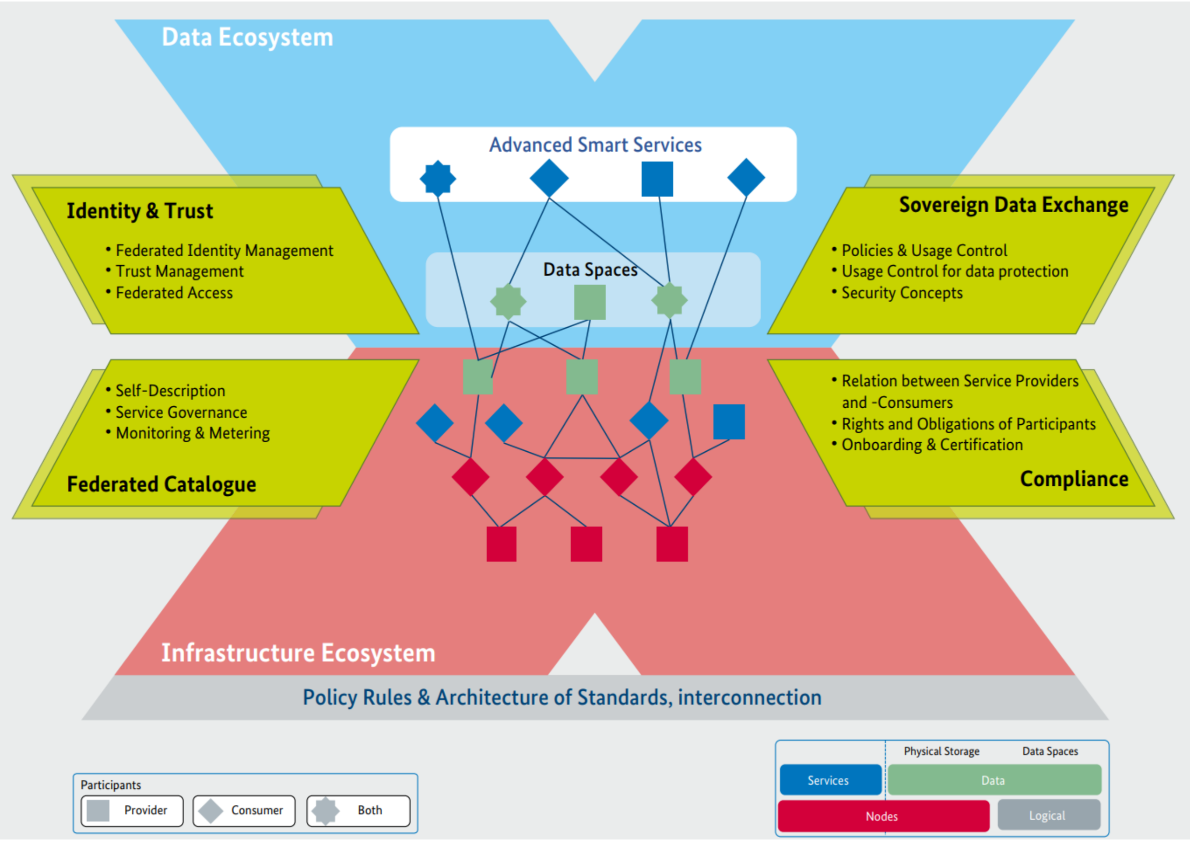

Figure 1 - High-level overview of the GAIA-X architecture showing the major architecture elements and functions accompanied by the Federation Services

9 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.

10 GAIA-X Technical Architecture https://www.data-infrastructure.eu/GAIAX/Redaktion/EN/Publications/gaia-x-technical-architecture.pdf?__blob=publicationFile&v=5.

2.2 BRIDGE Data Management Architecture

The BRIDGE Data Management Working Group focused on the further enhancement of Data Exchange Reference Architecture (DERA), iterating to version 3.0.[11] The architecture starts from the Smart Grid Architecture Model (SGAM) and associated CIM data exchanges to integrate data spaces in each interoperability layer: component, communication, information, function and business. The DERA 3.0 architecture is represented in Figure 2. An important aspect of the model is the differentiation between "local data space" and "federated data space", highlighting the building blocks, at the different interoperability layer, for each configuration. The BRIDGE architecture is aligned with the Harmonised Electricity Market Role Model (HEMRM)[12] and so offer easy instantiation options in the electricity sector in particular.

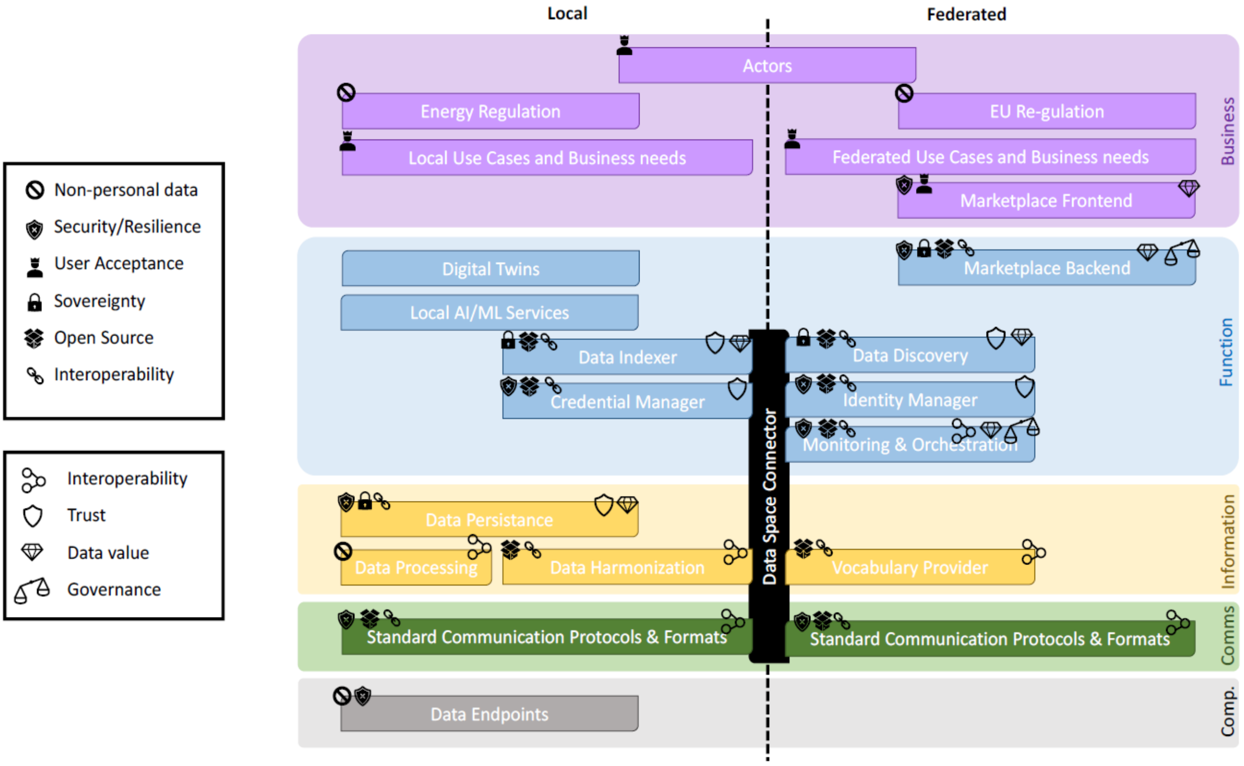

Figure 2 - DERA 3.0 layered architecture.

Beyond the energy domain, data spaces initiatives in other sectors have achieved advanced and tangible results; together with the "Industry 4.0" in the manufacturing domain, one example is given by CATENA-X[13] in the automotive domain. In general, in regard to the data exchange, the energy domain shall consider also other areas of activity, analysing the best practices and integrate them in the upcoming deployments.

Similarly in Tourism DATES[14] project activated cross domain stakeholders within tourism sector actors focusing on resilience use cases, low probability high impacts events management and other climate adaptation related use case. BD4NRG[15] and DATES projects conducted a joint workshop to explore interfaces, cross leverage between tourism and energy domains impacting data spaces design.

Leveraging the best practices from these parallel domain experiences can enable the integration of energy data with other data domains, such as mobility, industry, environment, tourism and agriculture. Development of new cross-sectoral services and applications, including marketplaces[16] can improve overall system performance, user experiences, and social impact of the system of system approach.

[11] BRIDGE Data Management https://bridge-smart-grid-storage-systems-digital-projects.ec.europa.eu/working-groups/data-management.
[12] The Harmonised Electricity Market Role Model (HEMRM), ENTSO-E, EFET and EBIX, version 2022-01. https://eepublicdownloads.entsoe.eu/clean-documents/EDI/Library/HRM/Harmonised_Role_Model_2022-01.pdf
[13] Catena-X https://catena-x.net/en/
[14] DATES https://www.tourismdataspace-csa.eu
[15] BD4NRG https://www.bd4nrg.eu/toolbox
[16] https://aioti.eu/wp-content/uploads/2021/03/Open-Energy-Marketplaces-Evolution-Published.pdf

3. Data spaces in the transforming energy systems

Data spaces provide the technology to address the current and upcoming transformations that are involving the energy systems, fostering the opportunities and enhancing the operations optimization towards the achievement of climate neutrality goals. Particularly, five aspects of energy systems transformation, to be interconnected with data spaces deployment, are presented hereafter.

1. Control room for system operator

This category of use cases is related to the progressive evolution of grid control room environments to adapt to new regulatory developments and the future electricity market design as well as the accelerated deployment of distributed energy resources, as the result of the increased system electrification. In fact, the ongoing exponential deployment of flexible assets, located in consumer premises, is creating new dynamic flow patterns in DSO networks as well as new cross border flow coordination across TSOs and DSO boundaries.
The first set of data space, largely based on the Common Information Model (CIM) and digital twins concept, should enable streaming of real-time structured information across grid control room environments down to DER interfaces.

2. Grid flexibility

The second category is related to the development of new market mechanisms to manage intraday wholesale transactions, grid ancillary services and congestion management, leveraging DER flexibility to optimize grid operation. In this regard, the typical service taxonomy to be considered for the development of these data spaces has been well summarized through the OneNet[17] project.
The associated data space should support the next implementation of distributed flexibility registers across European TSO and DSO to ensure necessary coordination for grid ancillary services and congestion management through single sets of interoperable APIs. Moreover, all associated data exchanges should be secured and ensure consent based and interoperable data exchanges as per the new data act.

3. Role of buildings in flexibility

Buildings play a central role in achieving the climate neutrality goals. Given the lifespan of buildings this means that a building's CO2 contribution is primarily from its energy performance, and several surveys demonstrate it needs to be improved significantly. Hence the crucial importance to progress from qualitative to data driven quantitative building energy performance assessments leveraging smart metering devices together with dedicated measurement devices associated to "behind the meter" Demand-Side Flexibility (DSF).

At the "grid-edge", the accelerated growth in the electrification of transport and heating significantly increases the need for grid reinforcements as well as add new renewable transient congestions to be managed through new flexible connections and flexibility markets. Moving forward the ability to dynamically balance the local LV distribution systems will soon become critical to optimize grid available capacity; hence, buildings represent critical energy hubs to mitigate congestion risks and turn intraday volatility into new revenue opportunities to consumers. High level real-time monitoring requirements will need to be managed by service providers, whilst provision of local services needs to be coordinated and potentially constrained by system operators, in order not to violate grid limitations. Submetering and Dedicated Measurement Devices will be integrated into the European regulatory framework, allowing multiple Flexibility Service Providers (FSP) and multiple suppliers to operate behind a final customer's connection.

4. Residential energy optimization & Smart Charging

DER such as residential PV, storage, Electrical Vehicle (EV) bidirectional charging or heat pumps are expected to deploy exponentially through consumer residential environments. These DERs are predominantly owned by prosumers who are implicitly opting for new cloud connection offered by the Original Equipment Manufacturer (OEM) of the DER to manage associated remote operation and maintenance. While most of these connected services are today focusing on basic energy management and maintenance services, new optimization opportunities arise, introducing new real-time connectivity challenges between DER owners, DER operators and new energy service providers (whether aggregators or energy communities). This new approach requires to develop new prosumer DER data spaces.

Furthermore, associated market enrolment mechanisms should be automated and made simple to ensure a fluid customer opt-in/opt-out for their preferred energy service provider and so ensure plug and play interactions with the various flexibility markets. A key principle for the design of this data space is that the participation of DER flexibility into flexibility markets must remain a matter of choice of DER owners, meaning consumers should be able to dynamically opt in/out for such services or decide for

[17] OneNet - One Network for Europe https://onenet-project.eu/.

most attractive FSP offerings through their user experience. New integration strategies and APIs for mass produced residential DERs need to be developed through the flexibility code to ensure a level playing participating of all resources into the market.

5. Smart sector integration

Data spaces can play pivotal role in enabling smart sector integration in energy[18], which is the coordinated planning and operation of the energy system across different sectors, such as electricity, gas, heating, cooling, transport, and industry. Data spaces in energy can facilitate the exchange and sharing of data among heterogeneous energy actors, such as consumers, prosumers, aggregators, utilities, grid operators, regulators, and service providers, while supporting the development and deployment of innovative data-driven solutions and services that can enhance the efficiency, flexibility, reliability, and sustainability of the overall energy system.

Regarding the integration facilitation, data spaces can enable the coupling of different energy carriers, such as electricity, green hydrogen, heat, through power-to-X technologies, such as power-to-gas, power-to-hydrogen, and power-to-heat. Data exchange and interoperability among these technologies and the respective energy networks would allow for the optimal use of renewable electricity and the reduction of greenhouse gas emissions as well as faster and more efficient integration and capacity building.

These five aspects are fully aligned with the 9 High-Level Use-Cases (HLUCs) from the ETIP SNET Roadmap 2022-2031[19], which describes the details of the most urgent R&I needs to be tackled through European Commission and national R&I work programmes and calls. Among the 9 HLUCs, the data spaces adoption will have the strongest impacts in the HLUC 2 (Market-driven TSO–DSO–System User interactions), HLUC 3 (Pan European Wholesale Markets, Regional and Local Markets), HLUC 5 (One stop shop and Digital Technologies for market participation of consumers (citizens) at the center) and HLUC 9 (Flexibility provision by Building, Districts and Industrial Processes).

4. Exemplary use-cases in the energy sector

The concept of an energy data space brings forth the potential for new or enhanced use cases (UCs) for different stakeholders, namely consumers, local communities, TSOs, DSOs, multi-energy utilities, RES investors and operators, and non-energy service providers. However, a fundamental prerequisite to fully capitalize on the benefits of the data space is to design UCs that: a) explore and combine data from different owners (i.e., *cross-silo* data sharing), and/or b) exchange/transfer data-driven models and knowledge extracted from shared data.

To ensure the realism of the proposed UCs, it is crucial that the solutions align with widely accepted and implemented regulations, while identifying gaps in the current policy preventing the use case to be implemented with more success across the European Union (EU). Additionally, the technology required for implementation should be readily available, and the proposed solutions must address actual industry or societal problems. To assess these aspects, each UC was evaluated based on the following criteria:

- **Alignment with social, political, and regulatory requirements**. The level of compatibility between the UC's requirements and existing EU regulations will be assessed to determine the potential conflicts.
- **Technological requirements and availability**. The necessary technologies for implementing the UC and their availability in the market will be evaluated to ensure feasibility.
- **Importance and real-world need.** The significance of the proposed solution and its practical relevance in addressing industry or societal challenges will be assessed.

Below, a non-exhaustive list of use cases from the energy sector that take full benefit from a data space is presented.

- **Transmission and distribution system operation**. TSO and DSO can improve the predictability of load and renewable energy forecasting by using the data space to promote close to real-time data sharing of individual or aggregated data from RES producers, DER operators, consumers, aggregators, etc.; a marketplace for forecasting is one potential use case [Gonçalves et al., 2021]. Another use case is to track behind-the-meter small-scale DER growth , flexibility potential, as well as real-time performance when participating in flexibility markets and this augmented observability can be used to better plan the network and system considering technology diffusion forecasts [Heymann et al., 2021], e.g., identify attractive network areas for the installation of flexible DER. Real-time data shared by consumers can be also used for outage detection and location as well as near real-time congestion mitigations and emergency smart load shedding controls , potentially combined with data from other sectors such as ICT service providers.

- **Electricity monitoring and local self-consumption optimisation** bring benefits to households and SMEs since it has enormous potential to save energy, reduce energy bills as well as stack new revenue opportunities from flexibility. It supports

18 Smart Sector Integration, towards an EU System of Systems - https://smart-networks-energy-transition.ec.europa.eu/sites/default/files/publications/ETIP-SNET-PP-Sector-Coupling-towards-an-EU-System-of-Systems-.pdf
19 ETIP SNET R&I implementation plan 2025+ https://op.europa.eu/en/publication-detail/-/publication/1f335dcf-461d-11ee-92e3-01aa75ed71a1

the active implicit customers participation in flexible mechanisms which can be leveraged by system operators to manage electricity network congestion and stability more efficiently. Future data exchange platforms will allow electricity consumers to consult, in an integrated manner and through single interfaces, all disaggregated information, current and historical, related to their boundary meter and corresponding dedicated measurements devices. Users should be able to authorize third parties service providers (e.g., aggregators) to access their data and thus offer them relevant energy services. Such platforms should also integrate other DER use cases, such as smart and bidirectional charging of electric vehicles, the participation in energy communities as well as the monitoring of heat pump operation.

- **Data centers energy control.** This UC focuses on addressing the challenges posed by the rapid growth of data centers in Europe. The development of a digitalized control infrastructure, in the form of a digital platform, will enable flexible coordination of cooling storage and waste heat reuse in data centers. The control and scheduling implemented at data center sites will utilize real-time energy and market data, including energy consumption, demand, and electricity prices, to optimize the operation of data centers and regulate server room temperatures, thereby reducing carbon emissions.

- **Inter-borders EV services.** The challenges related to roaming of mobility services (i.e., EV charging) across borders. The main obstacles include the lack of a legislative framework, poor information about the location and availability of public charging stations across borders, absence of real-time information about availability, tariffs and session prices, non-compatible tools and apps for accessing charging stations, and non-transparent business models with complex value chains. To overcome these obstacles, standardization and interoperability of the charging infrastructure, particularly the communication protocols, are proposed as solutions.

- **Instantiation of Local Energy Communities (LEC) and simulation of business models**. Optimize, in a planning phase, the sizing of LEC (i.e., DER capacity) and simulate their operation (e.g., estimate an internal reference price to study different business models) by combining data from different consumers. The data shared by different data owners (e.g., consumers, original equipment manufacturer - OEM, RES producers) is crucial to compute the benefits of belonging to the community.

- **Operation of LEC**. On top of "standard" functions like peer-to-peer trading, data shared between the community members can be used to compute additional sustainability indicators, such as the traceability of green energy supply within the community or "happy hours" for EV charging. Moreover, this data sharing fosters the development of local circular economic business models, which are particularly appealing in agricultural settings characterized by seasonal activity. In these models, a surplus of RES can be exchanged for other products/services through barter exchanges, including water, PV panels cleaning, raw materials, and biofuels.

- **Demand-Response schemes for final prosumers.** This UC exploits data spaces to revolutionize the energy sector by transforming demand-response schemes through seamless data sharing and real-time communication between consumers and grid operators. Via data spaces in the energy sector, consumers are also enabled to engage in demand-response programs, optimizing energy consumption through real-time analysis. Grid efficient management is empowered, reducing strain, and incentivizing consumers to shift their energy usage to off-peak times.

- **Learning energy utilization patterns to recognize potential problems and trigger alarms for vulnerable people.** Involves providing insurance and healthcare services to a community or individual consumers leveraging from data shared from smart meters or non-intrusive load monitoring devices. This could be undertaken by machine learning algorithms to analyze energy utilization patterns and identify potential issues. The primary focus could on addressing the needs of senior citizens with reduced mobility or disabilities, who lead independent lives but face the risk of accidents such as falls or other hazards without immediate assistance available.

- **DER asset management**. Presently, the data collected from operational wind turbines, PV panels, and storage systems are accessible only to RES power plant owners and OEMs, which are the only beneficiaries of the knowledge extracted from data. However, by exploiting machine learning expertise and other data sources (e.g., robotics inspection, satellite images, advanced sensors), access to real operational data allows to support different O&M actions or assess the financial risk of new investments.

- **Predictability of electrical mobility patterns and charging coordination.** Enhancing the predictability of charging point availability and EV charging needs is crucial for the effective planning of incentives for EV drivers and the accurate estimation of flexibility for aggregators, TSO, and DSO. This involves the integration of data from different sources, including charging points, mobile crowd-sensing platforms, and cloud-based systems provided by vehicle manufacturers, among others. To accomplish this, it is essential to establish incentive mechanisms that encourage EV drivers and mobility service providers to share their data securely and privately with various stakeholders.

- **Cross-sector consumer flexibility.** The availability of historical and/or operational data from diverse load types, assets, and processes across non-energy sectors (such as water, smart cities, mobility, and manufacturing) holds significant value in quantifying their flexibility potential and designing effective marketing and engagement strategies for consumers in those sectors. Access to such data enables consumers to unlock additional revenue streams through the provision of system services via data sharing. In this context, multi-energy infrastructure planning plan would benefit from a better understanding of how the electricity and gas demands are likely to evolve in the context of net-zero communities; the goal is the design of incentives to replace gas consumption with electricity.

- **Energy efficiency for final users.** Building large datasets with the impact and context of different energy efficiency actions at the building and household level is crucial to de-risk investment, and better designing financial support schemes and policies. The tracking of assets operation and corresponding efficiency, via shared data, help users to improve their operating strategies and schedules. End-users can utilize data space components for smart carbon accounting and increase knowledge on for track-and-trace of energy origin.

- **Energy efficiency for industry and sector coupling**. Several projects are developing insights into industry retrofitting and promotion of renewable energy integration;[20] moreover, AIOTI is working on introducing a comprehensive methodology to propose a method of calculating the carbon avoided emissions in an industrial sector/domain, when ICT is used as an enabling technology.[21] All these activities can benefit from the integration with data spaces frameworks. ETIP-SNET WG 1 recent paper[22] related to sector coupling, including the related use cases, data management and sharing needs based on the enabling platforms indicated the evolving demand for such exchanges among energy actors. The paper addressed aspects beyond the energy conversion issues focused on technologies building bocks bringing planning and project assessment criteria, regulation and policy needs, architectures and roles, data management and the related infrastructures and customer involvement. The wholistic approach proposed in the paper and the related architectures and data needs can be addressed by distributed data approach and the emerging paradigms.

All these use cases share a common vision where data sharing is viewed as a means to generate value from distributed data, without necessarily exchanging the data itself. Emerging paradigms, such as federated learning, transfer learning, and digital twins, hold the potential to create conditions for collaborative analytics and optimization, enabling data-enabled solutions to contribute towards decarbonization goals.

5. Reference data flows

Data exchange implies the access and sharing of relevant, essential data to activate the flexibility of consumers and prosumers. Data sharing and access should consider all relevant actors of the energy value chain including end-users as well as system operators, market players and power exchange platforms. The data exchange flows outlined in the Figure 3 have been identified as critical ones to enable DSF flexibility transaction across the energy value chain while connecting essential grid and market data spaces to ensure transparency and observability across energy actors.

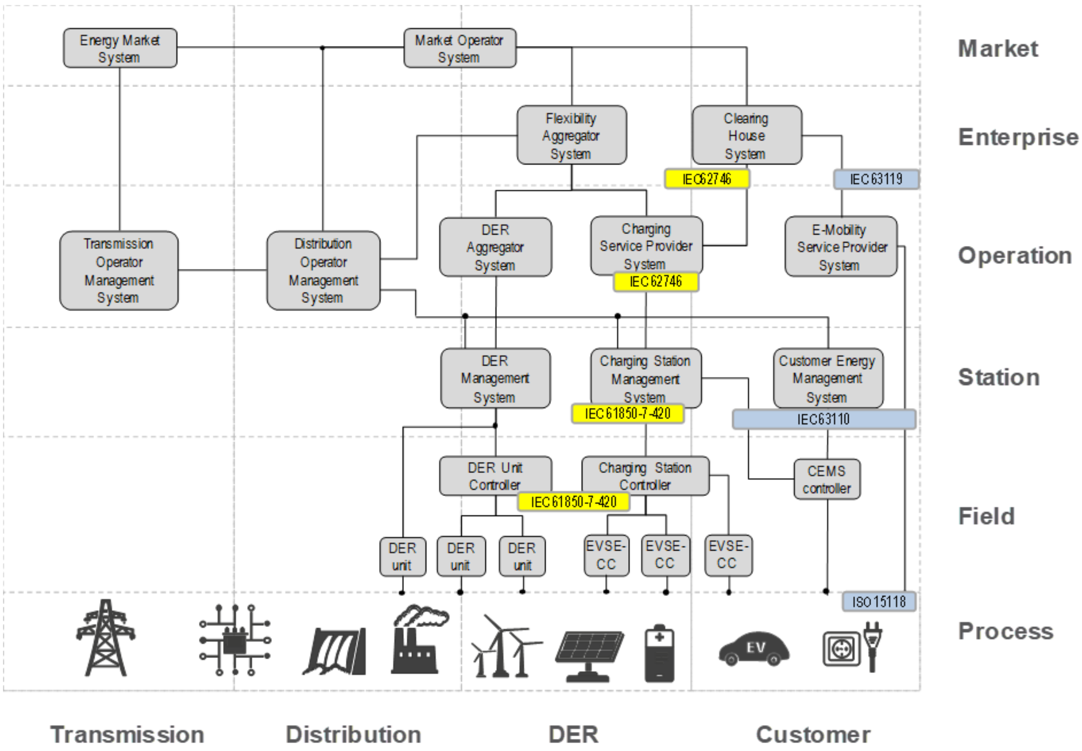

Figure 3. IEC TC57 Working Group 21: Grid – behind the meter data interactions.

[20] https://re4industry.eu.
[21] https://aioti.eu/wp-content/uploads/2022/11/AIOTI-Carbon-Footprint-Methodology-Report-Final-R1.1.pdf.
[22] Smart Sector Integration, towards an EU System of Systems - https://smart-networks-energy-transition.ec.europa.eu/sites/default/files/publications/ETIP-SNET-PP-Sector-Coupling-towards-an-EU-System-of-Systems-.pdf.

This high-level representation allows to distinguish different data exchanges to be associated to energy data spaces. These data exchanges may require synchronous data exchanges or streamed real-time data multi-casted across various service providers and system operators.

- **Between Behind-the-Meter (BTM) DER asset data space for BTM energy managements.** DERs can consists of different types of flexible devices such as white goods, heat pumps, home batteries, V1G or V2G chargers, as well as Building Energy Management Systems (BEMS). BTM data exchange flows relate to the ability of DERs to communicate between themselves.
- **Between BTM DER assets (individually or via BEMS) and Flexibility Market Operators through Flexibility Service Providers data space for Market Participation.** Each BTM DER assets can interact either individually and through dedicated resource operators, or they can be integrated through BEMS allowing an optimal operation of a building, by ensuring communication among individual BTM assets. This data space application is essential to automate DER response to implicit signals such as price, grid congestion alert as well as explicit measurement and control data for flexibility service providers to bid associated DER's flexibility into markets. End-users may decide to contract the procurement of a flexibility service from one or several flexibility service providers (FSP) for one or more of their DERs, eventually via a BEMS. Harmonization of the standards used for flexibility market interfaces is key to this data flow to enable the exchange of data in real-time to untap flexibility potential and accelerate deployment of FSPs at Pan European level.
- **Between BTM DER assets (individually or via BEMS) and System Operators data space for Grid Emergency Services and Flexible Grid Connection Operation.** Some DERs offer fast response flexibility services which, in some exceptional grid stability emergency cases or congestion redispatch near real-time, offer direct connection to grid operators for observability as well as emergency post-market controls, as already been defined through the ACER grid connection codes for larger front the meter DER assets. These datasets are usually limited to significant grid users, which may be exceptionally operated directly by the DSOs in case of system instability and emergency post-fault measures.

6. Key challenges implementing Energy Data Spaces in Europe

Comprehensive analysis on ongoing R&I activities allowed to identify several key challenges, which have to be addressed to leverage the deployment of energy data spaces in Europe on a large scale. Particularly, the desk study relates to the work of relevant EU Expert Groups and legislation, like the EU Smart Grids Task Force, as well as via a dedicated questionnaire that addressed relevant stakeholders and the activity conducted with the cluster of preparatory actions for energy data spaces: five innovation actions (IA)[23] and one coordination & support action (CSA)[24] of the Horizon Europe program.

In the following sections, the challenges are presented and grouped according to their different categories. In general, the regulatory and technical aspects need to be addressed together. When regulatory and technical challenges are separately considered, other and perhaps bigger challenges can arise. The main challenge would be constituted by the entire re-thinking of business processes of the whole energy sector and market. The data spaces design must consider how traditional market roles must evolve to function in a new decentralized digital energy infrastructure, where sector coupling and end-consumers are going to play a central role in grid control balancing.

Technical challenges: data availability and accessibility, technical and information interoperability.

- **Need for harmonization of data models, ontologies and architectures.** Multiple standards are currently in place in the energy domain to describe data models and ontologies; as examples, the standards IEC Common Information Model (CIM) is currently largely used by Grid, Market operators and has recently been endorsed as an obvious choice by flexibility service providers through Smarten as well as, of the ETSI SAREF which is fast developing for the description of behind the meter connected assets. In conjunction with these 2 standards, a diverse range of fundamental semantic ontologies has been meticulously crafted and harnessed to extensively cover the domain-specific aspects of energy (e.g., ThinkHome[25], Ontology for Energy Management Applications (OEMA)[26], Open Energy Ontology (OEO)[27], SEMANCO[28] as well as IEC61850-7 ontology for the description of Smart inverters). Aligning and integrating energy domain specific ontologies to acquire a

[23] DATA CELLAR: https://cordis.europa.eu/project/id/101069694;
EDDIE: https://cordis.europa.eu/project/id/101069510;
ENERSHARE: https://cordis.europa.eu/project/id/101069831;
OMEGA-X: https://cordis.europa.eu/project/id/101069287;
SYNERGIES: https://cordis.europa.eu/project/id/101069839.
[24] int:net: https://cordis.europa.eu/project/id/101070086.
[25] ThinkHome ontology - https://www.auto.tuwien.ac.at/index.php/research-fields/ontology.
[26] OEMA ontology network https://innoweb.mondragon.edu/ontologies/oema/ontologynetwork/1.1/index-en.html
[27] Booshehri, M., Emele, L., Flügel, S., Förster, H., Frey, J., & Frey, U. (2021). Introducing the open energy ontology: Enhancing data interpretation and interfacing in energy systems analysis. Energy and AI 2021; 5: 100074.
[28] Corrado, V., Ballarini, I., Madrazo, L., & Nemirovskij, G. (2015). Data structuring for the ontological modeling of urban energy systems: The experience of the SEMANCO project. Sustainable Cities and Society, 14, 223-235.

level of consistency and interoperability, ultimately depends on the specific use cases and requirements of each ontology and how they are designed to interoperate with others. In the existing scenario the achievement of interoperable solutions does not strictly depend on the creation of new standards and data models (except for new technologies) but, in most of the cases, on the mapping among different data models and standards. Specifically, the upcoming new business models associated with the data spaces will favor interconnection of different sectors (mobility, heating/cooling, city in conjunction electrical grids, at region and national level) and operational functionalities that require interoperability of data models among newly interconnected applications. Additionally, a common view on how to integrate reference architectures such as GAIA-X and DERA 3.0 should be defined for the implementation of an interoperable energy data space bridging behind the meter assets with Grid, Market and Service providers ontologies derived from CIM (particularly, a common vision on federation of different data spaces across domains as well as countries and at pan European level is still lacking.

- **Accessibility of data: smart meters and DER dedicated measurement devices.** The achievement of flexibility mechanisms through the data spaces entirely relies on an efficient and smooth sharing of data from each data space participant, including the end-users. The European directive 2019/944[29] and the new C(2023)3477[30] specify rules for TSOs and DSOs in regards to data from dedicated metering devices. Anyway, in the current situation, the access to smart meters data, which need to be viable for all main Advanced Metering Infrastructures (AMI) concepts, is still restricted and, hence, concrete actions on this matter are required. Moreover, specifications on the quality and resolution of shared data for Distributed Energy Resources have to be reinforced. Similarly, equivalent challenge involves the accessibility of data in the e-mobility, as well as storage and heating domains, particularly on the state-of-charge of EV or batteries used for PV self-consumption as well as any heat storage used in combination with Heat Pumps; in this respect, definition of usage rights like planned in the Data Act are necessary.

- **Identity management in the data spaces architecture.** The identity manager component has a fundamental role in the domain specific or domain-agnostic reference architectures: ensuring the trust among data exchange actors and the respect of governance agreements. The conventional implementations of data spaces position the identity manager component in the central, organizational levels. Anyway, for specific energy use cases there is the need to integrate the identity managers components at the end-user level of the data space ecosystem (e.g., in a local energy community, directly at the community members), in order to allow advanced development of marketplaces. Electronic Identification and Authentication Services (eIDAS)[31] and eIDs represent promising options for a common European pillar for reliable I&A across all Member States. With its upcoming amendment, representation of natural persons by other natural persons and legal persons by natural persons will be provided, which would make it an obvious candidate to connect Data Spaces from the I&A perspective.

- **Role of metadata.** Advanced grid services, including flexibility and demand response, enabled by data shared in the ecosystem rely, in addition to electrical measurements and power system quantities, on various categories of metadata. Although the maturity level of data models of electrical grid data is already advanced, the lack of formalized mechanisms for introducing metadata is still open and requires further developments to be able to take advantage of the reference CIM ontologies used across the Grid, market and flexibility service provider domains. Some progress has been achieved through ONENET[32] and its associated market participant connector leveraging IEC62325 and IEC62756 ontologies.

- **Use of AI technology.** The commercial use of AI, which is particularly critical for the success of data spaces[33], is prevented by the current draft status of the AI Act[34], in particular Art. 10 Para. 3. as these exclusively require "relevant, representative, error-free and complete training, validation and test data sets". Such databases are practically non-existent because a minimum error is intrinsic in the model; for this reason, specific regulatory actions need to be undertaken.

Organizational challenges: governance, data value and business aspects.

- **Federation of data spaces in the ecosystem**. The strategy to connect pan European domain specific data spaces with country level sub-data spaces needs to be defined. Ideally, considering the different use cases in the energy domain that lead to deployment of multiple data spaces, the viable path aims at a federated data spaces ecosystem that is constituted of several interoperable data spaces leveraging common semantic and ontologies. According to this approach, the future pan European energy data space corresponds to a common unique framework with defined governance mechanisms as well as specific architecture and set of building blocks using a pivot data models across country specific data spaces with different shared data content and instances according to the specific use case. The interconnection of different data spaces will be also accompanied by the mutual discoverability and accessibility through common data dictionaries such as CIM or SAREF4ENER, with benefits for every stakeholder.

[29] Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32019L0944.
[30] C(2023)3477 "Implementing regulation for access to metering and consumption data" https://energy.ec.europa.eu/publications/implementing-regulation-interoperability-requirements-and-non-discriminatory-and-transparent_en.
[31] eIDAS Regulation - https://digital-strategy.ec.europa.eu/en/policies/eidas-regulation.
[32] OneNet - One Network for Europe https://onenet-project.eu/.
[33] IEA https://www.iea.org/commentaries/why-ai-and-energy-are-the-new-power-couple.
[34] Proposal for a Regulation Of The European Parliament And Of The Council Laying Down Harmonised Rules On Artificial Intelligence (Artificial Intelligence Act) And Amending Certain Union Legislative Acts https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52021PC0206.

- **Business models of data intermediaries.** Acknowledged soft infrastructures of data spaces, at cross-sectoral and cross-country level, include in their reference architectures specific roles for intermediaries positioned between the data user and the data owner (i.e., federation services and required services for the operation of data spaces, as data or service provider and data consumer). As a challenge, the development of energy data spaces must account for a dedicated analysis, and consequent validation, of business models for the intermediaries.

- **Mechanisms for the long-term maintenance of the data space.** In the design phase, risks and countermeasures to possible issues must be considered and included in the governance rules. For example, the abandonment of the data space by a required intermediary (e.g., clearing house, governance body or service provider) shall be addressed so that the functioning, trust and security of the ecosystem is not compromised. Moreover, the evolving technologies and it implications, such as AI, will necessitate dynamic regulatory approach within the context of data spaces, which could also assume role of regulatory sandboxes.

- **Alignment of European legislation at member states level**. Data spaces will benefit from the data sharing among entities located in different geographical areas, as different European member states. The different forms and transposition of European legislation in every member state involves diverging conditions that could compromise the homogeneous accomplishment of governance, operational and business agreements. In fact, European regulations for energy consist in a complex integration of member state and pan European legislation with sometimes diverging definitions , leading to complex alignment process between "bottom-up"-approach and pan European legislations such as the Clean Energy Package and RepowerEU. Steps have been taken recently to improve such alignment through ENTSO-E and EU DSO joined working group for energy and flexibility data interoperability leading to the definition of a new harmonised role model defining actors roles and so setting solid bases to define data exchange (as reused for instance through the DERA architecture model).

Social challenges

- **Trust.** Companies present concerns about revealing their know-how by sharing their data, hence, gaining their trust in data spaces will be a major challenge to overcome. Moreover, an energy data space design will need to comply with regulations on personal data (e.g., GDPR) and consider that some data cannot be made openly available without anonymization or citizen formal consent. Next to the protection of personal data, the governance of data spaces should also address the issue of data ownership, to recognise latest data act developments especially regarding end user data ownerships principles. It will be necessary to develop technological solutions to ensure sovereignty, control over data usage, security and privacy.

- **Involvement of end users**. The full involvement of end users' participation requires specific enforcement measures and transparency to end users on associated data usage. An existing barrier is the current users' tendency to consider the data as "their power, compromised by its sharing"; hence the crucial importance to set up proper operational mechanisms for consent management clearly highlighting reciprocal business advantages (for both parties covering both monetary and indirect benefits). Moving forward, energy dataspaces should ensure end user are fully aware of the trustworthiness of the data space, corresponding to the full achievement of security, privacy and confidentiality of data sharing.

- **Data valorisation challenges:** seamless incentive mechanisms and data markets covering B2B and B2C scenarios. To enhance data sharing in both B2B and B2C scenarios, it is crucial to establish seamless incentive mechanisms and marketplaces. In the B2B context, promoting the development of fair data monetization strategies, incorporating digital technologies like Blockchain, and implementing data-by-data exchange strategies are vital. While open data initiatives hold value and advantages for some data of common interest, sustainable business models for data sharing platforms require assessing data's value based on its specific use cases. In the B2C setting, the involvement of social sciences and humanities (SSH) becomes essential in designing engagement strategies that encourage lifelong data sharing and consumer digital twins. Here, the data shared by the customers, with service providers and among themselves, have a value that is not necessarily economic but, as alternative, can enable specific services for the customers themselves (e.g., in the domain-agnostic digital environment, the customer's data on its position allows to define the traffic information, beneficial for herself/himself). In this regard, the following categories are identified:
    - **Data-by-money (monetary incentive):** data owners accept to share their data because they are financially compensated if their data is relevant for solving analytics/optimization tasks and pay in case data from the others is relevant to their own tasks. This approach is more suitable for the B2B or B2B2C context (such as for Flexibility Service provider).
    - **Data-by-data (non-monetary incentive):** barter trading, specifically a data-by-data exchange scheme for non-monetary compensations. There is no money involved and data owners agree to share and receive data with approximately the same value; exchanged data includes services as, for example, alarm signals, fault notifications and indications of maintenance actions. This approach is applicable to both B2B and B2C contexts.
    - **Apply an SSH-driven approach to combine the sharing economy, co-creation, and design thinking methodologies and place energy consumers (data owners) at the forefront**. The goal is to actively involve

and inspire consumer panels to share their energy data, leveraging from: i) offer consumer-centric value-added data-enabled services and ii) explore innovative and decentralized data governance roles within the dynamic interaction between data and energy value chains.

7. Policy and regulation recommendation

Starting from the challenges and risks to be considered for the effective deployments of data spaces, which have been described in the previous chapter, policy and regulation recommendations have been derived. These recommendations aim to propose tangible and specific measures to leverage the uptake of data spaces. Even if primarily defined for the energy domain, specific recommendations can be transposed to cross-domain deployments.

Recommendations on regulatory measures and standardization.

- **Foster harmonization of mechanisms and standards.** Although new technologies require effort in developing new dedicated standards, most of the energy use cases deploy data models, ontologies and functionalities that are already covered by existing standards with a predominance of CIM, SAREF4ENER and OCPP; in this latter condition, the main requirement consists of extensive alignment of existing technical regulations and standards. Hence investments on effective and long-term harmonization mechanisms are necessary, not only at the energy domain but also on a domain-agnostic perspective. At this scope, it is necessary to continue effort on developing standards and data models through the Bridge initiative; the landscape report[35] on energy and flexibility data models and interoperability across the sectors of energy, mobility and buildings gives guidance and directions on eligible standards and models. Additionally, the real-time capabilities in standard communication protocols (e.g., REST, HTTP, Kafka, MQTT) should be enhanced to cover Grid operator observability requirements.

- **Cooperation among European initiatives**. It is strongly recommended to foster cooperation among the different European initiatives in the energy domain and define a roadmap for the development of data spaces at EU level. This action must be accompanied by the target of a homogenous level of digitization in the energy system. Two parallel directions shall be pursued: (i) establish priorities and implement them in each country under a harmonized European framework and (ii) follow the sectoral development; (for example, from the system operators who should work together to create successful developments with the vision of the industry). **"One pager" about the visioned data** is required, which the member states could use in further spreading the understanding. Decentralized approaches like national data spaces are easier to be initiated, but in the long run these initiatives need to be integrated through pivot pan European dataspace federation, avoiding the use of a centralized authority approach as originally developed. In case centralized approaches are considered in some countries, the associated work should be jointly defined and accepted by all relevant parties – from Grid and Market Operator to Flexibility Service Operator down to DER operators and aggregator through a transparent, clear and easy to understand pool of current knowledge as well as validated roadmaps that consider co-dependencies as well as interactions (market-operations-assets) over different time-horizons are necessary.

- **Regulation for the functioning of data markets.** The Joint Working Group Data Interoperability organized by ENTSO-E and EU DSO Entity, which has been established on recommendation by Implementing Regulations following the Art. 24 of EU Directive 2019/944, aim to improve interoperability requirements. There is an existing need for regulating local energy markets and flexibility markets, to guarantee effective benefits for the prosumers. As a recommendation applicable but not limited to the energy domain, the data sharing agreements and templates, legally binding participating in data sharing, shall be formalized through that group which needs to be expanded to the other market participant stakeholders to ensure an end-to-end validation of associated concepts (as established through the flexibility network code drafting). Particularly, it is recommended to define both pan European transverse regulatory frameworks across member states for the management of common pan European data sets for the management of pan European legislations (such as for instance the one required for data interactions with mass produced DER sold across Europe such as EV chargers, residential storage or heat pumps), while considering local country specific data spaces integrating data related to each member state specific regulations. At this scope, regulatory and technical sandboxes are considered fundamental for fostering new digital infrastructure and market roles and define minimal interactions across dataspace partitions. In general, the energy data space should be composed of federated country level data spaces and be flexible enough to facilitate implementation in each EU country while at the same time standardized enough to ensure cross-country interoperability for certain legislations such as the flexibility code.

- **Avoidance of vendor and initiative lock-ins.** To foster the technology advancements, the benefits for the users and the data spaces deployment, the regulatory framework shall support competition and disruptive innovation, avoiding customer lock-in to vendors and initiatives. It should furthermore facilitate the reuse of Opensource libraries

[35] Landscape report on energy and flexibility data models and interoperability across the sectors of energy, mobility and buildings https://digital-strategy.ec.europa.eu/en/library/landscape-report-energy-and-flexibility-data-models-and-interoperability-across-sectors-energy.

as developed through European Research project to ensure the fastest innovation to market. Future Research projects should furthermore be guided to maximize the reuse of these dataspace to minimize development duplications on core infrastructures.

- **Implement data protection regulatory and measures in confines of data spaces:** On top of the existing EU legislation concerning data protection and privacy (e.g., EDPS,[36] the 2016/679[37] regulation, etc.), it is recommended that state-of-the-art principles should be defined, through the design and development of data spaces including consumer owned data, and integrating privacy and data protection principles from the outset. This includes recognizing advanced privacy measures scoping the entire lifecycle as well as defining necessary data portability measures in case consumers opt for different service providers. On top of that, blockchain technologies should be considered as an option to ensure secure and decentralized data sharing when use cases require such an approach. Implementing federated learning techniques for instance allows for collaborative analysis without centralized data, minimizing privacy risks associated with data sharing. By implementing these measures, the EU can demonstrate its commitment to robust data privacy and protection in data spaces, fostering trust, security, and innovation.

  The proposed data categorization aims to outline which energy-related data could be considered:

  - **highly sensitive data**, which cannot be shared, to preserve the security of the energy system;
  - **critical and sensitive data**, requiring specific agreements between parties and the highest level of confidentiality and protection measures;
  - **public data**, which can be shared for no, or minimal fee;
  - **exchangeable data**, not requiring specific protection measures to be shared via B2B or B2C agreements (with the exception of data of the same kind that qualify either as highly sensitive or critical sensitive).

  All types of data not belonging to the previous classifications (highly sensitive, critical and public), will be considered 'exchangeable'.

- **Data with high quality in dataspaces:** The EU demonstrates its commitment to data quality assurance, as exemplified by the effort conducted under ACER[38] quality assurance to establish high-quality transaction and fundamental data reporting. To address the evolving requirements of data spaces, it is imperative to develop frameworks and guidelines that specifically highlight data quality considerations. A cutting-edge approach to achieving this is by harnessing the power of Machine Learning (ML) and Artificial Intelligence (AI) algorithms. Training these models to detect anomalies, outliers, and data discrepancies, organizations can proactively identify and resolve data inaccuracies, thereby enhancing data quality.

Recommendations on investments and infrastructures.

- **Continuity of the data spaces.** A major risk in the functioning and running of established data spaces corresponds to the abandonment of one or more key actors (e.g., governance bodies, data providers, intermediaries). Dedicated supporting measures shall be established to minimize the effects of such situations for end-users and enterprises.
- **Openness of standards and interfaces.** To accelerate the knowledge sharing in the community and the development of new technologies and solutions, dedicated investments shall support the usage of open standards and the open APIs (e.g., interfaces for seamless onboarding of data). It is noteworthy that open-source elements of data spaces are available but not finalized yet and not customized for the needs of the energy sector.
- **Federated data spaces infrastructures.** A federation approach for data spaces is needed: the goal is to identify, connect and streamline the existing country level and domain specific data spaces and infrastructures in a bottom-up way. In doing so, federated infrastructures shall be able to accommodate not only data spaces but also key data hubs, platforms, distributed services and applications. Additionally, this orchestration of federated infrastructures shall

[36] European Data Protection Supervisor (EDPS) https://european-union.europa.eu/institutions-law-budget/institutions-and-bodies/search-all-eu-institutions-and-bodies/european-data-protection-supervisor-edps_en.
[37] Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation) (Text with EEA relevance) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2016.119.01.0001.01.ENG&toc=OJ%3AL%3A2016%3A119%3ATOC.
[38] ACER data quality - https://www.acer.europa.eu/remit/data-collection/data-quality.

consider the establishment of one or more registers for federated data spaces, each of which comply with dedicated certification.

Particularly, federation and linkage of data-sharing infrastructures should be supported by:

- Re-utilizing, to the highest degree, the existing deployments. The development of energy data spaces at national level must be compatible with a superordinate data space at European level.
- Alignment with the European approach to energy service interoperability expressed by Implementing Regulation (EU) 2023/1162 and follow-up acts, realizing the mandates given by Directive (EU) 2019/944, especially Articles 20-24.
- Promoting a broad application of eIDs and EIDAS while ensuring that natural persons can represent legal persons and other natural persons. Common means for identification and authentication between member states (and between data-sharing infrastructures) must be a core pillar, as highlighted in the communication "European Strategy for Data".
- Ensuring a well-defined mandate for data-sharing infrastructure operators, publicly available, clean and structured interfaces.

- **Hardware infrastructures.** Considering the extra-large volume of data that needs to be exchanged and stored in a distributed fashion, with performant computational requirements, dedicated infrastructures (e.g., scalable cloud-based combined with cognitive computing and edge solutions) are necessary and have to be realized. Particular attention must be placed on the energy consumption of the ICT sector, as stated in the "Digitalising the energy system - EU action plan": the adoption of technologies with low electricity consumption as well as circular models have to be prioritized. Outcomes of data and the related infrastructure models, such as CEI[39] focused on devising optimal edge to cloud computing continuums that should be considered, since one of the goals is prioritisation of data models at all enabling nodes.
- **Funding of data spaces deployments.** Bottom-up development of federated data spaces shall be achieved with public fundings addressing initiatives focused on specific use-cases as well as large horizontal ones to support pan European key legislations derived from the Clean Energy Package, RePowerEU and the new Electricity Market Design. Moreover, the sustainable funding of established solutions at the long run, rather than of new data spaces instances, shall be ensured to prioritize the focus on users' needs.
- **Measures to ensure the participation of consumers.** Specific measures must be put in place to reassure the consumers regarding the reliability, security, and privacy-compliance in the sharing of their own data. Economic benefit for the consumers consists of appropriate incentives, allowing to get back part of the investment in clean and smart technologies; in addition to developing consumer-centric solution, the technology shall be also affordable to all. Non-monetary benefits entail environmental advantages and are based on the social and behavioural needs. For example, the development of dedicated mobile applications and Graphical User Interfaces (GUI) for control of private energy assets consists of a reference starting point. Anyway, additional comprehensive instructive sessions on digitalization and energy solutions concepts, with dedicated tools, shall be continuously carried out.
- **Data privacy infrastructure.** To ensure secure data storage and transmission, a robust infrastructure with strong encryption protocols and secure communication channels must be established. This includes utilizing secure cloud storage solutions, implementing end-to-end encryption, and adopting secure data transfer protocols to protect data during storage and transmission. Regarding the access controls and user authentication, stringent related mechanisms shall be deployed to ensure that only authorized individuals can access and manipulate sensitive data. At this scope strong user authentication methods, such as multi-factor authentication, and role-based access controls are needed.

[39] CEI project https://eucloudedgeiot.eu/about/.

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