D4.2

Regulatory framework relevant for int:net

int:net

Interoperability Network for the Energy Transition

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ABSTRACT

Lack of interoperability is increasingly becoming a significant issue in the electricity sector. The need to integrate a growing amount of distributed resources, such as renewable energy sources and electric vehicles, means that interoperable energy services will play an increasingly vital role in maintaining the stability of the electricity system and enabling consumers to benefit from the energy transition. Much has been done to create a regulatory framework that can support the development of these new services and the related flexibility markets. However, the journey towards a completely digitalised electricity system which operates in a seamless way is still long. In light of this, this deliverable aims to provide policymakers and regulators with a series of considerations that may prove relevant when deciding how to improve the current regulatory framework. To develop these considerations, the main barriers to the development of interoperable energy services were identified through two main activities: a stakeholder analysis and an analysis of Horizon projects focused on the development of new flexibility services.

KEYWORD LIST

Interoperability, regulation, stakeholder analysis, Horizon projects, flexibility markets, standardisation, data sharing

DISCLAIMER

EXECUTIVE SUMMARY

The electricity sector is undergoing significant transformation, characterised by the integration of renewable and decentralised energy sources, alongside the emergence of digital technologies. This transformation brings both opportunities and challenges, particularly in managing the increasing volume of energy data and ensuring cybersecurity and data privacy within an expanding digital infrastructure.

Interoperability plays a crucial role in optimising energy flows and integrating diverse energy resources and sectors. However, achieving interoperability is complex and faces challenges across various dimensions. Among other barriers, market fragmentation, primarily caused by diverse regulations and standards across Member States, inhibits the realisation of interoperable energy services' benefits.

This deliverable aims to provide policymakers and regulators with relevant considerations to promote the development of interoperable energy services. To identify missing elements to realise a digitalised electricity sector, it is crucial to review existing knowledge. In this regard, the deliverable contributed by conducting a policy and regulatory review, engaging with stakeholders, and reviewing four R&I Horizon projects (i.e., OneNet, InterConnect, CoordiNet, and INTERRFACE).

Within the current policy framework, two main macro-strategies are identified, focusing on the data economy and energy transition. These strategies aim to harness the benefits of data usage across economic sectors and facilitate the transition towards a sustainable energy system. However, regulatory fragmentation remains a significant challenge, complicating the harmonisation of standards and consistent application of rules across markets.

The current regulatory framework aimed at fostering interoperable energy services falls short in steering stakeholders' decisions in this direction. In order to identify key barriers in the stakeholders' decision-making process, the stakeholder analysis conducted within T4.2 of the int:net project identifies three key dimensions: stakeholders' interest in developing interoperable energy services, participating in the (future) energy data space, and engaging with the int:net community. Fragmentation in the regulatory landscape poses a major challenge. This fragmentation complicates standard harmonisation and consistent rule application, hindering interoperable service deployment and complicating economic considerations for stakeholders. Additionally, stakeholders must address challenges such as privacy concerns, cybersecurity issues, infrastructure security, and consumer engagement to promote wider acceptance of innovative energy services. Despite stakeholder interest, a lack of understanding of the benefits of the energy data space, coupled with the absence of a supportive governance structure and clear regulatory guidelines, hinders participation and investments. Engagement within the int:net community faces sustainability concerns and ambiguity about its added value to stakeholders' core business activities, impacting commitment and participation.

The project analysis identifies significant technical barriers, alongside challenges stemming from insufficient stakeholder coordination, delayed implementations, and inadequate political guidance. Directed policy responses and clearer implementation guidelines could address these issues. Lagging standardisation contributes to proprietary solutions hindering interoperability, while governance concerns arise due to a lack of authority for standard adoption. Fragmentation complicates digitalisation efforts across the EU, with cybersecurity emerging as a key concern due to increasing vulnerabilities.

Emphasis is placed on robust data management, security protocols, and standards for data access and consumer privacy.

To address these challenges, several considerations are made. Firstly, incentivising stakeholders is crucial, particularly in sectors where the adoption of new technologies may be lacking. Regulatory adjustments and market-driven incentives can align stakeholder behaviours with system needs. Secondly, developing standards tailored to specific use cases is essential for ensuring technical and semantic interoperability. Mandating minimum interoperability requirements can enforce standards across the industry, fostering a competitive yet secure market environment. Addressing technical and organisational challenges is vital for successful implementation. Lessons learned from other sectors, such as telecommunications and healthcare, can inform strategies for accelerating the adoption of interoperable solutions in the electricity sector. Empowering consumers is also crucial for building trust and encouraging active participation in the evolving electricity markets.

In conclusion, while various tools are available to policymakers and regulators to promote interoperable energy services, careful analysis and collaboration among stakeholders are essential to overcome regulatory fragmentation and technical barriers. Further research and engagement activities within the int:net community will continue to drive progress towards a more interoperable and sustainable electricity sector.

CONTENTS

1 Introduction

The electricity sector is facing growing challenges with managing the complex and increasing flow of energy data due to the rise of renewable and decentralised energy sources, and the integration of various systems, such as building and mobility. These challenges include ensuring real-time data management, maintaining cybersecurity, and upholding data privacy across a sprawling digital infrastructure that is rapidly expanding in scale and scope. Effective interoperability is crucial for optimising electricity flows and integrating diverse energy resources like solar and wind power, which are intermittent and geographically dispersed [1]. In this regard, consumers can also benefit from interoperability development, for instance having access to a more reliable electricity system and offering grid services [2]. Additionally, interoperability is a prerequisite for the development of the energy data space, envisioned as an essential tool for orchestrating energy data flows.[1] But interoperability is multi-dimensional in nature and, therefore, developing interoperable energy services requires addressing all the barriers that arise across its various dimensions, from governance to technical aspects, while also considering the economic-regulatory dimension.[2]

Policymakers and regulators should always keep in mind which specific aspect of interoperability they aim to address. Their evaluations should not only reflect the particularities of the sector in question but also which dimension of interoperability their initiatives are intended to impact.

What is interoperability?

When discussing interoperability, the first step is obviously to consider its definition. Unfortunately, different definitions of interoperability can be found. Broadly speaking, interoperability refers to “the capability of two or more networks, systems, devices, applications, or components to exchange information among them and to use the information so exchanged” [5]. Among the other existing definitions some of them are more sector specific [6]. In any case, interoperability is not a binary concept but rather one of varying degrees, influenced by different approaches that lead to varying levels of openness. Moreover, interoperability is also a multi-dimensional concept that embrace aspects like governance, business and technical dimension of systems or organisations. This complexity entails that the barriers hindering the development of interoperable energy services are quite multifaceted.

[1] An energy data space is a digitally enabled environment where data exchange occurs securely and efficiently among multiple stakeholders within the electricity sector. This space is designed to support the interaction of data across various domains – energy production, smart home systems, electric mobility, etc. – under a unified framework that ensures data security, sovereignty, and compliance with regulatory standards. A data space reflects different objectives, as it enables data sharing, standardisation and compliance and consumer empowerment and innovation [3].

[2] Energy services include the provision of flexibility services to respond to the needs of the electricity system or to price signals from electricity markets. A review of the concept of energy services is offered by M. J. Fell [4].

The interoperability's multi-dimensional nature can be depicted in different frameworks, which define how organisations agree to communicate and share information. These frameworks exist not only in the electricity sector but also in sectors like public administration or healthcare. While the exact number of interoperability dimensions remains undefined, successful implementation requires consensus across all of them and the involvement of all pertinent stakeholders [7]. This deliverable refers to the SGAM framework as the reference.[3]

Market context can affect the options available for achieving interoperability but, broadly speaking, we can distinguish among three main categories: full interoperability, partial interoperability and data portability [8]. The most comprehensive form of interoperability, often termed "full protocol interoperability", is achieved through the widespread adoption of open and common technical standards. Such standards are foundational in sectors like telecommunications and have been crucial in the development of technologies like 5G and the internet itself through protocols like HTTP. This document mainly refers to this form of interoperability. When open standards are absent or unevenly adopted, a partial degree of interoperability can still be achieved. For instance, a company might facilitate interoperability between its service and another by providing the necessary proprietary technical specifications and interfaces. Sometimes, third-party services can serve as bridges, enabling interoperability among multiple services, like apps that allow users to transfer playlists among different music streaming platforms. Data portability, which often overlaps with interoperability, varies in form, from user-initiated downloads and transfers of data to more advanced, real-time data exchanges that necessitate standardised data formats or architectures, further enhancing interoperability. It is worth to mention that, additionally to standards, APIs (Application Programming Interfaces) are another common method to achieve interoperability. They can be "closed", limited to specific services, or "open", based on standards that foster broader interoperability. The range of data or functionalities that APIs allow access to can vary, influencing the degree of interoperability they enable. This spectrum of interoperability showcases its dynamic nature and its critical role in facilitating seamless interactions across different digital platforms and services.

Different degrees and dimensions of interoperability contribute to make its development quite complex: despite the clear advantages, achieving a high level of interoperability presents numerous challenges [1]. The electricity sector is marked by a vast array of technologies each developed with its own set of standards and protocols, creating significant hurdles in achieving seamless integration across different systems and devices. Additionally, regulatory frameworks often struggle to keep pace with rapid technological advancements, resulting in outdated standards that can stifle innovation and complicate the integration process. Security concerns are also amplified with increased connectivity. As more devices and systems become interconnected, vulnerabilities to cyber threats increase, posing risks to the stability and security of electricity network. Investment in robust cybersecurity measures is essential to protect electricity systems from potential cyber threats. Strengthening defences will ensure the integrity and reliability of the electricity infrastructure as it becomes more interconnected. Furthermore, fostering collaborations through public-private partnerships can help distribute the financial burden and pool resources for shared knowledge and technology development, easing the transition towards

[3] The interested reader can find further details here: https://syc-se.iec.ch/deliveries/sgam-basics/.

interoperable systems. In fact, the financial aspect cannot be overlooked; the costs associated with upgrading existing infrastructure to support interoperable systems are substantial. For many utilities or regions, especially those with limited financial resources, these costs can be prohibitive, further complicating efforts towards achieving interoperability. Moreover, enhancing data management capabilities is vital for handling and making sense of the vast amounts of data generated by interconnected systems. Sophisticated data management and processing frameworks are needed to analyse real-time data effectively, optimising electricity distribution to respond promptly to changing demand patterns.

Interoperability challenges are not exclusive to the electricity system but are prevalent across various economic sectors such as banking, telecom, transportation, manufacturing, and healthcare. The electricity system, however, faces unique complexities due to its vast scale, the multitude of stakeholders, and the need for real-time management. Progress in resolving interoperability issues will benefit all economic sectors. By recognising, learning from, and adopting strategies from these related efforts, we can foster synergies that enhance the likelihood of successful outcomes [5].

To address these issues, this deliverable aims to provide a series of considerations that should be taken into account by policymakers and regulators to foster interoperable energy services.

Objectives of the work reported

This deliverable primarily aims to provide a series of considerations for policymakers and regulators to promote interoperable energy services (and the energy data space). These considerations present a range of possible solutions to the lack of interoperability, each with its own pros and cons. Importantly, these considerations are not mutually exclusive, as multiple approaches can be implemented simultaneously depending on the context and the specific problem to be solved.

These considerations have been developed by creating a knowledge base built on experiences gathered so far on interoperable energy services. Although not exhaustive, these experiences were gathered by collecting viewpoints from various stakeholders in the energy, mobility, and building sectors and reviewing the results of four Horizon projects focused on the development of new flexibility services: OneNet, InterConnect, CoordiNet, and INTERRFACE. In light of that, this deliverable also meets another goal of the int:net project, which is to create a common base of knowledge around the theme of interoperable energy services.

Interacting with stakeholders through interviews conducted within the context of the stakeholder analysis, we have further contributed to another goal of the int:net project: the creation of the int:net community. In fact, during these interviews, it was possible to discuss stakeholders' expectations on the aforementioned community and to invite them to join it.[4]

[4] The int:net-interoperability network is formally established to exist beyond the project lifetime. With a comprehensive, FAIR knowledge platform and a series of attractive events, the int:net-community guides those who deal with the heterogeneous interoperability landscape of energy services. The interested reader can join the community using this link: https://community.intnet.eu.

To conclude, it is important to remark that the object of this deliverable is on the development of interoperable energy services. Although the main focus of this work is on interoperability issues, the development of the energy data space has also been considered. In fact, the energy data space can contribute to the development of interoperable energy services and is a topic of keen interest in both academic and regulatory contexts.

How to read this document

Reading this document requires limited prior knowledge about the topic, especially regarding the technical aspects of interoperability, which are not the main focus of this work. Chapters 2, 3, and 4 can be read quite independently of each other. Although Chapter 2 can be considered a common foundation for Chapters 3 and 4, these two chapters relate to two activities within T4.2 that were conducted completely independently. For an appropriate understanding of Chapter 5, however, it is recommended to be familiar with the concepts presented in the previous chapters.

Structure of the document

In addition to the initial introductory chapter and the concluding chapter, this deliverable consists of four main chapters. Deliverable structure is depicted in Figure 1.1.

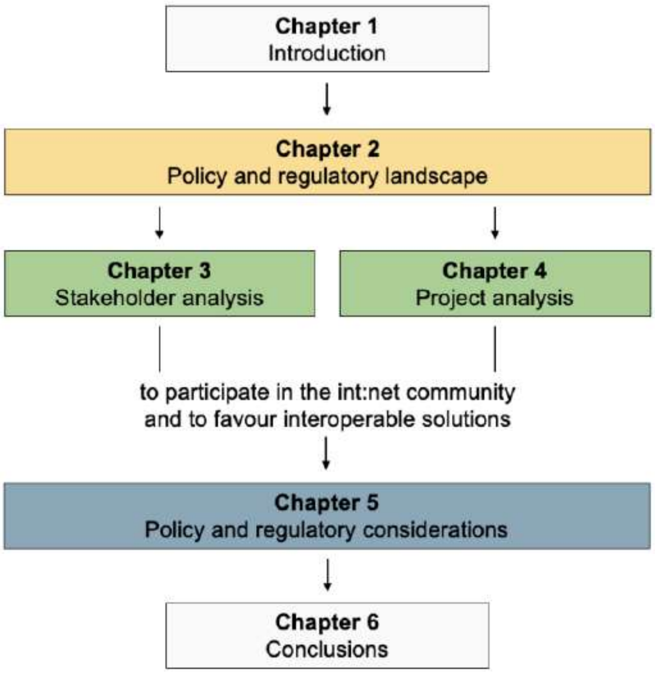

Figure 1.1 Structure of Deliverable 4.2.

Chapter 2 provides an overview of the current regulatory framework related to the development of interoperable energy services. More specifically, the chapter is divided into two parts. The first one is dedicated to the EC's strategic vision for the digitalisation of the electricity sector. The second part discusses the main legislative initiatives that have been implemented to support these strategies.

Chapter 3 presents the results of interviews conducted as part of a stakeholder analysis. This analysis aims to understand the main barriers stakeholders face in developing interoperable energy services, participating in the (future) energy data space, and their expectations regarding the int:net community.

Chapter 4 identifies the main barriers highlighted in four reference Horizon projects concerning the development of interoperable energy services: OneNet, InterConnect, CoordiNet, and INTERRFACE. The identified barriers have been grouped by common themes (e.g., standardisation, governance, cybersecurity) that reflect different aspects of interoperability.

Chapter 5 is devoted to presenting considerations that policymakers and regulators should keep in mind to promote the development of interoperable energy services (and the energy data space).

2 Policy and regulatory landscape

An ever-increasing volume of data is generated by machines or processes based on emerging technologies, such as Internet of Things (IoT), and is used as a key component for innovative services and products in the electricity sector. The ability to gather and access different data sources is crucial for innovation to thrive, while the provision of new interoperable energy services is possible as long as all sorts of devices can be interconnected and can exchange data (in real-time also). Therefore, access to data and data sharing practices are not only pivotal factors for unlocking competition and encouraging innovation but also for managing the electricity system securely. Looking beyond the electricity sector, the data economy is expected to account for about 4% of the GDP in the 27 EU countries and the UK by 2025, based on a baseline scenario from the EC [9].

However, numerous actions must still be taken to unlock this potential. In fact, the potential of the data economy is currently constrained by market fragmentation, which is exacerbated by varying regulations and standards across Member States (MSs). This fragmentation has led to the development of non-interoperable systems and services tailored to specific local needs, which now obstruct the cross-border flow of data and hinder the development of new services [10]. In this regard, the EC has long undertaken a series of legislative actions aimed at creating a favourable environment for the development of new technologies and services. These initiatives are part of a strategic policy framework that also aims to be in line with the goals of the energy transition.

The purpose of this chapter is to present this overall strategic vision and subsequently the main legislative initiatives that have been promulgated or are in the process of being approved to actualise the aforementioned policy. This chapter does not aim to be exhaustive about the policy and regulatory framework pertaining to energy and digital topics but aims to offer a high-level description of the legislative initiatives that are primarily linked to the development of interoperable energy services. Firstly, we present the policy framework related to the development of interoperable energy services. Then, we show how this policy framework has been implemented through various regulatory initiatives. Lastly, some regulatory issues related to data economy and interoperability are discussed.

From data economy to interoperable energy services: a European perspective

The policy framework related to the development of interoperable energy services is defined by a European strategy for the data economy and a strategy for the implementation of the energy transition. These two strategies actually consist of a set of different strategies that have been outlined in the context of various communications produced by the EC. They have been identified to facilitate the presentation of the current policy framework and should not be understood as completely independent. In this section, we first present the strategies related to the data economy, followed by those concerning the energy transition.

Data economy strategies

The EC released a series of policy documents that articulate its plan for a Europe fit for the Digital Age.[5] This includes the European strategy for data (Data Strategy), which was launched alongside a Commission communication titled Shaping Europe's digital future (Digital Strategy), and a White Paper on Artificial Intelligence (AI). These documents collectively express the Commission's aspiration for the EU to become a frontrunner in the data economy by collaboratively addressing issues such as data availability, computational capacity, and cybersecurity, while upholding individual privacy rights and fostering competition among major technology firms.

The Digital Strategy reveals the Commission's vision for digital transformation, aiming to produce technology that benefits people, supports a fair and competitive economy, and promotes an open, democratic, and sustainable society [11].

The Data Strategy, a key element of the overarching Digital Strategy, aims to articulate a detailed framework for Europe's data economy [12]. It emphasises the importance of data-driven innovation, primarily focused on increasing citizens' benefits. The strategy emphasises enhancing the accessibility and circulation of high-quality data for utilisation and re-utilisation, recognising data as a pivotal resource for economic growth. Specifically, the strategy aims to forge a unified European data market and outlines the need to:

- develop legislative measures and governance frameworks to guarantee data availability;
- address data monopolisation issues;
- invest in standards, tools, infrastructure, and skills necessary for data management.

Additionally, to augment the foundational measures laid out by the Data Strategy, there is a focus on creating common European data spaces across vital sectors such as healthcare, energy, and finance, to overcome barriers to data sharing. These sectors aim to boost data availability, quality, and interoperability. The operational guidelines for these data spaces are delineated in the Data Act and various sector-specific legislations, such as those pertaining to the European Health Data Space. Data spaces are envisioned to include data sharing tools and services, data governance structures, and improvements in data availability, quality, and interoperability. Participation is voluntary, with data reuse being compensated or offered for free, depending on the data holder's decision. Key principles include data control, governance ensuring fair access to data, adherence to EU rules and values (e.g., data protection, consumer protection, competition law), technical data infrastructure development, and openness to all organisations complying with EU rules [13].

Also in the Data Strategy interoperability is identified as crucial for enabling seamless information exchanges across administrative boundaries. Although a specific strategy to promote interoperability in the electricity sector has not been enacted, various sectors are facing similar challenges, and therefore attention has also been given to initiatives pertaining to other sectors. For instance, the implementation strategy for the European Interoperability Framework aim to enhance the digital collaboration across public administrations within the EU to support the digital single market [14]. The primary goal is to

[5] The interested reader can find more information here: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age_en.

streamline and enhance the efficiency, effectiveness, and user-centricity of public services through increased interoperability. This initiative recognises the need for public services to become fully digitalised to reduce costs, save time, increase transparency, and improve service delivery across MSs. The communication proposes an updated interoperability framework and action plan that increase the specificity of recommendations and focus on practical implementation. This includes the adoption of common data formats, improved data management, and enhanced governance of interoperability initiatives. Furthermore, the framework emphasises the importance of engaging stakeholders and raising awareness about the benefits of interoperability to ensure that services are designed and delivered with end-user involvement.[6]

Energy transition strategies

The EC set its strategy to address climate change in the European Green Deal, which aims to transform the EU into a sustainable and climate-resilient society by 2050 [15].[7] The Green Deal outlines actions across all sectors of the economy: energy, industry, buildings, and transport, each becoming more interconnected and efficient through digital solutions. It stresses the importance of an interconnected energy market, the use of digital tools for energy management, and the development of smart infrastructures that can support sustainable practices across the board. Pillar of this strategy is also the enhancement of digitalisation and interoperability across various sectors to facilitate the green transition. The deal emphasises the need for digital tools and smart technologies in energy systems, building renovations, and transportation networks to improve efficiency, manage resources better, and reduce emissions. Digitalisation supports the integration of renewable energy, optimises energy consumption in buildings, and contributes to smarter mobility solutions that can dramatically decrease urban congestion and pollution.

As part of the European Green Deal, the EC presented an EU strategy for energy system integration [16]. Central to this vision is the concept of an integrated energy system that operates as a unified whole, linking various energy carriers, infrastructures, and consumption sectors. The strategy emphasises the need for a more circular energy system, prioritising energy efficiency, reusing waste streams, and optimising resource use to reduce overall energy demand. Specific actions and legislative measures to achieve this vision are outlined, emphasising the need for immediate and coordinated efforts across all levels of governance and among all stakeholders.

A significant aspect of the strategy is the acceleration of electrification, particularly through the adoption of renewable energy sources for heating, cooling, and transport. The document highlights the potential of renewable and low-carbon fuels, including hydrogen, to decarbonise sectors that are challenging to electrify directly. The strategy also addresses the importance of creating electricity markets that support decarbonisation and the integration of distributed energy resources. This involves ensuring that market

[6] The interested reared can find further information here: https://joinup.ec.europa.eu/collection/nifo-national-interoperability-framework-observatory/european-interoperability-framework-detail.
[7] For a complete overview about the EU Green Deal, the interested reader can find further information here: https://fsr.eui.eu/publications/?handle=1814/75156.

mechanisms and pricing structures reflect the true costs and benefits of different energy carriers, promoting the most efficient and sustainable options.

Digitalisation plays a vital role in supporting energy system integration. The strategy underscores the need for advanced digital technologies such as Big Data, AI, 5G, and distributed ledger technologies to enable dynamic energy flows, real-time data matching of supply and demand, and remote monitoring and management of distributed energy resources. The adoption of interoperability requirements is proposed to enhance digitalisation and data exchange within the electricity sector.

In the energy landscape, a particular attention has been dedicated by the EC to three specific sectors: offshore renewable resources, transport and building. For each of these sectors, a specific strategy has been published.

To optimise the integration and management of (offshore) renewable resources within the European energy system, digitalisation, interoperability, and data exchange are necessary prerequisites. The key issue is to guarantee that different energy production and management systems can effectively communicate and coordinate, which is crucial for integrating a higher share of renewable energy into the grid. Moreover, digital tools and AI are seen as essential for optimising the design, operation, and maintenance of renewable energy infrastructures, thereby reducing costs and environmental impacts [17].

The Sustainable and Smart Mobility Strategy aims to transform the transport sector into a more sustainable, smart, and resilient system addressing the need for reducing greenhouse gas emissions and enhancing operational efficiency across all modes of transportation [18]. By leveraging technological advancements, digital solutions, and data-driven insights, the strategy seeks to improve the connectivity and interoperability of transport systems across the EU, thereby ensuring that mobility is sustainable, accessible, and efficient for all citizens. Interoperability is addressed through the promotion of seamless and efficient connectivity across various modes of transportation. The strategy highlights the importance of integrating intelligent transport systems and smart digital solutions to ensure that different transport systems work together smoothly. This includes the development and deployment of technologies like the European Rail Traffic Management System and enhancements in air traffic management to reduce CO_2 emissions and improve operational efficiency. The concept of a European Common Mobility Data Space is introduced to facilitate better data sharing and management across the transport sector. This data space aims to collect, connect, and make available a wide range of transport-related data to support EU objectives such as sustainability and improved multimodality. It is designed to function in synergy with other key systems like energy, satellite navigation, and telecommunications, ensuring comprehensive data integration and utilisation. Data management is also addressed with a focus on the availability, accessibility, and exchange of transport-related data. Lastly, the strategy proposes establishing a harmonised framework for measuring and reporting greenhouse gas emissions from transport and logistics, enhancing transparency, and enabling more informed decision-making. It also emphasises the importance of ensuring data interoperability and the secure sharing of data within the transport sector to avoid fragmentation and promote uniform standards across the EU.

The Renovation Wave initiative mainly aims at enhancing the energy efficiency and sustainability of buildings across Europe [19]. The primary goal is to double the annual energy renovation rate of buildings by 2030 to foster deep energy renovations, supporting the EU's broader objectives of achieving climate neutrality by 2050. A significant emphasis is placed on digitalisation of the building sector. The strategy highlights the integration of smart technologies and digital tools as key enablers for modernising Europe's building stock. Digital solutions, such as the Smart Readiness Indicator, are promoted to enhance the functionality and energy management of buildings, making them more adaptive to the needs of users and the electricity grid. In fact, these technologies can facilitate the transition towards smart buildings that are capable of efficient energy use, integration of renewable energy sources, and provision of data essential for optimised building management and city planning.

The energy sector has been the focus not only of these sector-specific strategies but also of a strategy aimed at promoting the digitalisation of the energy sector at large, the EU Action Plan Digitalising the Energy System [20]. The EU Action Plan champions the digital transformation as essential for achieving the goals of the European Green Deal and REPowerEU. It highlights the crucial role of deploying advanced digital technologies such as IoT devices, smart meters, 5G/6G connectivity, and digital twins of the energy system. These technologies are expected to enhance the functionality of the electricity grid, enable real-time electricity management, and support the widespread adoption of renewable energy sources. A core aspect of the EU's digital strategy is to improve interoperability across the European energy sector for the integration of diverse energy systems and for fostering innovation in energy services. In this regard, the Action Plan proposes the creation of a common European energy data space by 2024, aiming to facilitate the seamless and secure exchange of data among various stakeholders. Addressing the challenges of digitalisation, the strategy acknowledges the need for robust governance and coordination. It calls for enhanced EU-wide frameworks that support the interoperability among different systems and technical solutions. The strategy involves setting up regulatory environments that encourage innovation while ensuring consumer protection and cybersecurity. Moreover, the plan discusses the establishment of strategic groups and task forces to guide the deployment of digital infrastructures and to oversee the development of interoperability standards.

These strategies have found applications in various legislative acts that will be presented hereinafter.

A wide regulatory landscape

Interoperability is a multi-dimensional topic, and, from a regulatory perspective, the development of interoperable energy services is situated at the intersection of several regulatory initiatives, as illustrated in Figure 2.1. In a similar vein to what has been done for the policy framework, two main regulatory areas can be identified in the regulatory landscape relevant for interoperable energy services: one related to the data economy, one related to the energy transition. The regulatory area of the data economy is the broadest in scope. It aims to define rules and general principles that impact various sectors – not just the electricity sector – and is comprised of the legal tools through which to implement the European Digital Strategy. The regulatory area of energy transition consists of regulatory actions aimed at regulating more specific sectors. In this area, an overarching sector is identified by the regulation related to electricity markets. Other three sectors can be seen as specific sectors that are determinant for the development of interoperable energy services: renewables, mobility, and buildings. Additionally to these regulatory areas, other cross-sectoral elements of the regulatory landscape can be considered: the data privacy and cybersecurity regulation. In fact, they define relevant aspects to be taken into consideration for the development of interoperability. The identification of two key regulatory areas and two cross-sectoral regulatory elements is not intended to have legal significance, but simply aims to provide a high-level framework to navigate the complex system of legislative actions that can impact the development of interoperable energy services.

In the following section of this chapter, the main legislative initiatives undertaken by the EC in the designated framework are presented. We have considered not only the legislation that has been passed but also that which is under revision, for which proposals are available at the time of writing.

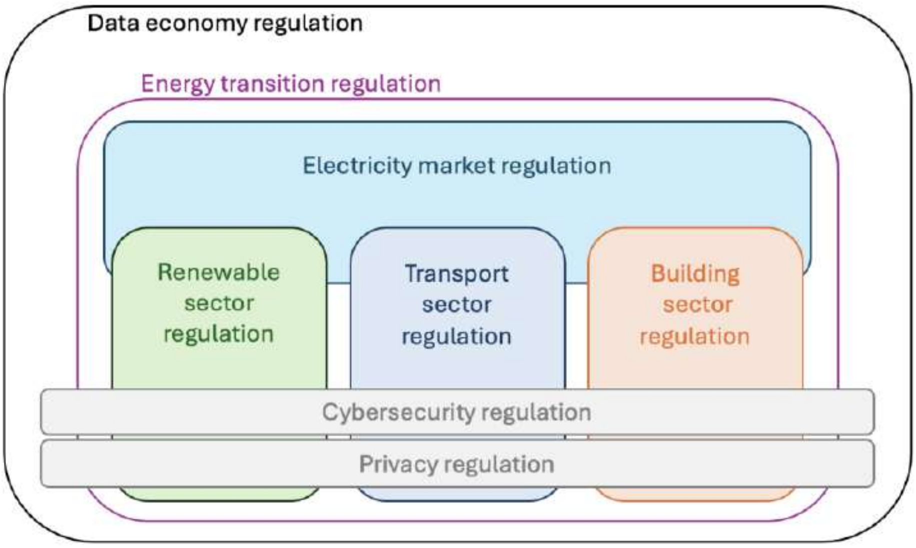

Figure 2.1 The regulatory framework relevant for the development of interoperable energy services.

Data economy regulation

In this section, the main legislative initiatives related to the data economy which are also relevant to the development of interoperable energy services are presented. More specifically, they are:

- the Data Governance Act,
- the Digital Market Act,
- the Data Act,
- the Implementing Act on High-Value Datasets, and
- the Artificial Intelligence Act.

Data Governance Act

Regulation (EU) 2022/868, commonly known as the Data Governance Act (DGA), establishes a framework for data governance within the EU, enhancing the mechanisms for sharing and reusing data across various sectors while ensuring high levels of data protection and security [21]. This legislation responds to the evolving digital landscape, recognising the central role of data in economic and societal transformation.

The DGA sets out to create a structured environment for data usage that ensures fairness, trust, and security in digital markets. It emphasises the establishment of common European data spaces across diverse sectors such as health, mobility, agriculture, energy, and public administration. These spaces are designed to make data accessible, interoperable, and reusable under the FAIR principles

(Findability, Accessibility, Interoperability, and Reusability), supported by robust cybersecurity measures.

A significant aspect of the regulation is its approach to handling sensitive and protected data, which includes personal data and commercially confidential information. The DGA delineates conditions under which such data can be shared and reused, focusing on ensuring that privacy and confidentiality are not compromised. It advocates for technical solutions like anonymisation and pseudonymisation and promotes the establishment of secure processing environments managed by public sector bodies.

Additionally, the DGA introduces the concept of data altruism, encouraging individuals and organisations to share data for the common good under regulated conditions. It outlines specific provisions for data intermediation services, setting a regulatory framework that ensures these services operate under strict neutrality, avoiding conflicts of interest and fostering a transparent data sharing ecosystem.

To enforce these regulations, the DGA provides mechanisms for oversight and compliance, ensuring that data governance across the EU adheres to the established principles and safeguards fundamental rights and freedoms. This regulation aims to foster a harmonised digital market, boosting innovation and ensuring that data-driven benefits reach all sectors of the economy and society, aligning with broader EU policies such as the European Green Deal.

Digital Market Act

Regulation (EU) 2022/1925, known as the Digital Markets Act (DMA), is a legislative framework designed to ensure fair and contestable markets within the digital sector, particularly addressing the dominance of large digital platforms known as gatekeepers [22]. These platforms, crucial in facilitating business and consumer interactions, have raised significant concerns due to their market dominance, characterised by strong network effects and control over vast amounts of data, which potentially stifle competition and innovation.[8]

The DMA aims to enhance the internal market's functioning by preventing these gatekeepers from abusing their market position to the detriment of consumers, business users, and the market itself. It defines gatekeepers based on their size, user reach, and the entrenchment of their market position, setting criteria that include controlling access to a large number of users and having a durable market presence.

To ensure competitive fairness, the DMA imposes obligations on these gatekeepers, such as ensuring interoperability and access to services and data, prohibiting unfair practices like blocking the uninstallation of pre-installed apps, and mandating transparency, especially in online advertising. These measures are designed to prevent conditions that could mislead or unfairly disadvantage business users and consumers.

[8] Network effects can actually be divided in direct and indirect [23]. Direct network effects are observed when the value of a platform increases for all users as more individuals join the network, as seen in social networks. Indirect network effects occur when digital platforms facilitate interactions across different user groups within an ecosystem, creating multi-sided markets.

Enforcement and compliance are overseen by the EC, which holds the authority to impose fines and other penalties for non-compliance. Additionally, the regulation includes provisions for periodic reviews and adjustments to adapt to the evolving digital landscape, ensuring its relevance and effectiveness in promoting a competitive market environment.

Data Act

The Regulation (EU) 2023/2854 establishes a comprehensive legal framework for the access and utilisation of data across the EU [24]. This regulation ensures that data generated by connected products and services can be accessed and used seamlessly across borders and sectors. In fact, a significant focus of the regulation is on promoting interoperability to overcome the fragmentation of the digital market. It also promotes the establishment of a unified European data space, setting essential requirements to facilitate interoperability.

The Data Act (DA) encompasses several key areas related to data management. It establishes a regime for data access that mandates data holders, such as manufacturers of connected devices, to provide users with access to data generated by and related to their usage of these devices. It mandates that data holders provide fair, reasonable, and non-discriminatory access to data not only to the users of connected devices but also to third-party entities authorised by these users.

Additionally, it allows users to authorise the transfer of their data to approved third-party recipients (excluding gatekeepers defined under the DMA). This is contingent upon certain conditions, including limitations on using the data to compete with the data holder and the stipulations concerning the contractual agreements necessary for data sharing. While the DA considers the role of data intermediaries as outlined in the DGA, it does not obligate their involvement in facilitating data sharing.

Furthermore, the DA includes measures that obligate cloud service providers to assist customers in transitioning to other providers. This includes enforcing specific mandatory terms regarding termination rights and associated fees. Similar to the DGA, the DA also enforces regulations on cloud services regarding the transfer of non-personal data outside the European Economic Area. In addition to facilitating access, the regulation reinforces the protection of personal data, aligning with the stringent standards set by existing EU data protection laws, such as the General Data Protection Regulation (GDPR). It ensures that any access to or processing of personal data adheres to the highest levels of data security and privacy.

Lastly, the Data Act stipulates regulations for operators of data spaces and sets minimum standards for smart contracts used in data sharing. These provisions aim to standardise and secure the process of data interchange.

Implementing Act on High-Value Datasets

The Commission Implementing Regulation (EU) 2023/138 outlines specific arrangements for the publication and reuse of high-value datasets, aimed at enhancing data accessibility across the EU [25]. This regulation supports the broader goals of the Open Data Directive (Directive (EU) 2019/1024), which encourages the use and reuse of public sector information.

The regulation details the classification of high-value datasets, which include categories like geospatial, earth observation and environment, meteorological, statistics, companies and company ownership, and mobility. These datasets are recognised for their high socio-economic benefits and potential to foster innovation across borders.

Key provisions of the regulation ensure that these datasets are made available with minimal legal and technical restrictions. They must be accessible in machine-readable formats and through APIs to facilitate ease of use and integration into various applications and services. Additionally, the regulation mandates that these datasets be provided free of charge, although certain exceptions are specified for datasets held by public undertakings where charging could avoid market distortion.

To safeguard personal data, the processing related to the reuse of these datasets must comply with the EU's strict data protection regulations, such as the General Data Protection Regulation (GDPR). MSs are encouraged to use advanced techniques like anonymisation to maximise data availability while protecting individual privacy.

Furthermore, the regulation stipulates that all datasets must be labelled as high-value in metadata descriptions to enhance their discoverability. It also lays out detailed requirements for maintaining and updating these datasets, ensuring they remain useful and relevant over time.

By standardising the access and reuse conditions of these high-value datasets, the regulation aims to strengthen the EU's data economy, supporting cross-sector innovation and providing valuable resources for research and development across the region.

AI Act

Another element of the Digital Strategy involves positioning the EU as a leading global centre for AI, with a strong focus on developing AI that is both human-centric and reliable. This initiative has prompted the drafting of the Artificial Intelligence Act (AI Act), which is undergoing trialogue negotiations at the time of writing.[9]

The AI Act is set to establish specific responsibilities for manufacturers, importers/distributors, and users (deployers) of AI systems within the EU, particularly targeting those identified as 'high risk'. High-risk AI systems are defined as those posing significant health and safety risks (for example, AI used in medical devices or safety equipment) or threats to fundamental rights (such as AI applications in asylum and border control or in the management of judicial and democratic processes). Manufacturers, and to some extent users, of these high-risk AI technologies will be required to conduct thorough risk management, fundamental rights assessments, and conformity checks, and to address any instances of non-compliance. The regulation will also set standards concerning the design of AI systems and the data used in their development.

In addition to regulating high-risk AI, the AI Act will ban certain types of AI applications, establish duties for providers of general-purpose AI systems and foundational models (like generative AI), and mandate transparency requirements for specific AI systems, including chatbots. Furthermore, it will introduce overarching principles for AI that apply universally.

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[9] The preliminary text is available at: https://www.europarl.europa.eu/doceo/document/TA-9-2024-0138-FNL-COR01_EN.pdf.

The legislation will be supported by the Artificial Intelligence Liability Directive, which aims to simplify the process of proving harm caused by AI systems. This includes introducing rebuttable presumptions of causation, especially relevant for high-risk AI systems, to address these legal challenges.

Box 2.1 Competition law in the context of the data economy

Competition law, also known as antitrust law, is designed to ensure fair competition in the marketplace by preventing monopolies and other business practices that could harm the competitive landscape. This legal framework is vital as it fosters innovation, guarantees lower prices, and ensures a wider choice for consumers. Interoperability has been recognised as a critical aspect also in competition cases [26].

The essential facilities doctrine prohibits a dominant firm from using a market bottleneck it controls as an entry barrier. This doctrine is especially pertinent in the digital economy where large online platforms control essential infrastructures that competitors rely on, and often, these platforms also compete in the markets they enable [27]. Digital platforms, by their very nature, present unique challenges to traditional competition law frameworks. Their operation spans across vast networks, often creating environments where network effects can reinforce monopolistic tendencies. This means a platform becomes more valuable as more users join, which can quickly lead to a single or few platforms dominating the market. For example, in digital marketplaces, these platforms can control not only the means through which goods and services are marketed and sold but also hold crucial data on consumer and supplier behaviour, which can be leveraged to further strengthen their market position [26].

The relevance of competition law in the context of digital platforms lies in addressing these complex scenarios. It becomes crucial to assess how platforms manage the interplay among various market sides – such as consumers, advertisers, and third-party sellers – to ensure they do not abuse their dominant position. For instance, a platform could favour its own services over those of competitors or use its control over data to disadvantage competitors in subtle but significant ways [*ibidem*].

Therefore, the application of competition law in digital platform contexts aims not only to manage direct abuses of market power but also to ensure that the market remains contestable and open to new entrants. This is particularly important in fostering an environment where innovation can thrive without being stifled by established players, maintaining a dynamic and competitive digital economy.

Energy transition regulation

The European Climate Law commits the EU to a binding target of achieving climate neutrality by 2050, with an intermediate goal of reducing emissions by at least 55% by 2030 [28]. Furthermore, the regulation of electricity markets has been continuously updated to keep pace with the integration of new technologies necessary to achieve the goals of this transition. This section explores three initiatives related to the development of electricity markets that are particularly relevant to the development of interoperable energy services, as well as three initiatives promoted under the EU Green Deal. More specifically, they are:

- the Electricity Directive 2019/944,

- the Implementing Regulation (EU) 2023/1162,
- the Network Code on Demand Response,
- the Revision of the Renewable Energy Directive,
- the Alternative Fuel Infrastructure Regulation, and
- the Energy Performance of Building Directive.

Electricity Directive 2019/944

The Directive (EU) 2019/944 aims to establish a fully operational and integrated internal market for electricity within the EU ensuring that electricity markets operate competitively and efficiently, fostering also consumer choices [29]. It discusses at length the concept of interoperability within the EU's electricity markets. The directive underscores the critical need for enhanced interoperability to achieve an integrated, competitive internal market for electricity. This involves ensuring that various national electricity systems, communication networks, and other infrastructural components can work together seamlessly to facilitate efficient and smooth electricity trading across borders.

A significant emphasis of the directive is on the deployment and utilisation of smart metering systems that are interoperable. These systems are designed to not only facilitate real-time energy management and consumer engagement but also to support the broader integration of renewable energy sources into the grid. Moreover, the directive addresses the importance of transparent and non-discriminatory access to metering and consumption data, which are essential for enabling services such as customer switching and demand response (DR).

The directive also considers interoperability as a foundational element in supporting new forms of consumer participation in the energy market and enhancing cross-border cooperation. This is particularly important as the electricity market evolves to accommodate more decentralised production and the widespread use of renewable energy sources.

Implementing Regulation (EU) 2023/1162

In compliance with Article 24 of the Electricity Directive (EU/2019/944) and with the Digitalisation of Energy Action Plan, in 2023, the EC adopted an implementing act to improve access to metering and consumption data. The Implementing Regulation (EU) 2023/1162 outlines specific requirements and procedures to ensure interoperability and facilitate access to electricity metering and consumption data across the EU [30].[10]

It mandates that all metering and consumption data systems should be capable of interacting seamlessly with each other, enabling efficient data exchange and access. This is crucial for ensuring that consumers, suppliers, and other market participants can access and utilise data effectively, which is essential for operational efficiency and innovation in energy services.

The regulation also introduces non-discriminatory and transparent procedures for accessing metering data. It specifies that data must be accessible to eligible parties in a manner that is timely, simple, and

[10] At the time of writing two more implementing acts are awaiting publication.

secure. Moreover, it ensures that consumers have control over their data, requiring explicit permissions for data access by third parties, which aligns with broader EU data protection standards.

Additionally, the document highlights the need for a standardised approach to data access across MSs, which involves establishing a reference model for data interoperability. This model lays out common rules and procedures to be adopted at the national level, accommodating specific national conditions while maintaining a unified framework across the EU.

Network Code on Demand Response

The Network Code on Demand Response draft proposal outlines comprehensive guidelines focused on improving interoperability and data management within the EU's electricity sector.[11] These guidelines are essential for facilitating a flexible, efficient, and responsive electricity system capable of integrating diverse energy resources and managing demand effectively.

Interoperability is a major issue in the proposal, emphasising the need for standardised processes that enable seamless switching and management of controllable units across different service providers. To enhance this capability, the EC, along with relevant entities like ENTSO-E and the EU DSO Entity, is directed to develop non-discriminatory requirements and procedures. These procedures aim to establish clear rules for data exchange and ensure that service providers can easily take over the management of units previously controlled by others. Furthermore, the proposal mandates the establishment of interoperability across all energy services within the EU, creating a unified operational framework that supports efficient service and data exchanges among market participants.

Data management is equally critical in the proposal, which calls for fully digitalised, secure, and easily integrable data exchange protocols. All system operators (SOs) are required to utilise advanced digital tools to ensure that data handling is secure and meets high cybersecurity standards. The proposal also introduces the concept of a ‘common front-door’ for registration modules, suggesting a unified approach to data handling that simplifies and standardises the process across the EU. This approach is expected to facilitate the management of diverse data sources and maintain consistency in data usage and privacy.

Moreover, the proposal addresses the simplification and standardisation of product prequalification processes. This is intended to reduce barriers and allow for the easier integration of standardised devices across Europe, supporting national and pan-European applications like balancing, congestion management, and voltage control. Additionally, efficient digital consent management capabilities are emphasised to ensure transparent and effective handling of data consents in a highly active digital energy market.

[11] The drafted proposal is available at: https://consultations.entsoe.eu/markets/public-consultation-networkcode-demand-response/supporting_documents/Network%20Code%20Demand%20Response%20v1%20draft%20proposal.pdf.

Revision of the Renewable Energy Directive

Overall, the directive stresses the importance of advanced data management and interoperability across systems to enhance energy efficiency, grid stability, and the broader transition towards sustainable energy solutions within the EU [31]. To facilitate the integration of renewable electricity more effectively, MSs must ensure that SOs provide detailed, timely data about the share of renewable electricity and the greenhouse gas emissions content of electricity in each bidding zone. This data should be available in intervals matching the market settlement frequency, enhanced with forecasts where possible. Moreover, if distribution SOs lack access to necessary data, they are to utilise existing data reporting systems under Directive (EU) 2019/944, with incentives provided for smart grid enhancements to improve real-time data monitoring and grid balance.

Additionally, the text outlines that data must be shared digitally in formats that ensure interoperability, allowing non-discriminatory use by various electricity market participants. This includes the ability for data to be interfaced with smart metering systems, EV charging points, and various building management systems.

Further regulations require manufacturers of batteries and vehicles to provide real-time access to essential management data, ensuring that battery owners and other stakeholders, such as building energy management services and electricity market participants, can access this information under fair, cost-free, and privacy-compliant conditions.

Lastly, the document discusses the need for MSs to support the participation of small or mobile energy systems – like domestic batteries and electric vehicles – in electricity markets. This includes providing technical standards for participation and ensuring a non-discriminatory environment for these decentralised energy sources, enabling them to contribute to grid management and flexibility services through aggregation. MS shall promote as well smart charging system and smart management system of energy in buildings.

Alternative Fuel Infrastructure Regulation

The EU Regulation 2023/1804 aims to ensure the widespread deployment of an alternative fuels infrastructure across the EU [32]. Defining interoperability requirements, it also mandates the standardisation of infrastructure for alternative fuels.

The Regulation emphasises the importance of creating a seamless and user-friendly network of recharging stations across the EU, which will not only support the current needs but also anticipate future demands. It introduces mandatory minimum targets for recharging points, ensuring they are accessible to the public and capable of servicing multiple types of vehicles including electric and hydrogen-powered ones.

Digitalisation plays a crucial role in this framework, focusing on smart technologies that enhance the efficiency and effectiveness of the infrastructure. These include real-time data exchange, smart metering systems that facilitate efficient energy use, and user-friendly payment and service information systems. The Regulation promotes interoperability across different systems and MSs, ensuring that EVs can easily recharge or refuel anywhere in the EU without compatibility issues.

Energy Performance of Buildings Directive

The EC proposal discusses the need for MSs to facilitate a competitive and innovative market for smart building services that enhance energy efficiency and integrate renewable energy in buildings. This involves ensuring that all stakeholders, including building owners, tenants, and managers, have direct access to data from building systems [33]. Access to this data can also be granted to third parties upon request, supporting investments in building renovation and the broader adoption of smart building technologies.

To streamline this process and avoid imposing excessive administrative costs on third parties, the text emphasises the importance of full interoperability of services and data exchange within the EU. This interoperability is essential for ensuring seamless communication and functionality across different building management systems and services.

The directive specifies that building systems data should include information related to the energy performance of building elements and services, building automation and control systems, meters, and charging points for electric mobility. MSs are tasked with defining the rules for managing and exchanging this data, ensuring that the regulations align with the existing EU legal framework.

Furthermore, the text stipulates that no additional costs should be charged to building owners, tenants, or managers for accessing their data or for making it available to third parties. However, charges for access to this data by other eligible parties, such as financial institutions and energy service providers, should be set by MSs and must be reasonable and justified.

Finally, the EC is set to adopt implementing acts that detail the interoperability requirements and establish non-discriminatory and transparent procedures for data access. These acts will ensure that data access and storage comply with relevant EU laws, including regulations on the protection of personal data, thus supporting the safe and effective implementation of smart building technologies across the EU.

Cross-sectoral elements

As previously mentioned, cybersecurity and data privacy are two key aspects of developing interoperability (these aspects are addressed in more details later in this deliverable). This section provides an overview of the main regulatory initiatives related to these two topics.

The Directive on Measures for a High Common Level of Cybersecurity across the Union (Directive (EU) 2022/2555) or NIS2 Directive expands the sectors that must adhere to network and information security requirements established under the earlier Directive on Security Network and Information Systems (Directive (EU) 2016/1148), also known as the NIS Directive [34]. This expansion includes changes in the scope of some obligations. Furthermore, the Cyber Resilience Act is set to establish cybersecurity responsibilities for providers of certain digital products [35].

In terms of privacy considerations, the Digital and Data Strategies emphasise a user-centric approach while ensuring that privacy rights are respected. The General Data Protection Regulation (GDPR) is applied comprehensively across all new laws to ensure that data sharing, interoperability, and advertising transparency adhere to stringent data protection standards [36].

GDPR principles are integrated by some of the regulations presented above:

- the DMA stipulates that gatekeeper consent for actions like data combination across platforms must comply with GDPR standards;
- the DMA address manipulative practices, aligning with the European Data Protection Board's guidelines on “dark patterns” under the GDPR;
- similar to existing privacy laws, the DGA and the DA regulate the international transfer of non-personal data, which can be challenging for organisations that handle both personal and non-personal data.

These legislative updates reflect a commitment to enhancing digital resilience while upholding robust data privacy and protection standards across the EU.

Some regulatory challenges on data economy and interoperability

Navigating the regulatory landscape of digital platforms involves addressing a complex array of challenges that stem from the unique dynamics of these platforms and their impact on competition and consumer protection. Their evolution can also contribute to shape new business models emerging around interoperable energy services. Digital platforms, by aggregating vast amounts of user data and leveraging network effect, can create high entry barriers for new entrants and consolidate market power in the hands of a few dominant players. This can inhibit competition, making it crucial for regulatory measures to maintain market contestability and fairness. These measures must curb anti-competitive practices such as self-preferencing and ensure mechanisms like data portability and interoperability to lower entry barriers and enhance innovation. However, defining and regulating market boundaries in the digital platform ecosystems pose additional challenges due to their multi-sided nature, where actions that benefit users on one side may harm those on another.[12] This complexity requires a regulatory framework that is flexible yet robust enough to prevent market abuse while fostering innovation, a balance that is pivotal to prevent stifling the transformative nature of digital platforms [26].

The DMA and DA represent a significant step by the EU to regulate the digital economy, ensuring it works for the benefit of all participants – consumers, businesses, and society at large. The DMA specifically targets large digital platforms operating as "gatekeepers" in the digital market. These are platforms that control access to large user bases and have a significant impact on market entry and competition. The DMA's primary focus is on ensuring fair competition and preventing the unfair use of market power by these dominant platforms. The DA focuses on data governance and accessibility, which are fundamental to the operation of digital services. The DA aims to facilitate data sharing across different sectors and among enterprises, boosting innovation and ensuring that small and medium-sized enterprises (SMEs) and start-ups can also benefit from data-driven innovations.

The DMA advocates for platforms to adhere to standards that ensure they can operate compatibly with other services, which is essential for user choice and technological innovation. However, defining these standards and keeping them up-to-date with rapid technological advances poses a regulatory headache.

[12] Multi-sided markets are markets that typically involve two or more users which interact through a third party, i.e., the platform [37].

These standards must be designed in a way that they do not curb innovation or allow dominant players to manipulate the standards to their advantage. This is critical to ensuring that smaller platforms have a fair chance to compete and innovate within the market [38]. Additionally, ensuring that these platforms do not use their control over data to disadvantage competitors requires constant vigilance and a deep understanding of the data-driven strategies that underpin many digital business models [39]. Regulators must stay ahead of the curve, anticipating future developments and adapting enforcement mechanisms to remain effective against evolving business strategies that may seek to bypass regulations [38].

One of the primary challenges in regulating digital platforms is balancing the need for transparency with the imperative to protect privacy and ensure the security of data. The DMA requires platforms to provide unprecedented levels of access to their data and algorithms, which is crucial for monitoring compliance and fostering market competition. However, this access should not compromise the sensitive personal or commercial information integral to the platforms' operation and users' privacy [38]. Each type of data – from online advertising databases to search engine queries – has different implications for privacy protections (and intellectual property rights). Crafting policies that facilitate essential data sharing without infringing on these rights requires a nuanced approach that considers the unique characteristics of each data type [38]. If companies know their data can be easily accessed by the state, they may be less likely to invest in its collection and analysis, which could stifle innovation and economic growth. Potential economic implications of mandatory data sharing concerns how data is priced and traded. The fear is that mandatory access could lead to undervaluation of valuable data sets or distort market dynamics, possibly leading to an inefficient allocation of resources [40].

Moreover, the DMA emphasises the need for a balanced approach that does not stifle innovation while ensuring fair competition. To this end, it outlines specific criteria for identifying "Large Gatekeeper Platforms", which are subject to more stringent regulations due to their substantial market influence and the significant network effects they exhibit. This designation is crucial because these platforms have the potential to control access to vast digital ecosystems, making it difficult for smaller competitors to thrive [40]. The complexities of platform-to-business relationships and rectifying the power imbalances often seen between large platforms and their smaller business users involves ensuring that terms of service are fair and transparent, and that changes to these terms do not unfairly disadvantage or exclude certain businesses. It also involves setting out clear rules for how data generated on these platforms can be used and shared, which is particularly challenging given the diverse and rapidly evolving nature of digital services [40].

Effective enforcement is perhaps the most critical challenge, involving not just the establishment of regulations but also their vigilant monitoring and adaptation. This requires robust mechanisms for regular audits, assessments, and adjustments based on real-world impacts and feedback from both industry and consumer advocacy groups [38]. The DMA requires a robust framework to monitor compliance and adjudicate disputes effectively, which implies not only having the technical expertise to understand the workings of complex digital platforms but also acting swiftly to mitigate any harmful effects arising from non-compliance [39].

The DA aims at reshaping how data is managed and shared within the EU, impacting various stakeholders from big tech companies to SMEs. The challenges primarily revolve around ensuring fair data access and preventing market monopolisation while fostering innovation and maintaining economic competitiveness [41]. The DA proposes mechanisms to ensure that SMEs can compete more effectively by giving them fairer access to data, which is often controlled by larger corporations. This includes establishing clear rules for data sharing and access that prevent large companies from exploiting their dominant position to the detriment of smaller entities that might rely on this data for their operations and growth [*ibidem*].

However, overly restrictive regulations could hamper the technological advancement and flexibility required by digital companies to evolve and meet changing market demands. The act aims to encourage innovation by making data more accessible and usable across different sectors, yet it must do so without creating cumbersome regulatory barriers that could inhibit technological development. In the context of the DA, enhancing interoperability across different platforms and systems is seen as essential for enabling access to valuable data across sectors. This access is particularly important for SMEs that might not have the same resources as larger corporations to develop or procure diverse datasets [41]. However, ensuring interoperability presents several challenges. It requires the establishment of common standards and protocols that all market participants must follow. These standards must be robust enough to secure data and flexible enough to accommodate innovations and advancements in technology. Additionally, they need to be comprehensive, covering not just technical specifications, but also semantic aspects to ensure that data shared across systems is understood and utilised effectively. The DA proposes to address these challenges mandating that platforms use common data formats or open APIs that enable third parties to develop compatible tools and services. Such measures are intended not only to enhance operational compatibility but also to foster an ecosystem of innovation where developers can build upon existing platforms without being hindered by proprietary barriers [*ibidem*].

Moreover, the act emphasises the importance of governance structures to oversee the implementation of interoperability standards. This involves regulatory oversight to ensure that companies comply with the rules and that these standards evolve in line with technological advancements and market needs. The success of this governance structure will be critical in ensuring that interoperability contributes positively to the digital economy, enhancing both competition and innovation [41].

Furthermore, ensuring compliance with the new regulations poses a challenge, particularly in terms of enforcement and the potential administrative burden on companies. The act emphasises the importance of creating a regulatory environment that is not only effective but also manageable for companies of all sizes. This includes considerations on how to monitor compliance and what support mechanisms are necessary to help companies, especially SMEs, adapt to new requirements without undue hardship [41].

Overall, the DA seeks to address these challenges by proposing a balanced framework that supports the fair and efficient use of data across the EU, fostering a digital economy that is competitive, innovative, and equitable. The success of this regulation will depend on its ability to align with broader EU policies on digital transformation and its capacity to be implemented in a way that is perceived as fair and beneficial by all stakeholders involved [41].

In conclusion, myriad challenges need to be addressed to ensure that such regulations do not inadvertently harm the very innovation ecosystem they aim to support. Balancing these concerns requires careful legislative crafting, broad stakeholder engagement, and a nuanced understanding of the digital economy's dynamics [40].

3 Stakeholder analysis

Stakeholder analysis stands as a strategic cornerstone in the domains of project management, policy-making, and organisational strategy. It is a methodical process aimed at identifying, assessing, and prioritising the roles, interests, and influences of various stakeholders within a project or policy framework. Broadly speaking, this process aims to dissect the complex interplay of interests, power dynamics, and the potential impacts posed by stakeholders on any given initiative. This analysis is highly relevant in the context of developing possible solutions that policymakers can adopt to foster the development of interoperable energy services. In fact, the development of new technological solutions by various stakeholders is inherently linked to the various economic and regulatory incentives and barriers they may face. While some business models can greatly benefit from the development of interoperable energy services, others may instead be based on exploiting market inefficiencies due to the lack of interoperability.

The purpose of this chapter is to present the results of the stakeholder analysis conducted within the context of T4.2. First, the theory underlying stakeholder analysis is presented. Then, we review the main economic barriers to the development of interoperability highlighted in the literature. Finally, the barriers mentioned by stakeholders will be discussed with reference to: the development of interoperable energy services, participation in the (future) data space, and engagement in the int:net community.

Stakeholder analysis: a theoretical perspective

Stakeholder analysis strategically identifies and categorises stakeholders to understand their interests, influences, and potential impacts on projects, policies, or strategic decisions (e.g., in the case of a company). In order to do this, however, it is necessary to define not only the purpose of a project (a policy or a strategic decision) but also who are the stakeholders that could potentially be impacted by or can impact the project itself. To preserve the ease of reading, the following discussion will refer to stakeholders of a project. This does not detract from the validity of the analysis conducted thereafter.

As already mentioned, stakeholders are entities or individuals with the potential to significantly influence or be influenced by the outcome of a project. Their identification is not merely a cataloguing of parties involved but a recognition of the intricate web of interests, expectations, and influence they bring to the organisational landscape. Stakeholders extend beyond the immediate project team and management to include a wide range of internal and external actors. Internal stakeholders typically comprise project partners, each with a direct stake in the organisation's operations and outcomes. External stakeholders, on the other hand, encompass a broader spectrum, including customers, suppliers, competitors, regulatory agencies, and the wider community. These stakeholders may not interact with the project directly but possess a vested interest in its implications and results [42].

Stakeholder analysis serves as a critical process for understanding the dynamic and often complex relationships between a project and its stakeholders [43]. This analysis involves several key dimensions:

- interest and expectations: understanding what stakeholders expect from the project and how their interests align or conflict with the organisational objectives;
- influence and power: assessing the ability of stakeholders to affect project outcomes, whether through direct action, resource control, or strategic influence;

- impact: evaluating the potential positive or negative effects stakeholders may experience as a result of the project's execution.

The essence of stakeholder analysis lies in its capacity to provide a strategic overview of the stakeholder environment. It illuminates the power dynamics, alliances, and conflicts that could shape the project's trajectory, offering insights that are crucial for effective decision-making and strategy formulation.

By expanding the definitions of stakeholders and stakeholder analysis, we gain a deeper appreciation of their critical role in shaping project outcomes. Stakeholders, with their diverse interests and capacities to influence, form the backbone of any strategic initiative. Meanwhile, stakeholder analysis offers the analytical lens through which organisations can navigate the complex interplay of stakeholder interests and influences, ensuring more informed, inclusive, and strategic decision-making processes.

Methodologies

Implementing stakeholder analysis involves a variety of methodologies tailored to the project's specific context and goals. The methodologies employed in stakeholder analysis are diverse, designed to map out and engage with stakeholders comprehensively. Beyond basic identification and mapping, these approaches are structured to dive deep into the stakeholders' interests, influences, and their potential impact on projects:

- identification and mapping: initial steps involve compiling an exhaustive list of stakeholders, followed by mapping their relationships to the project and each other. This visual representation helps in understanding the complex interplay of influences and interests at play;
- assessment of interests and influence: through techniques like interviews, surveys, and focus groups, stakeholders' interests in the project and their capacity to influence its outcome are evaluated. This step is crucial for prioritising stakeholders and tailoring engagement strategies accordingly;
- SWOT analysis: stakeholder analysis can incorporate SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis to identify how stakeholders' positions could impact the project. This method provides strategic insights into managing stakeholder relationships effectively.

Challenges

Despite its significant utility in enhancing strategic decision-making and improving project outcomes, stakeholder analysis confronts several challenges. These challenges often stem from the dynamic and complex nature of stakeholder relationships, including the accurate identification of stakeholders, assessment of their dynamic interests and influences, and management of potentially conflicting expectations.

Comprehensive identification of stakeholders

One of the foremost challenges in stakeholder analysis is the comprehensive and accurate identification of all relevant stakeholders. This difficulty arises from the vast array of individuals and groups that can potentially influence or be influenced by a project. The challenge is compounded in large-scale or public interest projects where stakeholders may not be directly visible or traditionally recognised. Overlooking key stakeholders at the outset can result in strategic oversights, unanticipated resistance, or missed opportunities for engagement and support.

Dynamic interests and influences

Stakeholders are not static entities; their interests, priorities, and levels of influence can evolve over the course of a project or in response to external factors. Keeping abreast of these changes requires constant vigilance and adaptability. Projects must incorporate mechanisms for continuous stakeholder engagement and feedback to accurately gauge shifts in stakeholder landscapes. This dynamism can introduce uncertainty into project planning and execution, necessitating flexible strategies that can accommodate evolving stakeholder profiles.

Managing conflicting interests

Projects and policies inevitably encounter stakeholders with conflicting interests. These conflicts may arise from competing priorities, divergent expectations, or differing visions for project outcomes. Navigating these conflicts without alienating key stakeholders or compromising project objectives is a delicate balancing act. It demands a high degree of diplomatic skill, negotiation, and sometimes creative problem-solving to find mutually acceptable solutions or compromises.

Engagement and communication strategies

Developing and implementing effective stakeholder engagement and communication strategies present another layer of challenge. Each stakeholder group may require a tailored approach based on their interests, influence, and preferred communication channels. Crafting messages that resonate with diverse audiences, fostering meaningful participation, and maintaining open lines of communication are all critical yet challenging aspects of stakeholder management.

Resource constraints

Stakeholder analysis and engagement are resource-intensive activities requiring time, personnel, and financial investment. Organisations often face constraints that limit their ability to conduct thorough stakeholder analyses or engage with stakeholders as fully as they might wish. Balancing the depth and breadth of stakeholder analysis with available resources, without compromising the quality and effectiveness of the process, is a continual challenge.

Ambiguity and complexity

Finally, stakeholder analysis is characterised by inherent ambiguities and complexities. Assessing stakeholders' true levels of interest and influence often involves subjective judgments and interpretations, which can vary among project team members. Furthermore, the interdependencies and networks among stakeholders add layers of complexity to the analysis, making it difficult to predict how stakeholder dynamics will play out over time.

Broadly speaking, these challenges necessitate ongoing engagement and adaptability in the analysis process to navigate the evolving landscape of stakeholder dynamics effectively.

Economic analysis of interoperability

Identifying challenges that stakeholders can face in promoting and developing interoperable solutions is not entirely new. An extensive literature discusses how fostering interoperability involves evaluating the distribution of economic benefits from data sharing and allocating the costs of developing new technical solutions among different stakeholders. Moreover, stakeholders like traditional energy market actors are addressing challenges posed by digital platforms, which enhance market coordination through digital technologies but may also compete with them in extracting value from the market. Although interoperability can enhance the management of the electricity system and reduce the market power of large digital platforms, implementing interoperable solutions can present challenges on managing this process in a non-disruptive way.

Historically, the electricity sector has been characterised by large, vertically integrated monopolies. These entities controlled everything from generation to distribution, with minimal input or interference from outside. More recently, there has been a significant increase in small-scale, renewable energy production sources, such as solar panels and wind turbines. These resources allow consumers to become “prosumers” which diversifies the energy production landscape and reduces dependency on large-scale power plants. Moreover, digital platforms are introducing new paradigms that challenge these traditional structures. These platforms facilitate interactions among smaller, decentralised producers and consumers, altering the flow and control of electricity production and distribution. Innovations such as smart grids, smart meters, and more efficient storage technologies are empowering consumers and allowing for more sophisticated management of energy flows. These technologies enhance the ability of platforms to integrate various energy services, creating a more responsive and user-centric energy ecosystem. Platforms can enhance market efficiency by better matching energy supply with demand in real time. This is particularly effective in decentralised networks where traditional grid management may struggle to efficiently integrate diverse, small-scale energy inputs [44].

However, as platforms rise, traditional utilities may find themselves relegated to the role of mere infrastructure providers, with less control over the customer relationship. Platforms could potentially centralise customer interaction, billing, and energy management, reducing utilities to operators of “dumb pipes” – simply the physical infrastructure without customer engagement. For platforms to successfully integrate into the energy market, they must have fair and equitable access to existing grid infrastructure. For instance, this is akin to the debate in telecommunications about net neutrality and equitable access to network infrastructure. Regulators need to ensure that the transition towards more decentralised and platform-driven energy markets does not compromise the reliability and stability of the energy supply. This involves creating regulatory frameworks that support innovation while maintaining rigorous standards for system security and resilience [41], [42].

A possible instrument to strengthen fairness and contestability in digital markets is interoperability (of platforms and services). In fact, interoperability increases fairness because it allows market entrants to share the same network effects the dominant firm exploits. Interoperability can significantly enhance market competition by reducing entry barriers, allowing more firms to enter the market and enabling existing firms to expand. Interoperability facilitates competition in complementary markets, which is particularly important when these markets are platform markets (e.g., app stores with complements like Facebook and YouTube apps) or where there's a risk of leveraging market power from a dominant platform with network effects to a complementary business line [46]. Moreover, interoperability contributes to lowering transaction costs as users can switch among products from different manufacturers [47]. This aspect not only enlarges the market but also fosters competition among providers, ultimately benefiting consumers with lower prices and more options. Interoperability lowers the barriers for new entrants, enabling them to compete on a more level playing field with established players. While the long-term benefits of interoperability include reduced transaction costs, the initial phase of achieving interoperability might involve significant expenses [48]. These costs are associated with upgrading old systems, training staff to handle new protocols, and initially setting up standardised interfaces and data exchange formats. Interoperability often involves the standardisation of protocols and interfaces across different systems. This standardisation eliminates the need for customised solutions for each pair of interacting systems, thereby reducing the costs associated with setting up, maintaining, and modifying these connections [46].

However, caution must be exercised in pursuing interoperability in the market. In this regard, a necessary distinction is between horizontal and vertical interoperability. Horizontal interoperability refers to the ability of products and services at the same level of the digital value chain to “work together”. The key feature of horizontal interoperability is that it allows sharing direct network effects. On the other hand, vertical interoperability allows services that are at different levels of the digital value chain to work together. Horizontal interoperability, when mandated, is likely to be detrimental in digital markets. It tends to cement the dominance of existing players, stifles innovation and differentiation among firms, and necessitates continuous regulation. In the rapidly evolving landscape of digital services, where differentiation is primarily achieved through innovation in features, horizontal interoperability could restrict this as it requires standardisation and stability. This low level of interoperability might lead consumers to flock to larger networks that offer more comprehensive features, reducing their motivation to use multiple services simultaneously - a key factor in promoting market competition. On the other hand, vertical interoperability is considered a valuable tool for regulating digital bottlenecks but should only be implemented when a gatekeeper is vertically integrated and there is clear evidence of potential harm, such as discrimination or the exclusion of complementary services that would not occur without such integration. Mandated vertical interoperability would require that gatekeepers provide the same level of access to their platforms for both their own services and third-party complementors without discrimination [27].

It is worth to notice interoperability efforts can be impeded by economic and political interests and differences in legal and regulatory frameworks across countries can restrict the implementation of interoperable systems. By an economic perspective, interoperability is driven by the need of businesses to share information with others. Business processes enable the necessary information exchange. At the organisational layers, interoperability requires agreement on the business process interaction that is expected to take place across an interface [5]. Manufacturers often exhibit reluctance to adopt interoperable standards due to concerns over losing market share or profitability. The fear is that interoperability could dilute brand loyalty and diminish the unique value propositions of proprietary systems, leading to a more competitive market where price and generic features could overshadow branded uniqueness. Similarly, service providers and system integrators, whose business models frequently rely on delivering customised, proprietary solutions, might view interoperability as a threat. The standardisation implied by interoperability could potentially undercut the demand for specialised services, thereby affecting their business profitability. Moreover, the initial financial outlay associated with integrating IoT technologies or developing semantic models can be substantial. These costs pose a barrier, particularly for smaller enterprises or in market segments where the economic returns of such investments are not immediately evident. The overarching challenge is thus not just technological but deeply economic, revolving around how best to balance the benefits of open, interoperable systems against the economic inertia that favours existing proprietary models [49].

Box 3.1 Competition, innovation and regulation

The relationship among competition, innovation, and regulation is complex, with cause-and-effect links that are not easily discernible. The role of regulation in fostering competition and innovation remains a topic of ongoing debate.

There are instances where regulation has both positively and negatively impacted innovation. For example, enforcing interoperability and promoting standards can lead to uncertain outcomes. Implementing standards, particularly in technologically dense areas like smart grids, presents both challenges and opportunities. By preventing market fragmentation and promoting competition, the adoption of standards in industries such as smart grids is demonstrated to facilitate innovation [50]. However, overly stringent regulations might stifle innovation by imposing excessive compliance costs or limiting the economic incentives for risk-taking and investment in new technologies. Moreover, regulatory interventions should be designed to not only address current market dynamics but also to be adaptable to the rapid changes typical of digital markets [51].

When considering measures to reduce market power and increase contestability, regulators should be aware that new entrants can potentially become market leaders. In this context, competition economists typically distinguish between short-term (or static) and long-term (or dynamic) competition. Static competition ensures efficiency and cost-effectiveness in the short term, while dynamic competition is essential for long-term sustainability and growth. Markets operate optimally when there is a balanced interplay between these two forms of competition [52].

Static competition primarily focuses on the immediate dynamics among firms that are competing on price, quality, and service without significantly altering the underlying technology or business model. This type of competition is visible in many traditional sectors where the pace of innovation is modest and product offerings remain relatively unchanged over time. In such markets, the benefits to consumers are often immediate and tangible. These benefits include lower prices due to cost-cutting measures, promotions to attract consumers, and minor improvements in service quality. Essentially, static competition drives firms to fine-tune their existing offerings, making short-term gains prominent.

In contrast, dynamic competition is about the big leaps – the introduction of new technologies, products, or business models that shift the competitive landscape. This form of competition is most prevalent in high-tech industries, where innovation is a constant and companies vie to outdo each other with ground-breaking technologies. Here, the benefits to consumers extend far beyond immediate price reductions or service enhancements. Instead, dynamic competition fosters an environment ripe for significant innovations that can increase the quality of life, open up new markets, and offer completely new types of products and services. These innovations may take time to develop and mature but have the potential to deliver lasting benefits that fundamentally change consumer experiences and expectations.

The relationship between these two types of competition and their corresponding benefits can be illustrated by looking, for instance, at the telecommunications industry. In the short term, static competition among mobile service providers might lead to lower monthly plans or enhanced customer service. However, the dynamic competition involving the development of 5G technology promises transformative long-term benefits by enabling faster internet speeds, reduced latency, and the emergence of new applications like smart cities and autonomous vehicles.

Thus, understanding the interplay between static and dynamic competition helps explain why some industries advance rapidly, continuously offering novel benefits to consumers, whereas others maintain a more gradual pace of improvement, focusing on optimising existing goods and services.

Stakeholder analysis methodology

The stakeholder analysis conducted in the context of T4.2 consisted of a series of semi-structured interviews primarily with stakeholders from the energy sector. However, stakeholders from the mobility and building sectors have also been considered, given the relevance of these two sectors in the context of interoperable energy services. In order to identify relevant stakeholders, various categories of stakeholders pertinent to this deliverable have been mapped:

- system operators,
- market/platform operators,
- charging point operators,
- market actors (e.g., utilities, aggregators),
- original equipment manufacturers (OEMs)
- technology and/or service providers,
- consumer.

Also associations representing some categories of these stakeholders were interviewed. Additionally to them, stakeholders (in the broadest sense of the term) from the academic and research community have also been interviewed. Beyond contributing with their expertise, the involvement of these stakeholders has been very significant in defining the boundaries of the stakeholder analysis.

The interviews were conducted using a common basic format to address three main dimensions of the int:net project: the development of interoperable energy services, the stakeholder participation in the future energy data space, and their engagement in the int:net community. The purpose of the interviews was to identify the main barriers and incentives that a stakeholder might encounter with respect to these three mentioned dimensions. Regarding the development of interoperable energy services and the participation in future data space, the analysis primarily focused on economic and regulatory barriers. The reference framework can therefore be considered the business layer of the SGAM. As for participation in the int:net community, the analysis aimed to understand the interests that might drive various stakeholders to join the community and identify the main issues that, conversely, might discourage participation.

Where possible, efforts were made to interview professionals with expertise in economic and regulatory issues within their company. Additionally, both established market companies and new market entrants, including start-ups, were contacted. 29 stakeholders participated in the interviews. Figure 3.1 displays the distribution of the roles held by the interviewees at the time of the interview, while Figure 3.2 presents the distribution of the types of stakeholders who were interviewed. Figure 3.3 lists (in a random order) the stakeholders who agreed to participate in the interview.

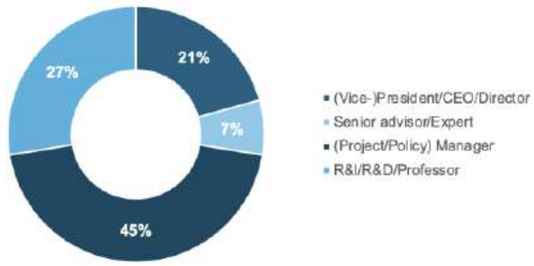

Figure 3.1 Distribution of interviewees per core role.

Figure 3.2 Distribution of the types of interviewed stakeholders.

Figure 3.3 List of the interviewed stakeholders.

Stakeholder analysis' results

The results of the stakeholder analysis are presented with reference to: the development of interoperable energy services, participation in the (future) energy data space, and participation in the int:net community. Broadly speaking, the conducted interviews have outlined a rather complex picture where various barriers and interests intertwine, making it difficult to identify clear solutions for the development of interoperable energy services and the energy data space. The development of the int:net community will also require addressing the expectations and concerns highlighted by some stakeholders as much as possible. In general, there was a certain consensus around many of the issues that characterise these three elements of the int:net project. Where there is no common vision, differences of opinion have been appropriately highlighted.

Table 3.1 Stakeholder analysis structure and identified barriers.

Stakeholder analysis dimensions	Barriers
Development of interoperable energy services	• Regulatory landscape(s) • Business cases and market dynamics for interoperability • Technical and semantic interoperability • Balancing innovation and standardisation • Data sharing and privacy issues • Cybersecurity and infrastructure security • Consumer engagement
Participation in the (future) energy data space	• Business cases for the energy data space • Regulatory framework • Missing priorities • Technical and contractual issues
Participation in the int:net community	• Community "lifespan" • Community added value

Development of interoperable energy services

The discussion surrounding the development of interoperable energy services has aimed to highlight the main challenges stakeholders face in implementing interoperable energy services within the context of their core activities. In the following, emerged barriers are presented.

Regulatory landscape(s)

The regulatory landscape presents a complex puzzle to stakeholders, with data and electricity regulation often at odds. A first element of complexity is the existence of two main regulatory levels: the European and the national one. A second element is the interconnection of the electricity regulation with regulation related to the digital sector.

The existence of dual regulatory levels means that efforts made at the European level to harmonise the electricity sector do not always find alignment at the national level. At the EU level, a mature regulation defining the rules for stakeholders providing interoperable energy services do not yet exist. For instance, regulation is not clarifying how new flexibility markets could interact with other electricity markets. This is an issue for some stakeholders because it impacts their investment decisions, as the profitability of an asset depends on access to various market segments.

While the EC is attempting to propose a regulatory framework consistent with the development of interoperable energy services, individual MSs play a significant role in implementing rules (and standards) that are harmonised with those of other jurisdictions. Moreover, different stakeholders must comply with various SO requirements to provide their services. The necessity to adapt the same bureaucratic procedures to different requirements set by various regulatory contexts represents a significant barrier to operating across different markets.

Some stakeholders have also pointed out a kind of inconsistency between the regulatory sphere related to the electricity sector and that related to the digital sector. For instance, while processing consumer data is acknowledged as necessary to deliver new interoperable energy services, the current regulations do not enable services that would require more granular management of consumer data. However, stakeholders have shown differing opinions on this issue, as will be illustrated below.

Business cases and market dynamics for interoperability

Stakeholder perspectives underscore the complexity of fostering interoperability in an environment characterised by diverse interests and competitive pressure. The economic and business implications of interoperability are significant, with stakeholders carefully weighing the costs of transitioning to interoperable systems against the potential benefits. While interoperability promises enhanced efficiency and better integration of renewable energy, the initial investments and uncertainty about immediate financial returns pose challenges. The business case for interoperability, therefore, must clearly articulate the long-term benefits and provide mechanisms to mitigate the financial risks associated with adopting new standards and technologies.

The quest for market share and the desire to establish barriers for competitors often stand in contrast to the collective benefits of interoperable systems. Furthermore, the cultural resistance from some major players and the unclear economic potential of data sharing reflects the challenges in achieving consensus. Many stakeholders report a lack of a clear regulatory framework that clarifies the economic benefits of developing interoperable energy services and the business cases that can therefore be implemented. Currently, many stakeholders do not see the added value of being interoperable and sharing their data. This issue is evident, for example, among many manufacturers who are generally reluctant to share data from their devices: sharing such information could cause them to lose a potential competitive advantage induced by the implementation of a new regulatory framework.

Technical and semantic Interoperability

At the heart of the communication gap among several stakeholders lies the dual challenge of technical and semantic interoperability. Technical interoperability demands a common set of standards, protocols, and formats for data exchange, ensuring that different systems can communicate effectively. Format of time span and granularity of data have been highlighted as key examples of technical requirements that need to be defined. Semantic interoperability goes a step further, necessitating a shared understanding of the exchanged information, enabling meaningful data interpretation across diverse systems. The diversity of data formats, protocols, and standards for information exchange, employed by various stakeholders including EV manufacturers, charging infrastructure providers, utility companies, and government agencies, complicates the seamless integration and harmonisation of data. This issue extends to the charging infrastructure realm, where a wide array of charging stations, networks, and payment systems makes it difficult for EV drivers to access charging services ubiquitously, irrespective of their location or the charging network they encounter.

Currently, these barriers are partially addressed by technology and service providers who manage data from various sources using APIs. However, these solutions, besides being time-consuming activities, must be adapted each time to the specific needs of the client and cannot offer systemic solutions to the lack of technical and semantic interoperability.

Balancing innovation and standardisation

Balancing innovation with the need for standardisation is a delicate task. While innovation drives the sector forward, introducing new technologies and solutions, premature standardisation could stifle creativity and block the development of novel approaches. The slow pace of standard-setting processes, coupled with the resource constraints faced by some stakeholders, highlights the tension between maintaining flexibility and establishing common standards to ensure interoperability. An example is the customisation in information and communication solutions: although beneficial from the perspective of the client needs, may hinder the convergence toward interoperable solutions, underscoring the need for a strategic approach to innovation and standardisation.

Data sharing and privacy issues

The tension between the need for open data sharing and the protection of consumer privacy is a critical issue in the quest for interoperability. While open standards and transparent data practices can facilitate interoperability, concerns about privacy and data ownership present significant hurdles.

Many stakeholders have pointed out that in many use cases, the actual owner of the data is the consumer themselves, who has the right to request the transfer of their data to third parties. This right should make consumers aware of which data to share, with whom, and for what purposes. Despite this theoretical possibility, such practices seem to be rarely applied in reality. Moreover, not all consumers are aware of this right. Some stakeholders have noted that the real issue is not actually related to consumer privacy protection; this aspect can be managed through specific contractual agreements. Instead, problems arise when privacy protection is cited as a reason to deny third parties' access to data. In other words, GDPR has not been mentioned as a real impediment to business activities, but it has been emphasised that this regulation is sometimes applied improperly or overly cautiously by data holders. However, as mentioned earlier, GDPR has been mentioned as a barrier when the provision of interoperable energy services requires specific data that, for instance, can offer insights into consumer behaviour.

To conclude, the challenge is to establish data sharing protocols that respect privacy concerns while ensuring that the data remains useful and of high quality for energy market participants. Addressing these concerns requires a nuanced understanding of the trade-offs involved and the development of frameworks that balance openness with security.

Cybersecurity and infrastructure security

Cybersecurity is a critical concern within the electricity sector, with potential risks to both individual consumers and national infrastructure. Interoperability indeed increases the attack points of a system, and many stakeholders are not willing to compromise the security of their systems, especially when delivering services of national relevance. The security of charging infrastructure and the need for neutral entities to establish trust illustrate the specific challenges faced by the electricity sector. Addressing these concerns requires a comprehensive approach that encompasses not just technical solutions but also regulatory and policy measures to ensure the security and resilience of energy systems.

Consumer engagement

A significant barrier to adopting smart energy technologies and DR services is consumer confidence. Factors such as data privacy concerns, apprehensions about cost, and the complexity of services contribute to consumer hesitance. The challenge is compounded by misinformation, opaque contractual terms, and the overall lack of transparent, accessible information.

The absence of full interoperability leads to concerns about technology lock-in, where consumers fear being confined to specific service providers due to incompatible devices. This situation stifles innovation and limits consumer choices, emphasising the importance of implementing and enforcing interoperability standards.

Participation in DR programs involves financial risks, especially concerning asset ownership and bundled products. The need for transparent, fair contractual terms and conditions, particularly where significant investments are involved, is paramount. Addressing these financial uncertainties and clearly communicating the potential risks and benefits to consumers will be essential in mitigating hesitance and encouraging wider adoption.

The issue of misinformation and the opacity of contractual terms and conditions has been identified as a barrier to consumer participation in DR programs. Misleading advertising regarding potential costs, revenues, or savings, coupled with complex contract terms that are difficult for consumers to comprehend, diminish trust and deter engagement. Ensuring transparency and simplicity in contractual agreements and advertising practices is crucial for fostering an environment where consumers feel informed and confident in their decisions.

Participation in the (future) energy data space

As introduced in Chapter 2, a data space is an environment based on relevant data infrastructures and governance frameworks that aims to facilitate data pooling and sharing.[13] At present, the concept of data space does not have a complete and unambiguous definition. Although this can avoid that a too rigid definition might prematurely exclude potential technological and governance solutions, the ambiguity of the concept poses a barrier for many stakeholders in approaching the topic.

Business cases for the energy data space

The most frequently mentioned barrier by stakeholders deterring participation in the energy data space is the lack of a vision for how it can be advantageous for their business cases or how it could unlock new business potentials. This lack of awareness became even more apparent among those stakeholders who, during interviews, did not express a specific vision on this matter. In this regard, bringing stakeholders on board was highlighted as a key requirement for the data space deployment. In fact, the participation of a sufficient pool of stakeholders reflects (at least) two main needs: *i*. ensuring

[13] The interested reader can find further details here: https://digital-strategy.ec.europa.eu/en/library/staff-working-document-data-spaces.

an adequate amount of data exchanged to enable business opportunities, and *ii*. guaranteeing the procurement and maintenance of the minimal infrastructure necessary for the operation of the data space. To enhance data sharing in both business-to-business and business-to-consumer scenarios, stakeholders need incentive mechanisms (not necessarily economic, as data can be shared reciprocally just to enable new business cases) or marketplaces that allow the development of "fair" data monetisation strategies.

Regulatory framework

According to some stakeholders, it is not the lack of interoperability per se that is inhibiting the creation of the energy data space, but rather the absence of an appropriate regulatory framework. In other words, new business cases that could be enabled by the data space are currently impeded by the lack of clear market rules. Moreover, regulation is also lacking in creating the right incentives for the SOs to increase the coordination of the market actors – rather than investing in new infrastructures. Regulation should be complemented by a governance structure that clearly defines roles and responsibilities for the different actors.

Missing priorities

An additional barrier identified as a cause of potential slow development of the energy data space is the lack of prioritisation of actions to be taken and use cases to be enabled. However, differing opinions have been found among various stakeholders. Indeed, some believe the development of the data space should focus on the pan-European dimension of electricity system management, thereby excluding a more local dimension. For others, it is not conceivable to imagine the development of local flexibility services unless the assets employed also have the opportunity to operate in other market segments.

Technical and contractual issues

Some stakeholders also raised a series of technical and contractual issues that can be crucial for the successful development of the energy data space. Indeed, managing a significant amount of data can prove costly from a system cost perspective. This problem becomes even more significant when data management needs to occur in real time. Some stakeholders view cloud edging as a possible solution, but currently, it is not always possible to access information from assets behind the meter. The ability to manage these data must be accompanied by the ability to handle data from different contracts, for example, between the same consumer and various market actors. Moreover, various stakeholders (consumers and others) need assurances on how and by whom their data are used. Privacy issues can be a significant inhibitory factor to the willingness to share one's data. Lastly, the creation of flexibility registries represents a more controversial technical aspect. While they are seen as necessary for the proper management of the electricity system, they are also perceived as potentially slowing down the development of new interoperable energy services in many member states.

Engagement in the int:net community

One of the goals of the int:net project is to establish a community of experts on interoperable energy services. When the interviews were conducted, the purpose of the community was not yet fully defined, nor was it possible to present stakeholders with a complete list of potential activities that will be conducted within the community. Therefore, the results from the interviews should be considered partial and preliminary, and further engagement efforts will be necessary until the end of the project.

Generally, most stakeholders have shown interest in the community. This interest is primarily driven by the opportunity to increase company know-how (e.g., by participating in the various focus groups) and to generally keep track of the outcomes of the int:net project and the horizons that are currently collaborating with it. Some stakeholders also see the community as an opportunity to share their own know-how or successful national experiences that could serve as examples for other stakeholders active in other MSs.

However, some critical issues were highlighted by stakeholders to make the int:net community a successful experience. The first concerns the survival of the community: when called upon to subscribe, stakeholders want assurance that the community will survive beyond the end of the int:net project. Additionally, some of them are already part of other communities and may not have the resources to allocate to another community. This is particularly relevant for those stakeholders for whom the added value of the int:net community, such as its relevance to their business activities, is not clear. As previously mentioned, these are preliminary impressions from the stakeholders, and therefore these specific issues can be addressed before the end of the project. The stakeholder engagement activity is proceeding in parallel within the context of WP5.

4 Project analysis

Although many initiatives have been taken both at the regulatory level and by other stakeholders in the electricity sector – and beyond – to manage the partial degree of interoperability of the electricity system, the development of interoperable energy services is still the subject of ongoing research activities. In this regard, extensive knowledge on developing interoperable energy services has been generated by various Horizon research projects, which aim to pilot innovative solutions that could subsequently be scaled up. This chapter aims to provide an overview of the experiences gained from the R&I efforts to digitalise the electricity sector. Among the many different activities taking place across Europe, we decided to focus our analysis on Horizon 2020/Europe projects, which are examples of significant innovation efforts coordinated across multiple MSs.

This chapter begins with a brief presentation of the four projects to highlight their relevance. Next, the methodology used to review the project results is presented. Finally, the barriers to the implementation of interoperability are discussed.

Presentation of the selected projects

The main criteria for selecting relevant Horizon projects for analysis were that the projects should focus on the digitalisation of the electricity sector and facilitate data exchanges and coordination among different actors (Transmission System Operators – TSOs, Distribution System Operators – DSOs, Flexibility Service Providers – FSPs, and consumers). Additionally, the projects needed to be either recently completed or in the final stages of implementation. Based on these criteria, four projects were selected:

1. OneNet, which focuses on TSO-DSO-consumer coordination,
2. InterConnect, which aims to connect smart homes and other end-use applications with grid operators,
3. CoordiNet, which addresses the coordination of grid services use and procurement between TSOs and DSOs, and
4. INTERRFACE, which deals with interactions between TSOs and DSOs.

All these projects have collaborated on testing and deploying interoperability across multiple pilot sites in Europe.

OneNet

The goal of the project was to achieve seamless, near real-time integration of all stakeholders across countries, creating conditions for synergistic market and network operations that optimise overall energy management, promote an open and fair market structure, and maximise consumer participation.

The key elements of the project were, firstly, the definition of a common market design for the EU with standardised products and key parameters for grid services aimed at coordinating all actors, from grid operators to customers.

Secondly, the project worked on a definition of a common IT architecture and interfaces to facilitate an open architecture of interactions among various platforms, rather than creating a single IT platform for all products, allowing anyone to participate in any market across Europe.

Finaly, the concepts were implemented in large-scale demonstrators designed to showcase the scalable solutions developed throughout the project. Organised into four clusters, the demonstrators included countries from every region of the EU and tested innovative use cases that have never been validated before [53].

InterConnect

The InterConnect project focused on developing and demonstrating advanced solutions to connect and integrate digital homes and buildings, aiming to ensure a cleaner, secure, and affordable electricity system. Following the adoption of the EU action plan for digitalising the energy system, the InterConnect project also set a new goal: to contribute to the development of a Common European Reference Framework (CERF) for energy-saving applications. This framework enables voluntary reductions in energy consumption and assists in lowering energy costs.

The core developments of InterConnect, namely the Interoperable Recommender, the Semantic Interoperability Framework, and the DSO Interface, are publicly available and were used to demonstrate the capability to connect consumers, grid stakeholders, technology enablers, devices, and service providers to realise differentiated energy applications.

Furthermore, the InterConnect project expanded the development and real-life testing of the CERF for energy-saving applications through its cascaded funding mechanism. A first generation of energy-saving applications was tested within the scope of the InterConnect project, in a controlled environment across three EU MSs where existing InterConnect pilots were active [54].

CoordiNet

The CoordiNet project aimed to demonstrate how enhanced coordination between TSOs and DSOs could activate new grid services and create favourable conditions for all participants in the grid. TSOs are tasked with balancing electricity supply and demand between power stations and consumers, managing high-voltage transport grids, while DSOs oversee medium- and low-voltage grids. The project also seeks to dismantle barriers that restrict customer and small market player participation in the energy market, particularly those connected to distribution networks.

CoordiNet has defined standardised products that facilitate the exchange of flexible services within the electricity system and has outlined the requirements for a unified European energy platform. It has contributed to establishing mechanisms for delivering necessary grid services at both the distribution and transmission levels. Innovative technologies such as the IoT, AI, big data, peer-to-peer energy trading platforms, and blockchain have been utilised to enable market participation by small-scale energy prosumers. The solutions tested in CoordiNet are designed to support the development of an interoperable pan-European market, allowing all market participants to offer energy services and potentially opening new revenue streams for consumers who provide grid services [55].

INTERRFACE

INTERRFACE connected stakeholders across the entire electricity value chain through the creation of an Interoperable Pan-European Grid Services Architecture (IEGSA). Serving as a bridge between transmission and distribution network operators, it standardises methods of market operation, service design, and procurement.

The IEGSA platform consists of various components that streamline day-to-day market operations. The flexibility register gathers and disseminates information on potential sources of flexibility, facilitating the integration of FSPs into the market. This component captures both static and dynamic characteristics of flexibility resources, providing precise insights into the available flexibility potential and aiding efficient portfolio management for service providers. The coordination platform enhances cooperation among SOs by enabling data exchange through well-defined, interoperable, and standardised application programming interfaces that adhere to the Common Information Model standard. It also supports the qualification of bids in various interconnected service markets. The "single interface to market" component links marketplaces with the platform to facilitate the exchange of market-related data. Additionally, the settlement unit is tasked with calculating energy settlements.

INTERRFACE's platform is operational in nine countries. Demonstrations focus on three key areas: congestion management and balancing, peer-to-peer trading, and the pan-European electricity market [55].

Project analysis methodology

For the selected projects, all relevant publicly available and completed deliverables were reviewed to identify potential barriers in the regulatory framework supporting interoperable energy services. The relevance of the deliverables was determined based on their high-level focus (e.g., summary deliverables presenting results of a work package or deliverables presenting recommendations based on project learnings) and their tables of contents.

A preliminary review revealed that none of the projects specifically addressed barriers in the regulatory framework for interoperability, beyond noting that certain components of the framework, such as the Network Code on Demand Response, have not yet been finalised.

However, regulatory barriers are not the only focus of this deliverable. Many technical interoperability barriers, which represent a significant focus of the analysed projects, can also be addressed at the regulatory level. Additionally, the four projects highlighted non-technical barriers relevant to regulators, such as challenges related to poor coordination among stakeholders. While these issues may not require changes to the EU regulatory framework, appropriate policy responses, such as implementation guidelines, strategic planning, or political directives for relevant stakeholder groups, could be beneficial.

These barriers were documented and tagged with keywords or topics. To synthesise the findings, the barriers were categorised under several high-level topics. These topics were determined using a bottom-up approach, aiming to encapsulate the main insights from the projects while retaining as much detail as possible.

Project analysis' results

Table 4.1 displays the high-level topics that have been identified, along with the corresponding barriers in the development of interoperable energy services. They are arranged from a broad perspective, starting with general topics such as the need for standardisation to keep pace with innovation in the energy sector, to more specific issues focusing on particular aspects of interoperability, such as metadata interoperability for data exchanges in the electricity sector or the challenges in applying research and innovation results in this field. Given the more technical nature of this chapter, to facilitate readability for non-experts, each topic begins with a brief section that highlights the topic's relevance for enhancing interoperable energy services. Each topic introduction is followed by detailed paragraphs that describe each barrier and provide evidence from the four analysed projects.

Table 4.1 Barriers in implementing interoperability principles in the energy sector.

Topic	Barriers
Standardisation lagging behind	• Actors using proprietary (non-interoperable) solutions • Existing standards not covering all required use cases • Existing standards not suited to cover all new use cases • Limited consensus on the coverage of market process phases
Missing governance structure for interoperability	• There is no authority with clearly defined responsibility • Missing framework for identification of best practices • Lengthy and inflexible procedures for standardisation, profiling, and testing practices • Not all stakeholders are involved in the interoperability and standardisation efforts
Cybersecurity and privacy issues	• Complexity of data management and data security • Cost of maintaining high level of cybersecurity • Missing standards for data access and consent management
Standardisation and harmonisation of flexibility services	• Lack of roles and responsibilities definitions • Lack of standardisation on the different interoperability layers • Different business processes on national level
Metadata	• Lack of metadata standardisation • Lack of metadata and reference data governance
Energy data space	• Scalability of data exchange platforms • Standardisation and decentralisation of platforms
Data exchange process efficiency	• Protracted duration of the exchange processes
Gap in transformation of R&I results into practice	• Research projects working on multiple parallel solutions • Project results not published in sufficient detail • Development of closed/proprietary solutions

Standardisation lagging behind

Standardisation is a key stepping stone to achieve interoperability in the electricity sector, as it reduces barriers to connecting isolated systems, enables market participation, opens markets to new entrants or reduces overall costs due to economies of scale.

Since standardisation is a wide term, it should be noted that this section covers specifically the standardisation of data exchanges among different actors in the electricity sector, such as SOs, market operators, FSPs or final consumers. The scope of standardisation mentioned in this section covers data exchanges for market-based interactions as well as technical coordination interactions (for grid management).[14] These are currently the main focus of the standardisation efforts as they can enable seamless communication among different actors in the electricity sector. These efforts are a prerequisite for realisation of digitalisation objectives of the electricity sector, where safe operation and planning of the electricity system is based on close-to-real-time information.

There is a lot of work that has been already done to standardise data sharing, especially in data exchanges among TSOs, Regional Coordination Centres and Nominated Electricity Market Operators, to establish a single European electricity market (as mandated by the European regulation, starting with the Third Energy Package) [56].[15] However, as the regulatory requirements for data exchanges widen with the subsequent regulatory developments, the scope of actors involved, type of data to be shared and use cases to be covered are increasing. As many more actors are also encouraged to take active role in the electricity system (e.g., active customers and aggregators), the management of the system is also becoming more decentralised. In this environment, where many actors are deploying different solutions, or are relying on already existing systems, it is increasingly more difficult to reach consensus about a concrete solution (or solutions) ensuring interoperability among different use cases and data exchanges.

The role of standardisation in this context is to offer solutions for any future applications, as well as a target model for adopting existing solutions to be interoperable with the rest of the energy sector. Having these standardised solutions available and deployed across the EU – instead of proprietary solutions not capable of mutual data exchange – would ensure easing service replicability and, making the whole system more cost-efficient [57].

To illustrate this, in the OneNet project, demonstrations had to develop new IT solutions for some of the tested use cases (of flexibility market platform deployment and data exchange among TSOs, DSOs and customers), because of the lack of available extensions of CIM [56], [58].[16] This suggests that, in the absence of interoperable standards, non-standardised solutions are being developed. These solutions are often proprietary and therefore not easily replicable by others. The experience of the

[14] For clarification, when the text below talks about "solutions" or "IT systems", it usually refers to applications that cover these kind of data exchanges.
[15] Regional Coordination Centres are established by TSOs to perform tasks of regional relevance for system operation, market related and risk preparedness tasks.
[16] Common Information Model for grid models exchange and for energy markets. More information available at: https://www.entsoe.eu/digital/common-information-model/#common-information-model-cim-for-grid-models-exchange

OneNet demonstration shows that path dependency (e.g., compatibility with existing IT systems), cost, and ease of application are significant concerns for actors such as SOs when deploying data exchange infrastructure. However, market actors are sensitive to their own costs and not to the overall system costs. Developing interoperable solutions can lower the overall systemic cost of the entire electricity system due to more efficient markets and network management. However, these solutions may not be in the direct interest of individual actors because they might not profit directly from the overall systemic cost savings. On the contrary, they may have to invest in changing or adapting their IT systems to be interoperable. Therefore, identifying best practices and standardising available interoperable solutions should be fostered to prevent potential future sunk costs related to investments in non-interoperable solutions.

At the same time, the project outputs do not reach a consensus on the exact form this standardisation should take. Given the wide scope of solutions and the significant differences in the capabilities of various actors to use digital exchange tools (for example, between a TSO and an owner of a smart household appliance), there is no unified vision. The debate is whether there should be a single, or a few, standards covering a wide range of use cases, or multiple smaller-scale standards, each focusing on a limited number of use cases, while being mutually interoperable.[17]

Actors using proprietary (non-interoperable) solutions

The OneNet project reveals that there is limited interoperability among vendors and smart appliance producers, as they often develop their own proprietary solutions [60]. For instance, the project has found that deployed smart meters did not have a unified standard for data exchange, sometimes also using proprietary solutions [61].

Existing standards not covering all required use cases

For data exchange, there is a call for developing universally usable data interfaces [56]. However, there is a need to distinguish the actors participating in the data exchange. In fact, different needs are required for communication between TSOs and DSOs, or between a DSO and an active consumer (for example, in terms of volume of exchanged data, metering frequency and cyber-security requirements) [58]. In the TSO-DSO data exchanges, CIM standards seems to be acknowledged as the best solution, however it is currently not covering all the flexibility use cases, especially related to DSOs [58]. These use cases include energy forecasting, flexibility data or the distributed energy resources management [62]. Additionally, CIM does not support sharing information on consent to handle personal data [60].

Experience from OneNet demos has shown that most demonstrations needed to develop extensions to the CIM standard or proprietary communication solutions for the data exchange interfaces between DSOs and flexibility platforms. This necessity arose because CIM does not cover all required use cases and because there is a need to ensure compatibility with the existing proprietary IT systems of the involved companies [58].

[17] This issue was highlighted during a workshop on Accelerating Standardisation in the nexus of mobility, buildings and energy, organised by the European Commission and the Alliance for the Internet of Things Innovation in January 2024 [59]

Existing standards not suited to cover all new use cases

In addition to data exchanges among the main actors involved in interoperability use cases (such as flexibility services procurement), the standards should also consider the specific interactions with actors playing supportive roles. These supportive actors can be small in size and located at the grid edge, particularly end users who are important producers of data. For example, in the experience of the OneNet project pilots, existing standards, particularly CIM, were too complicated for end-user applications. Adopting these demanding communication requirements would incur disproportionate financial costs, effectively increasing entry barriers to the flexibility markets [58]. Some solutions for data exchange with end-users exist on national level but are not further standardised across EU [60]. Moreover, there is a noted lack of standardisation in the area of data anonymisation.

In the end, it will probably not be possible to develop a single standard covering all interaction with end users and grid edge devices, resulting in multiple standards covering particular use cases (e.g., EV charging and smart home energy management system) [56].

Limited consensus on the coverage of market process phases

The developed standards vary in their coverage of data exchanges supporting all phases of the market process. For example, the OneNet project highlights gaps in the standards for baseline calculation (settlement phase), bid selection, and forecasting processes [60]. This topic is covered in further detail in a separate section on standardisation of flexibility services.

Missing governance structure for interoperability

Standards play a crucial role in enabling interoperability by codifying solutions that all actors can adopt. To develop these standards, a framework is needed for identifying solutions, reaching consensus on them, and monitoring the standards' relevance. Since identifying suitable solutions and best practices is an iterative and continuous process that must evolve with the sector, this framework needs long-term maintenance and a robust governance structure. The governance structure is also necessary to involve all stakeholders in the standardisation process, ensure their needs are met, and clarify the responsibilities of each stakeholder.

There is no authority with clearly defined responsibility

The OneNet project highlights that there is no authority (in the European context) with power to make the stakeholders use a certain standard (or set of standards) [60]. As a result, SOs and other actors often work on digitalisation in parallel, without clear leadership. This leads to several different standards being used, making the system more complex to develop, implement, deploy, update, and maintain [61].

Missing framework for identification of best practices

The INTERRFACE project has found that, despite the fragmentation in digitalisation efforts, the solutions for data exchanges across the EU are often similar. However, there is a lack of a framework to bring together relevant stakeholders to share their experiences, identify best practices, foster harmonisation and standardisation, monitor the implementation of standards, and support interoperability testing [63].

Lengthy and inflexible procedures for standardisation, profiling, and testing practices

To become operational, data exchanges require supporting standards that have already been tested and implemented. This process necessitates designing data exchange requirements several years before the exchange becomes operational, making the process extremely lengthy and inefficient. Formulating these requirements so far in advance, well before the business processes depend on the exchange, creates rigidity, impeding the process's adaptability and responsiveness to evolving needs [64].

Not all stakeholders are involved in the interoperability and standardisation efforts

Currently, not all stakeholders are involved in developing standards for data exchanges. For example, OneNet notes that final consumers have little control over the data, data formats, and set points they are required to use, and their interests are often overlooked in the creation of standards in R&I projects [60]. It is also important to recall that the original purpose of the four projects analysed in this deliverable was to enhance the standardisation of TSO-DSO-customer data exchanges. While these projects have set out a blueprint for such exchanges, further development in a collaborative and inclusive manner is needed.

It is not expected that non-expert consumers would have insights into the merits of different data models or standards. However, the OneNet project suggests facilitating stakeholder involvement and knowledge exchange by promoting consumer-focused workshops and initiatives. These efforts are intended to raise consumer awareness about the importance of their participation in flexibility markets and maximise the benefits of interoperability [65]. Additionally, these initiatives aim to involve stakeholders in the definition of data models and data exchange protocols.

Cybersecurity and privacy issues

Cybersecurity is a fundamental building block for ensuring the security of electricity supply, especially in the context of the increasing digitalisation of the energy sector. Attempting to increase interoperability in the energy sector can also elevate cybersecurity threats, as it will involve more actors in data exchanges and result in higher volumes of exchanged data. The OneNet project also notes that innovation introduces additional potential threats in the sector, as it leads to the deployment of new, untested instruments [66].

The increased volume of exchanged data will also include large amounts of personal information and detailed insights into consumer behaviour. Therefore, the challenge of ensuring privacy is closely connected to cybersecurity. One of the main topics related to interoperability is consent management for private data. This involves ensuring that only authorised entities have access to personal data and can use it only for authorised purposes, as well as allowing consumers to choose and change their level of privacy by granting and managing consent for third parties to access their data [65]. Another important issue is data anonymisation, making data anonymous enough so that they cannot be identified with an individual consumer or other actors.

Complexity of data management and data security

One of the data exchange barriers identified by the CoordiNet demonstrations is the cost and complexity of data management and data security [67]. The increasing number of distributed flexibility sources, such as distributed renewable generation, adds further complexity to ensuring secure data exchanges. Moreover, the lack of standards in the security assessment of information exchanges among FSPs, SOs, and other entities makes the process extremely difficult. GDPR and ownership policies should consistently safeguard the development of increasingly complex frameworks for data collection and information sharing.

Cost of maintaining high level of cybersecurity

Upgrading the IT systems of actors in the electricity sector to meet security requirements in the context of increased interconnectivity and the growing amount of data exchanged requires significant investment. Moreover, the IT infrastructure must be updated regularly to maintain a high level of security. All actors must weigh the cost of these cybersecurity measures against the potential risks. An additional barrier to sustaining these investment costs exists for SOs, who are regulated entities and therefore need to get these investments and operational costs approved by regulators [65].

Missing standards for data access and consent management

The OneNet project notes that current standards do not address access to metering data by end users or by third parties with the data owner's consent. This limitation restricts the potential for end-user participation in the market and the ability to market their data to third parties. Additionally, it weakens the protection of user privacy, as there is no standard solution to guarantee a consistent level of security [60].

Standardisation and harmonisation of flexibility services

The need to integrate more distributed energy sources, such as renewable sources and electric vehicles, while preserving the stability of the grid, has opened the possibility of developing new local flexibility markets. Although policymakers envision the development of these markets, they have not provided specific provisions regarding their architecture [68]. Consequently, the four projects analysed in this document explored different market configurations, which present various challenges when discussing interoperability requirements. The provision of flexibility services requires data exchanges to ensure coordination among SOs and other market actors, such as FSPs. Therefore, interoperability issues need to be addressed in all aspects, from the definition of clear governance to more technical dimensions (e.g., data formats and communication protocols).

Lack of roles and responsibilities definitions

Roles and responsibilities should be assigned to standardised roles within the market process, independently of specific real-world entities. This approach aids in standardising information exchange, preventing responsibilities from being monopolised by particular entities, and allowing for flexibility in national implementation and adaptation to future needs. For example, the role of DSOs regarding the implementation of the flexibility register needs to be clarified, as well as the requirements for TSO-DSO coordination in this context [69].

Lack of standardisation on the different interoperability layers

Given the diverse nature of interoperability requirements, a portfolio of standards is often necessary to address various use cases. Emphasising open international standards over proprietary ones ensures inclusivity in development, enables reusability, and fosters innovation and supplier competition. Standardisation is an ongoing process, with standards subject to adaptation or substitution as technology evolves. For example, two main problems have emerged due to the lack of standardisation for enabling interoperability: *i*. communication among IoT and sub-metering and control devices (e.g., aggregator with appliances, etc.), *ii*. interfaces among different systems and platforms (at DSO and energy asset level) [61].

Different business processes on national level

A challenge for the interoperability of national data management models is the stark differences in handling use cases across MSs. Both business processes and data exchange procedures differ from country to country, and there is a lack of standardisation and harmonisation. Market participants that want to expand their business to other MSs are currently forced to set up parallel IT infrastructures to accommodate the different systems and processes in place across countries, resulting in increased costs and effort. The markets for flexibility products for DSOs are also locally focused, addressing local needs, and therefore harmonisation is more difficult than in the case of TSO ancillary services. Data exchange schedules are not necessarily aligned with market processes and market results, which reduces the possibility for stakeholders to make informed decisions [56].

Moreover, among the more than 2000 European DSOs, there are significant differences in their readiness to engage in digitalisation, based on their size, expertise, and national context. This makes the effort to adopt standardised interoperable solutions more challenging [58]. Similarly, many operators are locked in in the existing, already deployed, solutions, and conversion to more interoperable systems would be too costly [67].

Metadata

Metadata are reference data which provide attributes of the information it describes, such as format, author, creation date etc. By summarising information on the underlying data, metadata facilitate the use and exchange of the underlying information, contributing to efficient access and comprehension.

Metadata are key for semantic interoperability, defined as the ability of different systems to exchange and understand data with shared meaning or semantics.[18] By ensuring that the exchanged data are understood in the same way by all parties involved, semantic interoperability goes beyond syntactic interoperability, which, on the other hand, ensures that systems can exchange data without errors in structure or format. Semantic interoperability relies on common understanding and interpretation of data semantics, and it is achieved by using standards and ontologies. Thus, metadata and their standardisation are relevant to unambiguous exchange of information and are essential for the interoperability of the new flexibility services and the new common data space [71].

[18] As defined in the European Interoperability Framework Implementation Strategy [70].

Lack of metadata standardisation

As analysed through the Interoperable pan-European Grid Services Architecture (IEGSA), developed by the INTERRFACE project, to ensure the scalability of the architecture, standards (such as CIM and CGMES) which comply with SOs needs must be developed and incorporated in the information layer of the IEGSA, together with the associated metadata [72].[19,20] In fact, even stakeholders using common standards which do not address metadata may encounter semantic issues. Thus, the lack of metadata and header specifications standardisation pose a risk to data exchange interoperability.[21]

Lack of metadata and reference data governance

As mentioned here above, the omission of metadata from the (IEGSA) has emerged as a significant impediment to the achievement of TSO-DSO interoperability [72]. In addition, metadata governance is also key for such achievement.

While there may exist candidates for metadata and reference data standards (e.g., W3C ontologies, CIM), the absence of a structured governance framework to oversee and ensure their widespread adoption still needs to be addressed.[22] Moreover, metadata, boundary and reference data specification exchange between TSOs and DSOs still need to be explored. Consequently, efforts directed towards fostering the adoption of metadata standards and metadata exchange remain an unmet requisite for interoperability.

Energy data space

For coordinated and efficient data exchange in the field of energy services, critical challenges have emerged that require specific analysis and strategic interventions. Although the projects analysed do not focus on the development of the energy data space per se, they aim to establish platforms for flexible services within the energy sector. In this context, critical issues such as the scalability and replicability of ICT systems, as well as the integration and data exchange among decentralised platforms, have emerged as fundamental prerequisites for achieving interoperability in power system data exchange.

This section aims to explore these interconnected elements and their importance in the context of the advancement of service platforms in the electricity sector.

Scalability of data exchange platforms

A critical gap in the definition of data space is managing the scalability of data exchange platforms due to the need for integration with multiple data exchange platforms distributed across borders or sectors [63]. As data exchange increases, current ICT systems and platforms will need to scale to accommodate the growing demand. Without proactive measures, the scalability of these platforms may become a constraint rather than an enabler of future data-driven services among various business actors.

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[19] The interested reader can find further details here: IEGSA Platform (renewables-grid.eu)
[20] The interested reader can find further details here: Common Grid Model Exchange Specification (CGMES) (entsoe.eu)
[21] Header specifications are specifications that describe and build metadata models and header schema to exchange electricity grid and market data.
[22] The interested reader can find further details here: OWL - Semantic Web Standards (w3.org)

Furthermore, missing integration among multiple distributed data exchange platforms at cross-border or cross-sector level is hindering the full potential of data-driven services and the ~~foster~~ collaboration among various business entities.

Standardisation and decentralisation of platforms

Most of the commercial solutions and R&I projects for digital platforms tackling interoperability challenges choose a centralised approach – providing a centralised platform to facilitate data exchange in a uniform manner [71]. Due to the difficulty of mastering technology and the risks associated with retrofitting digital systems already in production, semantic interoperability is usually facilitated by intermediaries. This creates a technical and business dependence on centrally hosted facilitators, imposes limitations on hosting capacity, and increases the risk to data privacy and security due to reliance on third-party processing [71]. Moreover, centralised platforms limit the adoption of new technologies and standards, as well as the expansion of interoperability features, which depend on the support and empowerment of the platform facilitator. Lastly, while established standards such as IEC61850 and CIM provide a solid foundation for the interoperability of DSO systems, a new framework is still needed to encourage a more decentralised and standardised approach for enabling semantic interoperability, fostering the resilience and autonomy of the data space [71], [73].[23]

Data exchange process efficiency

The standardisation of grid-related and market-related data exchange profiles is needed to avoid inefficient and ineffective data exchange processes. These profiles, described as the specifications (e.g., classes, properties, and relationships) that define the information required in a specific data exchange, serve to delineate the requisite information in any given business exchange scenario.

The efficacy and efficiency of data exchange initiatives can be markedly enhanced by streamlining processes and instituting mechanisms to prevent duplicative data transfers. Additionally, attention to detail and ensuring that data exchange focuses on pertinent information are crucial for enhancing process efficiency. Oversharing information can impose significant costs on involved parties in terms of time and complexity, while withholding crucial information can hinder effective data exchange.

Protracted duration of the exchange processes

One of the challenges in data exchanges is the lengthy duration of processes (e.g., data transmission, data decoding) due to their inherent complexity and the multitude of stakeholders involved. This is especially true in scenarios requiring a comprehensive data merge on an hourly or quarter-hourly basis, where creating a unified grid model demands meticulous attention to detail. In such cases, grid model data exchange tends to take a long time because of the complexity and the number of parties involved. Therefore, it is important to optimise the process to avoid frequent exchanges of duplicated data [74].

[23] IEC61850 is an international standard that defines communication protocols to provide communication among different equipment located in a substation.

Gap in transformation of R&I results into practice

Since interoperability is a general term that is not clearly defined in the electricity sector and covers a broad range of applications, no single R&I project, or effort can encompass the implementation of all interoperable solutions (as discussed in the previous section on governance). This means that multiple research projects and initiatives are working on developing solutions for innovative use cases in the electricity sector, such as the integration of DERs and flexibility service provision. Besides the challenge of coordinating these R&I efforts, addressed in the previous section on governance issues, it is also necessary to ensure that the solutions developed will remain in use after the projects end and that they will be further adopted by other stakeholders. This is important because the R&I activities are led by a limited number of advanced actors with the resources to work on innovative solutions, while others lack the capability to do so. In the European context, the landscape of actors who will need to ultimately adopt interoperable solutions is very varied, including thousands of DSOs of different sizes.

Research projects working on multiple parallel solutions

There are multiple research projects that work on use cases that are related to interoperability but are not using the same standards. Because of that, the developed solutions are not fully interoperable, and cannot be deployed together [57]. The parallel efforts of the projects and absence of harmonised interoperable solutions also pose barrier to adoption of the research results and to extending the innovative business use cases to other countries [60].

Project results not published in sufficient detail

In OneNet, it was noted that not enough information about the developed use cases is published, in particular regarding the data exchange practices [60]. Therefore, it is not possible to replicate the results in other settings. This is problematic also because these R&I efforts were co-financed from public budgets.

Development of closed/proprietary solutions

Some of the innovation activities conducted in research projects are not geared toward developing open solutions for adoption by all actors. Instead, they either focus on developing proprietary solutions tailored to specific contexts or creating closed solutions that only work within a single vendor's ecosystem. These solutions are difficult to replicate in other settings, and stakeholders considering using them risk vendor lock-in [60].

5 Policy and regulatory considerations

As highlighted in Chapters 3 and 4, various barriers are currently hindering the development of interoperable energy services (and of the energy data space). A comparison of the two chapters reveals how several barriers impact both the stakeholders in the electricity sector, such as by limiting the potential to develop new business cases, and the activities of research projects, thus impacting their achievable outcomes. These barriers encompass various dimensions of interoperability, from the absence of a clear governance framework to more technical aspects such as the lack of open standards adopted by the majority of stakeholders.

In light of our findings, the purpose of this chapter is to outline a series of considerations that may prove relevant from the perspective of policymakers and regulators. Indeed, as highlighted at the beginning of this work, interoperability is not only a matter of technical nature, but its development also requires appropriate policies and regulatory initiatives. However, producing specific recommendations would also require a detailed analysis which can demonstrate that the proposed recommendation is indeed the best among other possible alternatives (for instance, based on the approach of economic efficiency). Moreover, the effectiveness of interoperability as a regulatory intervention in markets is uncertain and can be accompanied by several risks. These include stifling innovation among established companies, promoting excessive similarity across services, and potentially leading to higher prices or lower quality due to the associated costs. Furthermore, interoperability is not a comprehensive solution for all competitive challenges in digital markets [8]. These kinds of evaluations go beyond the scope of this deliverable; therefore, a more neutral stance is adopted here, where a basket of various alternatives that can contribute to the development of interoperable energy services (and the energy data space when relevant) is presented. Where possible, these solutions will also be accompanied by considerations regarding the advantages and disadvantages of the specific solution. Obviously, these solutions are not mutually exclusive but can be adopted in synergy and tailored to the specifics of the problem at hand.

The following considerations result from internal brainstorming, supported by external sources when relevant, and have also been integrated with perspectives from the interviewed stakeholders. Table 5.1 lists our considerations and the related sub-topics.

Table 5.1 Considerations for policymakers and regulators to foster interoperable energy services.

Considerations	Sub-topics
Identifying incentives for various stakeholders	• Incentive-based regulation • Regulation for new flexibility services
Enhancing a governance framework for interoperability	• Data exchange optimisation • Digital twin development
Developing standards tailored to specific use-cases	• Stakeholder engagement • Priority setting • Common European data and reference data for electricity
Mandating minimum interoperability requirements	• Competition law • Labelling
Learning from other sectors	
Empowering consumers	

Identifying incentives for various stakeholders

While it is recognised that a lack of interoperability often results in high transaction costs, enhancing interoperability in the electricity sector also incurs significant direct expenses, particularly affecting incumbent firms, which might need to lead these initiatives. To facilitate progress, significant investments in both digital and physical infrastructure are essential. Traditionally, energy producers are compensated for meeting electricity demand, and SOs are paid to ensure adequate network capacity for end-users. New business models could involve compensation for incremental efficiency gains or contracts for differences to cover costs saved. To stimulate investment from traditional energy sectors, where funds might otherwise be lost as sunk costs, market incentives or targeted regulations may be necessary, focusing on specific use cases.

As highlighted in Chapter 3, not all stakeholders may have a "natural" incentive to develop interoperable energy services. To identify the right incentive (or incentives), it is crucial to understand the main reasons stakeholders' behaviours deviate from adopting solutions that align with the system's needs. In this regard, a broad division can be made between:

- regulated stakeholders, and
- non-regulated stakeholders (operating in the “free” market).

For the former, appropriate incentives can be implemented by changing the regulatory framework. In the latter case, stakeholder behaviour primarily responds to economic signals from the market. However, regulators or policymakers play a significant role in designing market rules that may favour one behaviour over another.

In the case of market stakeholders, a further broad distinction can be applied among new market entrants, and well-established firms, which may include stakeholders with significant market power. As observed during the stakeholder analysis, these two categories of stakeholders generally exhibit greater and lesser propensities, respectively, to adopt interoperable energy solutions. The cost associated with converting their data management systems represents a significant disincentive for the latter group, who, in certain circumstances, may even benefit from their market position due to the absence of interoperable solutions. The regulator could consider targeted measures for these two categories of stakeholders, taking into account the specificities of the targeted industrial sector, similar to the approach taken by the DMA. However, such interventions must consider the dynamism of companies operating in the electricity and digital sectors, where competition and innovation are always to be considered as temporal dependent dimensions.

Among the possible tools that policymakers and regulators have at their disposal to incentivise regulated and non-regulated stakeholders, two are particularly considered here:

- incentive-based regulation, envisioned as a regulatory framework capable of promoting the digitalisation of the electricity infrastructure, and
- the regulation for new flexibility services, which can help enable new business cases.

Incentive-based regulation

Traditional regulatory models of SOs primarily emphasise cost efficiency and reliability. However, the growing importance of energy transition policies necessitates regulatory frameworks that not only ensure efficient operation and investment but also encourage network utilities to contribute societal value by facilitating the deployment of low-carbon technologies. Creating a more flexible regulatory environment can be crucial to accommodate the integration of renewable energy sources and the decentralisation of electricity systems without compromising the reliability of the power supply. This may include the introduction of remuneration and incentive-based regulations that encourage SOs (DSOs in particular) to prioritise digital solutions and advanced grid operations. These incentives need to be supported by methodologies for evaluating the benefits of digitalisation projects. Moreover, the regulatory frameworks should be sufficiently flexible to allow DSOs to innovate without the risk of regulatory constraints and to adapt to new business models and technological innovations [75]. There is a growing consensus that the predominant models based on revenue or price caps are inadequate under these new conditions. In light of that, it has been suggested that regulatory frameworks need to be re-evaluated, for instance extending the regulatory period, placing a greater emphasis on measurable outputs, and enhancing the focus on performance indicators to encourage active system management and smarter infrastructure investments [76].

Broadly speaking, incentive regulatory strategies can focus on either the inputs (the cost of innovation activities) or the outputs (the results of these activities). An input-oriented model, where costs are independently appraised or benchmarked, might protect the firm from the financial risks of unsuccessful innovations. Conversely, an output-based model encourages firms by allowing them to fully benefit from successful innovations but also exposes them to significant risks, especially when outcomes are hard to measure or verify, such as activities that go beyond the network utility's core functions [77].

Innovating within the network sector is inherently risky, thus requiring a compensation scheme that balances risk sharing among network utilities and their customers. This is complicated by information asymmetry, where the regulator may not be fully aware of the innovation opportunities available to the firm or the efforts of its managers. To manage this, regulators might link the allowed revenue of network companies to their performance, though this raises concerns about penalising firms for genuine efforts that do not yield successful outcomes. This situation necessitates a regulatory design that provides both incentives for innovation and insurance for risk aversion, especially when outcomes are uncertain [77]. A more need-reflecting regulatory framework can help to mitigate economic barriers, for instance, introducing remuneration bonuses for digital investments, renegotiation of returns on digitalisation projects, and enhancing support for innovation expenses. Moreover, the lack of clearly defined roles and responsibilities in local markets affects DSOs' willingness to invest in digital initiatives and data-sharing. Developing performance monitoring systems for flexibility providers and enhancing compliance monitoring can help to ensure adherence to digitalisation requirements [78].

On the technical front, integrating new technologies with aging infrastructure presents significant challenges, exacerbated by interoperability issues. The development of user-friendly, real-time information systems and robust data management frameworks is crucial. Regulation should foster collaboration with technology providers to improve integration and address the cybersecurity risks posed by the increasing complexity of systems. However, integrating new technology in a system is also dependent on the human-organisational dimension of an institution. Human barriers, notably the lack of necessary digital and electro-technical skills, slow down the pace of digitalisation. Life-long learning initiatives and cross-sector partnerships can play a key role to build a skilled workforce capable of supporting digital transformation in energy distribution. Organisational barriers include siloed structures that limit effective data-sharing and digital strategy development. Promoting a cultural shift towards openness and establishing cross-functional teams are potential solutions to foster better collaboration and innovation. This also involves enhancing trust and cooperation among SOs, supported by comprehensive industry-wide data management standards [78].

As highlighted in the stakeholder analysis, the landscape of national electricity regulators within the EU is notably diverse, despite sharing a common legal framework set by the European legislation. This diversity is evident in the varying administrative powers and resource endowments of these regulators, as well as in the heterogeneous characteristics of the SOs they regulate. These network operators are complex entities, consisting of multiple tasks each with distinct economic and regulatory characteristics that may evolve due to factors like technological progress, demand shifts, and country-specific conditions.

Given the limited resources typically available to National Regulatory Authorities (NRAs) and the multifaceted nature of network operators, there is no one-size-fits-all solution. NRAs should identify a workable regulatory alignment that matches the most appropriate regulatory tool with the characteristics of the targeted network task and the NRA’s capabilities. Obviously, this regulatory alignment requires ongoing adjustments through a process of trial and error. NRAs must continuously reassess and realign their regulatory strategies to ensure they remain consistent with evolving regulatory goals, the availability of resources, and the changing nature of the tasks performed by network operators. In the context of persistent differences among EU MSs and often limited resources, collaboration among European regulators is even more important [79].

Regulation for new flexibility services

As emerged in the context of the stakeholder analysis, the lack of vision regarding new business opportunities that can be enabled by the development of interoperable energy services (or participation in the energy data space) represents one of the major reasons stakeholders cite for not adopting new technological solutions. The regulatory framework can establish rules that clarify the benefits derived from participating in the new flexibility markets, for which interoperable energy solutions are necessary.

In the current evolving energy landscape, DR and other flexibility services play a crucial role in optimising grid operations, enhancing energy efficiency, and integrating renewable energy sources. Enabling consumers to adjust their electricity consumption patterns in response to market signals and grid conditions help improve grid reliability, reduce peak demand, mitigate the impact of intermittency, and, ultimately, advance the energy transition.

In this regard, the new Network Code on Demand Response and implementing regulation focusing on data interoperability for demand response and related services should help to:

- unlock flexibility by establishing an EU-framework for the integration of technology-agnostic distributed flexibility in transmission and distribution-related services considering existing national terms, conditions and methodologies;
- promote the use of international and European standards and technical specification and facilitate the standardisation of processes and products for new flexibility services at national level, including data access, and standardised data exchange formats. The development and implementation of electricity market data exchange standards could facilitate the deployment and maintenance of market platforms and communication tools. Some minimum requirements on data should be established and could advantageously be implemented in the process of product harmonisation, including aspects such as granularity, accuracy, level of data aggregation;
- support the development of a framework for the interoperability between grid components and market platforms to improve interoperability on energy data exchange.

Broadly speaking, the future regulatory framework on flexibility services should support also the definition of clear business processes and implementation guidelines for the new flexibility services, following the example of the already existing CIM Market Implementing guidelines – which define Electricity balancing platforms use cases and data exchange models.[24] Moreover, developing or promoting a clear and consistent roles and responsibilities models (including new agents involved in the defined flexibility services, e.g., Harmonised Electricity Market role model) can clarify risks and opportunities for stakeholders.[25]

[24] The interested reader can find further details here: https://www.entsoe.eu/publications/electronic-data-interchange-edi-library/.

[25] The interested reader can find further details here: https://eepublicdownloads.entsoe.eu/clean-documents/EDI/Library/HRM/Harmonised_Role_Model_2022-01.pdf.

Moreover, regulatory contribution could be relevant in developing a comprehensive data exchange framework that defines the types of data to be exchanged, data formats, protocols, and security requirements. This framework may ensure that relevant data, such as DR availability, performance, and consumption patterns, can be shared securely and efficiently among market participants while protecting consumer privacy and confidentiality. In this regards, several options are available:

- establishing standardised data models, formats, and interfaces for exchanging information related to DR, including availability, performance, and consumption data e.g., CIM families of profiles: Common Grid Model Exchange Specifications (CGMES), European Style Market profile (ESMP), harmonised data format CIMXML and XML;
- adopting common communication protocols to enable seamless integration and interoperability of DR systems, devices, and platforms e.g., secure Advanced Message Queuing Protocol;
- ensuring compatibility with existing data exchange standards and frameworks to promote interoperability with legacy systems and infrastructure;
- standardised messages in terms of semantics and communication protocols among TSO-DSO-aggregator-FSP when bids are procured, and activation is recommended.

Enhancing a governance framework for interoperability

Numerous and diverse stakeholders are currently engaged in interoperability efforts but often without a cohesive and goal-oriented coordination. To enhance higher degrees of interoperability, the impact of policies should be evaluated across various governmental levels, namely the EU and national levels. The project analysis shows that governance of common data and reference data is important for ensuring the integrity, consistency, and reliability of information within the EU electricity sector. By establishing clear governance frameworks, stakeholders can define ownership, responsibilities, and processes related to the creation, maintenance, and usage of common data and reference data. Robust governance of common data and reference data is essential for driving innovation, optimising performance, and achieving long-term sustainability goals. In fact, governance can ensure that data is accurately captured, standardised, and maintained in accordance with established policies and standards. It can promote transparency, accountability, and trust among stakeholders, facilitating effective decision-making and collaboration.

Moreover, the electricity sector undergoes continuous transition when implementing new requirements to meet business needs and regulatory initiatives. Updates to network codes, methodologies, and standards occur frequently, reflecting the dynamic nature of the industry. Given the complexity of the electricity ecosystem and the reliance on various data sources for exchanges, it is crucial to enforce best practices during transition periods. This ensures that all involved entities can adapt promptly, preserving the reliability of the electricity system within their respective responsibilities Without clear directions and understanding of feasible timelines, entities may become demotivated, leading to a slowdown in the overall process. This can result in excessive demands on resources, as entities struggle to manage multiple versions of standards or specifications concurrently or fail to consistently utilise the latest standards. Such challenges impede the industry ability to innovate rapidly. Therefore, establishing clear guidance and facilitating smooth transitions is essential for sustaining momentum, fostering innovation, and ensuring the resilience of the EU electricity sector.

An effective governance framework can facilitate the accurate and standardised management of data, which is crucial for optimising data exchanges. This, in turn, may also support the development of a comprehensive digital twin of the electricity system by ensuring that the necessary data is consistently available and reliable.

Data exchange optimisation

As highlighted in Chapter 4, the use of outdated data exchange standards or the absence of appropriate standards can lead to significant complexities in the data exchange process. This complexity often results in the duplication of data, either because IT systems fail to adhere to standards or because data-sending entities lack well-established data management principles. Additionally, variations in the interpretation of confidentiality and data transparency rules further exacerbate the situation, leading to unnecessary preparatory activities before data transmission. To address these challenges, it is important that EU regulations, methodologies, and standards provide clear guidance aimed at optimising the data exchange process. Entities responsible for implementing business processes should prioritise efforts to minimise data duplication and streamline data management practices. In this regard, facilitating discussions among key stakeholders is essential, perhaps through dedicated forums.

Establishment of an interoperability framework at EU scale would support implementation of various data exchange requirements at both regional and European level. Beyond standardisation, testing and certification can contribute to strengthen both digital and physical systems, enhancing data and infrastructure security. Testing confirms that specifications meet requirements and continuously demonstrates the validity of test models, ensuring they adhere to standards. Real-world testing is crucial to verify that developers comply with specifications, helping to achieve interoperability objectives effectively. There is often a debate surrounding the allocation of costs for interoperability testing and conformity testing schemes and procedures. Determining which entity should bear these essential activities' costs can be a challenging task. A possible solution could be the establishment of a framework at the EU scale with sufficient funding to ensure the availability of resources. Such a framework could draw upon the principles established in the above recommendation for establishing a network code on interoperability and data exchange. By implementing a centralised approach with adequate funding, the burden of costs can be distributed equitably among stakeholders while ensuring the effectiveness and consistency of testing processes. This could not only promote fair and transparent practices but could also facilitate the seamless implementation of interoperability standards across the EU energy landscape.

The definition and standardisation of testing procedures, conformity assessment processes, certification programs and interoperability testing facilities may be promoted to ensure compatibility and compliance with technical specifications and standards e.g., CGMES conformity assessment and CIM interoperability test. In this regard, within the framework of the int:net project, ENTSOE-E hosted a CIM/CGMES Interoperability test (IOP) to foster the harmonisation and interoperability of energy services throughout the EU by focusing on the adoption and implementation of CGMES v3.0, an IEC standard (IEC 61970-600-1&2:2021).[26] The event helped reaching the following conclusions:

- a stable IOP framework should be implemented and IOP organised on specific topics to both draft international standards and support big implementation projects;
- conformity assessment should be enhanced through business-specific site acceptance testing for data suppliers' compliance;
- bidirectional communication among vendors, standardisation bodies, and TSO/DSO organisations should be improved;
- early announcement of business needs and transparent technical discussions for interoperability should be addresse;
- seminars, forums, and R&D projects to enhance knowledge sharing and standard adoption should be promoted.

Digital twin development

The modelling of the pan-European electricity system presents a multifaceted challenge, requiring the realisation of objectives to develop a digital twin of the electricity system while accommodating the substantial data exchanges necessary for constructing a Common Grid Model (CGM) at hourly or even more frequent intervals. Stakeholders shall navigate complexities to optimise data merging and CGM creation processes, ensuring efficiency and paving the way for the development of a comprehensive digital twin of the electricity system. It is essential to distinguish between the physical characteristics of the grid and operational or situational parameters. This separation enables the creation of a model, or digital twin, which is sufficiently parameterised and detailed to meet the requirements at the national, regional, and pan-European levels.

Achieving this goal demands a multidisciplinary approach, with implementation projects leveraging innovative methodologies and technologies to overcome inherent challenges. Furthermore, these efforts require legislative support to address data confidentiality issues, safeguard commercial sensitive information among different parties, and enhance the overall process efficiency.

Developing standards tailored to specific use-cases

Both the stakeholder and project analyses have highlighted how the lack of common standards on data exchange is fragmenting the electricity sector and has promoted the implementation of specific technological solutions that are not scalable beyond the specific context for which they were developed. In order to be effective, standards need to be implemented for specific use cases while simultaneously enabling interoperability across different use cases. To this end, it is necessary that these standards guarantee both technical and semantic interoperability. However, within the context of the stakeholder analysis, some stakeholders suggested that standard implementation should not be overly burdensome for the stakeholders adopting them. More specifically, standard adoption should not impact the data management systems of the various organisations, but rather focus on the level of communication

[26] The interested reader can find further details in the IOP Report available at the following link: https://intnet.eu/resources/technical-resources.

interfaces. Indeed, promoting open standards that are freely available is not sufficient to eliminate the conversion costs that some stakeholders might face.

Additionally, from a system efficiency perspective, it is also necessary to identify the key interfaces and levels of the energy supply chain where it is most appropriate to promote the adoption of common standards. In this regard, much has already been done, for example, by some of the stakeholders interviewed, such as EEBus, or by associations like smartEn [80]. Broadly speaking, the identification of these key levels can be promoted by pinpointing essential use cases for the integration of distributed sources while preserving grid security. An example in this regard is Paragraph 14a of the (German) Energy Industry Act.[27] This paragraph allows grid operators to temporarily reduce the output of controllable energy-consuming devices during potential grid overloads, though not completely shut them off. In exchange, consumers benefit from reduced grid fees. Newly commissioned controllable energy devices are mandated to comply with this regulation. This way, companies in the electricity sector have an incentive to develop home energy management systems that can communicate with the rest of the grid. Looking outside the EU borders, a good example of how regulation can react to technological changes is Australia.[28] In order to manage the potential risk rising from unmanaged domestic photovoltaic generation, new regulations mandated that these installations be capable of remote disconnection from the electricity grid during emergencies to enhance grid stability. The approach avoids overly prescriptive specifications, focusing instead on the broader use case and requiring a certified third party to manage the disconnection process when needed. This ensures that the interoperability framework not only meets immediate goals but is also robust enough to handle future developments without stifling innovation [1].

In the EU, the Smart Grid Task Force, comprising representatives from the industry, national regulators, consumer groups, and the Commission itself has been pivotal in advising on regulations and standards for privacy, data protection, cybersecurity, and industrial policy related to smart grids. Specifically, the expert group aimed to tackle the hurdles to creating interoperable frameworks across the EU for the streamlined exchange of energy data. The guiding principles for transitioning to interoperability included ensuring adaptability for various time resolutions, flexibility to accommodate distinct needs of each MS, scalability for future variables, ease of implementation, and a non-rigid approach to data formats, promoting compatibility with existing systems [1], [2].

Stakeholder engagement

Adopting common standards requires stakeholder engagement. This activity involves high coordination costs, which can be reduced by identifying associations, stakeholders, or their representative bodies that are already active in defining a set of standards that can be adopted in relevant use cases. Specifically referring to the electricity sector, this activity may benefit from the experience gained by system and market operators in orchestrating the electricity system or may be performed by an

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[27] The interested reader can find further details here: https://www.gesetze-im-internet.de/enwg_2005/__14a.html

[28] The interested reader can find further details here: https://www.aemc.gov.au/sites/default/files/documents/nera_smart_meter_data_access_framework_options_-_metering_review.pdf.

independent entity, as suggested by the INTERRFACE project [63]. Their expertise and first-hand operational insights are valuable in shaping robust and practical standards that effectively address the complexities of energy transmission and distribution systems. Incorporating diverse perspectives and experiences at the standardisation table enriches the development process, resulting in standards that are not only more comprehensive but also more resilient to real-world challenges. By fostering dialogue and collaboration among stakeholders representing various sectors and interests, we can ensure that the standards accurately reflect the multifaceted needs of the electricity industry. This inclusive approach promotes the creation of standards that are not only technically sound but also pragmatic in their application, ultimately enhancing the reliability, efficiency, and interoperability among actors in the EU electricity sector.

In this regard, the int:net community can play a key role in forming a network of experts and identifying the key stakeholders to bring to the same discussion table. Therefore, the stakeholder engagement activity undertaken in the context of T4.2 could continue even in the subsequent phases of the int:net project.

Priority setting

Encouraging the development of crucial standards through regulatory measures is essential for advancing the reliability and the efficiency of the EU electricity system. In addition to regulatory incentives, it is important to establish clear priorities and requirements that guide standardisation efforts effectively. Setting these priorities ensures that standardisation efforts align with overarching EU objectives and address pressing industry needs. It is unrealistic to expect potentially divergent regional approaches to be standardised without careful consideration, particularly in the context of data exchanges. Therefore, legislators should take proactive steps to ensure that regional peculiarities are appropriately addressed in a manner that supports seamless data sharing and streamlines business processes. By acknowledging and accommodating regional nuances within the standardisation framework, greater collaboration and interoperability across regions can be fostered.

Common European data and reference data for electricity

As shown in Chapter 4, metadata, often referred to as common data or reference data, plays a crucial role in fostering a shared understanding of data across various stakeholders. It serves as a foundation for aligning interpretations and usage of shared data among different actors.

Establishing common data and reference data for electricity in the EU is relevant for several reasons. Firstly, the growing integration of renewable energy and interconnected grids necessitates standardised data to ensure smooth communication and coordination across borders. Common data frameworks keep information on energy production, consumption, and distribution consistent and accessible, boosting the network's efficiency and reliability. Secondly, standardised data supports effective monitoring and management of the energy transition, enabling policymakers and regulators to make informed decisions using accurate and current information, often shared among multiple entities. Failure to recognise the importance of standardised exchange of metadata and its governance may carry significant risks, including data duplication and misinterpretation, which ultimately hinder interoperability efforts and data management processes.

There are already existing good practices that may be followed on the matter: for instance, the EC oversees the maintenance of specific datasets, while ENTSO-E has launched several initiatives aimed at standardising the structure of common data and reference data within the electricity sector. Nevertheless, to maximise their effectiveness, these efforts require harmonisation and promotion at the EU level.[29]

Mandating minimum interoperability requirements

Interoperable solutions can be supported by the regulatory framework but also mandated by imposing minimum interoperable requirements. When exploring how authorities can mandate interoperability in practice, various approaches and considerations are identified, reflecting the complexity and context-dependent nature of enforcing interoperability [8]. The considerations are categorised into several key areas: identifying which firms should be subject to interoperability obligations, determining the functionalities or data that should be interoperable, deciding the required level of openness, considering the role of standard-setting processes, defining the terms under which interoperability should be provided, and establishing governance and monitoring arrangements.

The application of interoperability obligations often targets specific firms, particularly those with significant market power, to avoid burdening smaller firms or new entrants. Many interviewed stakeholders believe that a minimum set of interoperability requirements could be imposed on those OEMs whose devices are essential for providing interoperable energy services. However, this asymmetric approach necessitates clear criteria to identify firms that should be obligated, balancing flexibility, transparency, and regulatory certainty. The scope of interoperability, whether narrow or broad, affects its impact and the implementation costs. Ideally, interoperability should focus on core functionalities that significantly influence user behaviour, such as willingness to switch or use multiple services simultaneously. Authorities can opt for minimal interventions that increase transparency or more impactful measures that enhance interoperability. The degree of openness chosen will influence the competitive impact as well as the associated costs and risks.

The process of implementing interoperability involves complex standard-setting, which might be led by standard-setting organisations involving various stakeholders. These processes can be slow and subject to influence by powerful firms. Ensuring that interoperability standards are effective and neutral requires careful regulatory oversight and possibly international coordination, given the varied legal frameworks across different jurisdictions.

Governance and monitoring are crucial to ensure that interoperability obligations achieve their intended outcomes and to mitigate risks such as firms undermining the process. This may involve setting milestones, establishing independent monitoring bodies, and allowing stakeholder feedback.

Lastly, interoperability can have broader implications beyond competition, such as affecting privacy, security, and online safety. Ensuring that interoperability measures respect privacy standards and provide secure data sharing is essential. The potential risks and benefits must be carefully balanced,

[29] The interested reader can find further details here: https://op.europa.eu/en/web/eu-vocabularies/authority-tables.

with a consideration for how interoperability can enable positive changes in these areas by enhancing user choice and promoting competition over privacy and security features.

Alongside economic and regulatory considerations, there is another aspect of a more technical nature. Interoperable energy services, as repeatedly emphasised, are a fundamental pillar for maintaining the security of the electricity system. Discussing with some stakeholders, it emerged that the identification of minimum interoperability requirements could be carried out by identifying a series of fundamental use cases to preserve network stability, as previously discussed in the section “Developing standards tailored to specific use-cases”. Identifying these use cases can lead to the recognition of potential bottlenecks in the energy supply chain in terms of lack of interoperability through a “reverse engineering” action. Should considerations of network security take precedence over economic considerations, the regulator could require relevant stakeholders to comply with minimum interoperability requirements.

Competition law

Interoperability can also be enforced through ex post interventions grounded in competition law, a method available in many countries under certain conditions. This approach is relevant when a dominant company’s refusal to share interoperability information is viewed as an abuse of power. For instance, while a company might release technical interoperability data, competition law can still address potential anticompetitive behaviours at the data layer. In this regard, an interesting case involves Google and Enel X Italia [81].

While antitrust actions can be effective in promoting interoperability in targeted scenarios, they often trail behind market developments due to the lengthy nature of enforcement procedures. These measures also impose considerable costs on governments responsible for their enforcement. However, the specific and narrowly focused nature of antitrust interventions provides the necessary flexibility to adapt to varying market, technological, and legal contexts [8].

Labelling

To address potential information asymmetries, the government can adopt a traditional approach that enhances transparency by mandating the disclosure of interoperability characteristics of specific products or services. This regulation may vary in aspects such as the details and visual presentation of the information disclosed. In the absence of "specific" legislation tailored to interoperability, such regulatory measures can also be enforced through consumer protection laws or competition law, even though these are not always mandatory.

Certification programs often fulfil the role of enhancing transparency, although not explicitly required by law. The effectiveness of labelling requirements in promoting interoperability is challenging to measure. Success largely depends on the design of the labelling and its ability to balance between insufficient and excessive information. Recent studies suggest that for labelling to be effective, it must be integrated into consumer decision-making processes. Despite the monitoring and enforcement costs associated with labelling, its overall efficiency is generally more favourable compared to other regulatory approaches. Labelling’s flexibility is advantageous due to its indirect approach, reducing potential conflicts with future technological advancements [82].

Learning from other sectors

Interoperability is not an issue specific to the electricity sector. Other sectors already faced quite similar challenges. For instance, in the initial stages of mobile phone adoption, users encountered challenges when traveling accross regions, primarily due to system incompatibilities and a lack of interoperability. However, through international collaboration and technological advances, mobile roaming capabilities were developed, enabling seamless global connectivity for users across different regions. Therefore, significant lessons can be learned from the telecommunication sectors but also others like healthcare, which have extensively implemented interoperability standards. Specifically, the ISO/TR 28380 standard in healthcare, which has facilitated global standards for health informatics and the exchange of information. The evolution of interoperability in these sectors is already mirrored in the EV charging sector, emphasising the potential to enhance customer experience, integrate EVs more effectively into the electricity system, and boost consumer adoption through the use of open, interoperable standards [1]. In this regard, the successful experience of the Open Charge Alliance represents a good example of the promotion of open standards.[30]

Moreover, there are possible synergies to be found from cooperation with other sectors, and also lessons learned that should be picked up from national practices. By examining the practices of other sectors, the electricity sector has the potential to fast-track its learning process, effectively skipping some initial stages and catching up more quickly. Successful experiences are documented in the literature [83]. This accelerated learning can be achieved through various methods. Interoperability is evolving into a challenge that transcends individual sectors. While focusing within silos might yield quick fixes for specific sector challenges, such solutions often fall short of addressing the broader requirements necessary for creating a citizen-centred, interoperable, and decarbonised energy system. To effectively tackle interoperability, it must be approached both from sector-specific angles to resolve targeted issues and from a cross-sectoral perspective to prevent redundancy. This dual approach allows for the utilisation of shared solutions across sectors, thereby accelerating progress [6].

Empowering consumers

The EU 2019 Electricity Directive emphasises the pivotal role of consumers in the energy market ecosystem, advocating for the deployment of smart metering systems to facilitate their active participation. As digitalisation progresses, the participation of consumers in electricity markets – who have traditionally been viewed merely as endpoints of consumption and revenue – should be increased. This goes beyond just providing technology [1].

To enhance consumer confidence and empowerment in the smart home technology sector and ensure their participation in DR programs, it is crucial that consumers are provided with clear and understandable contract terms, coupled with the flexibility to opt out of these contracts if the services do not meet expected standards. This approach ensures consumers are not bound by unfavourable conditions, thereby fostering trust in technology providers [84]. Moreover, it is crucial to establish comprehensive consumer protection frameworks. These protections need to be clearly communicated

[30] The interested reader can find further details at: https://openchargealliance.org.

and robust enough to safeguard consumer interests as the market evolves. Effective risk management practices must be in place to identify and mitigate potential negative impacts on consumers, promoting transparency and fairness in the deployment of new energy services [85].

Additionally, accessible and responsive support systems are essential. Consumers should have straightforward avenues for obtaining assistance, whether for troubleshooting, service inquiries, or resolving disputes. A well-structured support system not only improves the user experience but also bolsters consumer confidence by demonstrating that providers value their clients' satisfaction and are responsive to their needs [84].

Lastly, giving consumers control over their personal data is paramount. Transparency in how data is used, along with providing consumers the power to manage their own data sharing preferences, is key to protecting privacy and empowering users. This not only helps in building trust but also assures consumers that they retain control over their personal information, aligning with broader data protection standards [*ibidem*].

A collaborative approach among all stakeholders – including government agencies, regulators, and energy providers – is essential for developing these protective measures. Such cooperation helps in refining regulatory policies that support innovation in energy usage while prioritising consumer welfare. This is especially important as the electricity sector moves towards more flexible and sustainable practices, which are vital for achieving broader environmental targets like reduced emissions and energy efficiency [85].

6 Conclusion

The electricity sector is facing challenges in managing the increasing volume of energy data from renewable and decentralised sources, alongside integrating various systems like mobility and buildings. These challenges are compounded by the need for real-time data management, robust cybersecurity, and strict data privacy within an expanding digital infrastructure. In this context, interoperability is essential for optimising energy flows and effectively integrating diverse and geographically scattered energy resources, such as solar and wind power. Improved interoperability not only enhances the reliability of the electricity system for consumers but also allows them to contribute to energy services. However, interoperability is a multi-dimensional concept that can also be ambivalent in terms of openness that it brings to a system. Therefore, achieving interoperability faces challenges across all its dimensions. Among others, the realisation of interoperable energy services' benefits is currently hindered by market fragmentation caused by diverse regulations and standards across MSs.

To promote the development of interoperable energy services, this deliverable aims to provide relevant considerations for policymakers and regulators when addressing these issues. In fact, much has been done to create a policy and regulatory framework that can promote the development of interoperable energy services, but there is still much to be accomplished. To understand what elements are missing to realise a digitalised electricity sector enabling seamless exchange of data, it is also necessary to take stock of what has been learned so far on these topics. The contribution of this deliverable is threefold: firstly, we conducted a review of the policy and regulatory landscape shaping the development of interoperable energy services. Secondly, we generated foundational knowledge by engaging with stakeholders in the electricity sector and beyond, identifying key barriers highlighted by four horizon projects (i.e., OneNet, InterConnect, CoordiNet, and INTERRFACE). Lastly, in light of the previous analysis, we produced a series of considerations applicable at the policy and regulatory levels.

Within the current policy framework aimed at promoting the development of interoperable energy services, we identified two main macro-strategies, each consisting of various strategies outlined in communications issued by the EC. The first macro-strategy relates to the data economy and primarily aims to harness the benefits arising from the use of data across all relevant economic sectors. The second macro-strategy concerns the implementation of the energy transition and encompasses several interconnected sectors, including electricity markets, mobility, and buildings. Although addressing different aspects, these strategies are not to be seen as disconnected from one another. On the contrary, each strategy progresses in tandem with the others in a mutually supportive relationship. These strategies have been deployed through a series of legislative initiatives that we divided into two primary regulatory areas. The first area focuses on the data economy, which includes regulations and general principles affecting various sectors beyond just electricity. The second regulatory area concerns the energy transition, targeting specific sectors such as electricity markets, renewables, mobility, and construction. In addition to these main areas, cross-sectoral regulatory elements such as data privacy and cybersecurity are crucial for ensuring the safe and effective development of interoperability across services. However, regulating the data economy is not a straightforward activity. Digital platforms, through aggregating user data and leveraging network effects, can create barriers to entry and consolidate market power among a few dominant players, stifling competition. Regulatory measures are necessary to ensure market contestability and fairness, addressing anti-competitive practices and enhancing mechanisms for data portability and interoperability to promote innovation. The EC has taken significant steps, such as enacting the Digital Market Act DMA and the Data Act, to regulate the data economy and benefit all market participants, including consumers. The successful implementation of these regulations requires a collaborative effort among regulators, digital platforms, and other stakeholders to foster a transparent, competitive, and fair digital market environment.

Although the current regulatory framework is geared towards the development of interoperable energy services, it is still insufficient to steer stakeholders' choices in this direction. The stakeholder analysis conducted within the context of T4.2 was carried out with reference to three dimensions, which are three fundamental pillars of the int:net project: stakeholders' interest in developing interoperable energy services, participating in future energy data space, and engaging with the int:net community.

Among the barriers highlighted by stakeholders in the development of interoperable energy services, the fragmentation of the regulatory landscape presents a significant challenge. This fragmentation spans both European and national levels, making it difficult to harmonise standards and ensure consistent application of rules across markets. Consequently, this fragmentation not only hampers the deployment of interoperable services but also complicates the economic and business considerations for stakeholders. They must carefully weigh the costs of transitioning to interoperable systems against the potential benefits. Additionally, stakeholders must address prominent challenges such as privacy concerns, cybersecurity issues, infrastructure security, and consumer engagement to promote broader acceptance of these innovative energy services. Furthermore, there is a discernible lack of understanding among stakeholders regarding the advantages of engaging in data space, which hampers their willingness to participate and invest in these initiatives. The absence of a supportive governance structure and clear regulatory guidelines makes it challenging to align market actors and foster the coordination necessary for the successful implementation of data space. Lastly, engagement within the int:net community, while met with interest, is overshadowed by concerns about its sustainability beyond the project lifetime and its overlap with other communities stakeholders are already involved in. The unclear added value of the int:net community to stakeholders' core business activities further affects their commitment and participation.

To support the regulator's activities and enable new use cases for stakeholders, various research activities conducted within the context of R&I projects aim to promote the development of interoperable energy services. The project analysis performed in the context of T4.2 provides a comprehensive overview of experiences and lessons learned from the Horizon 2020/Europe projects. These projects, selected based on their focus on digitalisation and their advanced stage of implementation, address a range of activities from TSO-DSO-consumer coordination to connecting smart homes with grid operators. They share a common goal of enhancing interoperability across the EU electricity market, which is crucial for facilitating efficient energy management and creating an open, competitive market environment.

The analysis reveals that while technical barriers are significant, many challenges also stem from inadequate coordination among stakeholders, delayed implementations, and insufficient political guidance for setting priorities. These issues could potentially be addressed through more directed policy responses and clearer implementation guidelines. One prominent issue is the lag in standardisation, where current standards do not fully support all required use cases or adapt to new market needs, leading to the development of proprietary solutions that hinder interoperability. The governance of interoperability also emerges as a critical concern, with no clear authority to enforce or facilitate standard adoption among diverse stakeholders. This fragmentation contributes to the complex landscape of digitalisation efforts across the EU. Cybersecurity is another significant concern, with increasing digitalisation introducing new vulnerabilities. The need for robust data management and security protocols is emphasised, alongside the development of standards for data access and consumer privacy.

The policy and regulatory review, combined with the outcomes of the two analyses serve as inputs for formulating considerations to foster interoperable energy services.

First of all, incentivising stakeholders is critical, particularly in sectors where the natural motivation to adopt new technologies may be lacking. Regulatory adjustments or market-driven incentives could help align stakeholder behaviours with the broader system needs. For instance, regulated stakeholders might need adjustments in the regulatory framework, while non-regulated stakeholders might be more responsive to economic signals from the market. Implementing the right incentives also need a governance framework that can manage the complexities of interoperable systems effectively, looking also at the definitions of clear roles and responsibilities. Secondly, developing standards tailored to specific use-cases is another crucial aspect. It involves engaging stakeholders in creating standards that ensure both technical and semantic interoperability, essential for seamless system integration. Moreover, mandating minimum interoperability requirements could help enforce standards across the industry. This could involve identifying key functionalities that require interoperability and setting the appropriate level of openness to foster a competitive yet secure market environment. Addressing technical and organisational challenges is vital. Integrating new technologies with existing infrastructures poses significant challenges, necessitating not only robust technical solutions but also organisational changes to support innovation. This includes enhancing digital skills among the workforce and promoting a culture of collaboration and openness within organisations. Lessons can be learned from other sectors, such as telecommunications and healthcare, which have successfully navigated similar interoperability challenges. These sectors have developed standards and frameworks that could potentially be adapted to the electricity sector to accelerate the adoption of interoperable solutions. Finally, empowering consumers is a fundamental aspect of fostering interoperability. Ensuring that consumers are well-informed, protected, and have control over their data is crucial for building trust and encouraging active participation in the evolving electricity market.

To conclude, various tools are available to policymakers and regulators to promote the development of interoperable energy services. However, the adoption of specific solutions requires careful analysis that takes into account the specificities of the considered use case to avoid unintended side effects, such as inhibiting competition and innovation. In this regard, further research activities are necessary, for example, regarding the remuneration strategies for new data sharing mechanisms. It is also important that new regulatory initiatives consider not only the benefits that interoperable energy services can bring to the electricity system or consumers but also the technical and economic constraints that various stakeholders must adhere to. Therefore, the engagement activities undertaken in the context of this task should continue within the int:net community, which, in this regard, can represent a continuation of the work initiated by this deliverable.

7 List of Tables

8 List of Figures

9 List of Abbreviations

AI	Artificial Intelligence
API	Application Programming Interface
CERF	Common European Reference Framework
CGM	Common Grid Model
DA	Data Act
DGA	Digital Governance Act
DMA	Digital Market Act
DR	Demand Response
DSO	Distribution System Operator
EC	European Commission
EU	European Union
EV	Electric Vehicle
FSP	Flexibility Service Provider
GDPR	General Data Protection Regulation
ICT	Information and Communication Technology
IoT	Internet of Things
IT	Information Technology
MS	Member State
NC on DR	Network Code on Demand Response
OEM	Original Equipment Manufacturers
R&I	Research and Innovation
SGAM	Smart energy Grid Architecture Model
SME	Small and Medium-sized Enterprise
SO	System Operator
SWOT	Strengths, Weaknesses, Opportunities, Threats
TSO	Transmission System Operator
UK	United Kingdom

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